Integrating Climate Change into Northeast and Midwest State Wildlife Action Plans

DOI Northeast Climate Science Center
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EXECUTIVE SUMMARY

The Department of Interior Northeast Climate Science Center (NE CSC) conducts research that responds to the regional natural resource management community's needs to anticipate, monitor, and adapt to climate change. The NE CSC is supported by a consortium of partners that includes the University of Massachusetts Amherst, College of Menominee Nation, Columbia University, Marine Biological Laboratory, University of Minnesota, University of Missouri Columbia, and University of Wisconsin. The NE CSC also engages and collaborates with a diversity of other federal, state, academic, tribal, and non-governmental organizations (NGOs) to conduct collaborative, stakeholder-driven, and climate-focused work.

The State Wildlife Action Plans (SWAPs) are revised every 10 years; states are currently working towards a target deadline of October 2015. SWAP coordinators have been challenged to incorporate climate change impacts and species responses into their current revisions. This synthesis is intended to inform the science going into Northeast and Midwest SWAPs across the 22 NE CSC states ranging from Maine to Virginia, and Minnesota and Missouri in the eastern United States. It is anticipated that this synthesis will help guide SWAP authors in writing specific sections, help revise and finalize existing sections, or be incorporated as an appendix or addendum.

The purpose of this NE CSC-led cooperative report is to provide a synthesis of what is known and what is uncertain about climate change and its impacts across the NE CSC region, with a particular focus on the responses and vulnerabilities of Regional Species of Greatest Conservation Need (RSGCN) and the habitats they depend on. Another goal is to describe a range of climate change adaptation approaches, processes, tools, and potential partnerships that are available to State natural resource managers across the Northeast and Midwest regions of the United States. Through illustrative case studies submitted by the NE CSC and partners, we demonstrate climate change adaptation efforts being explored and implemented across local and large-landscape scales.

This document is divided into four sections and addresses the following climate and management relevant questions:

1. Climate Change in the Northeast and Midwest United States: How is the climate changing and projected to change across the Northeast and Midwest regions of the United States?
2. Northeast and Midwest regional species and habitats at greatest risk and most vulnerable to climate impacts: What are the relative vulnerabilities of fish and wildlife species and their habitats to climate change in the Northeast and Midwest?
3. Biological responses to climate impacts with a focus on Northeast and Midwest Regional Species of Greatest Conservation Need (RSGCN): How are threatened fish and wildlife likely to respond or adapt to climate change in the Northeast and Midwest?
4. Scale-appropriate adaptation strategies and actions in the Northeast and Midwest United States: What approaches, strategies, and actions could be taken to sustain fish, wildlife and their habitats in the short and long term across the Northeast and Midwest?

The outline and content for this document were developed with input from State Coordinators, members of the Northeast Association of Fish and Wildlife Agencies and Midwest Association of Fish and Wildlife Agencies, DOI Northeast Climate Science Center affiliated researchers, and other partners including the Landscape Conservation Cooperatives, the Northern Institute of Applied Climate Science, the Wildlife Conservation Society, and The Nature Conservancy. Terwilliger Consulting, Inc., was especially instrumental in helping connect and coordinate the authors of this report with State representatives through conference calls and email surveys to develop the most needed and effective information for current SWAP revisions.

On a final note, the SWAPs are living documents that can be added to and evolve on timescales beyond the 10-year revision cycle. The development of this report was timed such that SWAP coordinators and writers would have sufficient time to implement this input before their October 2015 deadline. However, this document is also meant to serve as a starting point for coordinated and collaborative climate science and adaptation across the region; the NE CSC endeavors to continue to provide actionable science during the coming years in collaboration with its diverse federal, state, NGO, and academic partners.

CHAPTER 1: CLIMATE CHANGE IN THE NORTHEAST AND MIDWEST UNITED STATES

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CHAPTER 1: CLIMATE CHANGE IN THE NORTHEAST AND MIDWEST UNITED STATES

Summary Points

The climate is changing rapidly in ways that have already impacted wildlife and their habitats. Here, we present a summary of the observed past and projected future climate changes in the region that are relevant to wildlife and ecosystems, as well as what we know and don't know in order to raise managers' confidence in their planning. A number of large-scale regional changes affect the overall terrestrial landscape within the Northeast and Midwest United States:

- Warming is occurring in every season, particularly in winter, at higher latitudes, at higher elevations, and inland (i.e. away from the ocean and lake coasts).
- Heatwaves may become more frequent, more intense, and last longer.
- Precipitation amounts are increasing, particularly in winter and with respect to high-intensity events in summer.
- Snow is shifting to rain, leading to reduced snowpacks and extent of snow cover, as well as harder, crustier snowpacks.
- Atmospheric moisture content is likely to increase.
- Wind speeds are declining, though wind gusts may be intensifying.
- Streamflows are intensifying.
- Streams are warming.
- Thunderstorms may become more severe.
- Floods are intensifying, yet droughts are also on the rise as dry periods between events get longer.
- Blizzards and ice storms are occurring more often in some areas, though most areas experiencing milder winters (i.e., warmer and with less snow).
- Growing seasons are getting longer, with more growing degree days accumulating earlier in the season.

In addition, localized climate change is occurring in specific regions:

- U.S. Atlantic coast

    - Sea level is rising at an accelerating rate.
    - Tropical cyclones and hurricanes may be intensifying and storm tracks have been shifting northward along the coast.
    - Oceans are warming and becoming more acidic.
- Great Lakes
    - The lakes are warming.
    - Winter maximum lake ice extent is shrinking.
    - Lake evaporation rates are increasing.
    - Lake-effect snow events are becoming more severe, longer lasting, and shifting to rain, but occurring less often.
    - Water levels have decreased, but may not be linked to anthropogenic climate change.
- Appalachians
    - Warming may be occurring more rapidly at higher elevations.
    - Greater intensification of heavy rainfall events may be occurring.

In the short term (i.e., over the next 5-20 years), the direction and magnitude of warming in the global climate are mostly consistent across all emissions scenarios and with strong agreement across models. Accordingly, we are certain that the Northeast and Midwest will see longer growing seasons. We are likely to see shifts from snow to rain, though shifts in the amount of total precipitation (rain and snow) are less certain. Severe weather events (e.g., thunderstorms, tornadoes) are challenging to detect. Soil moisture and evapotranspiration trends are neither robustly observed nor consistent amongst modeling studies.

I. INTRODUCTION

There is abundant evidence that the climate is warming (Hartmann et al. 2013; Kennedy et al. 2010), and that the global atmosphere has warmed faster over the past century than any point in at least the last millennium (Masson-Delmotte et al. 2013). Global average temperature has risen by slightly under one degree Celsius since the industrial revolution with the vast majority of this change due to human emissions of carbon dioxide and other greenhouse gases (Christensen et al. 2013; Cook et al. 2013; Fischer & Knutti 2015). Under a "business as usual" scenario of rapid emissions growth throughout the 21st century, global temperature is projected to rise by 3-5 degrees Celsius; under a scenario where emissions are aggressively reduced, temperature rise could likely be held in the 2-3 degree Celsius range (Collins et al. 2013). Global temperatures are expected to rise beyond the range of natural variability (Rawlins et al. 2012).

The Northeast and Midwest Regions of the United States (hereafter referred to as the Northeast and Midwest) are vulnerable to a range of climate threats including extreme temperatures, heavy precipitation, sea level rise, and warming lake waters in the Great Lakes. These changes are likely to cause widespread ecosystem disruption in the region (Kopp et al. 2014), resulting in adverse effects on wildlife, as discussed in subsequent chapters. Extreme temperatures may rise faster than the mean in the region (Kodra & Ganguly 2014; Horton et al. 2014). As a result, the frequency, magnitude, and duration of heat waves are expected to dramatically increase (Meehl & Tebaldi 2004). Winter minimum temperatures are projected to rapidly rise, reducing the frequency of extremely cold days by an order of magnitude by mid-century (Sillmann et al. 2013). Changes in the frequency and magnitude of some extreme events (e.g., extreme heat and cold, drought, and heavy rainfalls) resulting from climatic warming are also anticipated (Alexander et al. 2006; Walsh et al. 2014).

This synthesis is provided by the Northeast Climate Science Center (NE CSC) and partners to help guide the 22 states within its geographical footprint (**Figure 1**) in their efforts to incorporate climate change information into their State Wildlife Action Plans (SWAP) revisions. While management planning typically operates on 5- to 20-year planning horizons, it is important to anticipate longer-term future conditions and offer some end-of-century projections. In addition, management actions typically occur on a local level (e.g., watershed, county, or smaller), yet there are many challenges in gleaning reliable information from models at small spatial scales, as described in the next section.

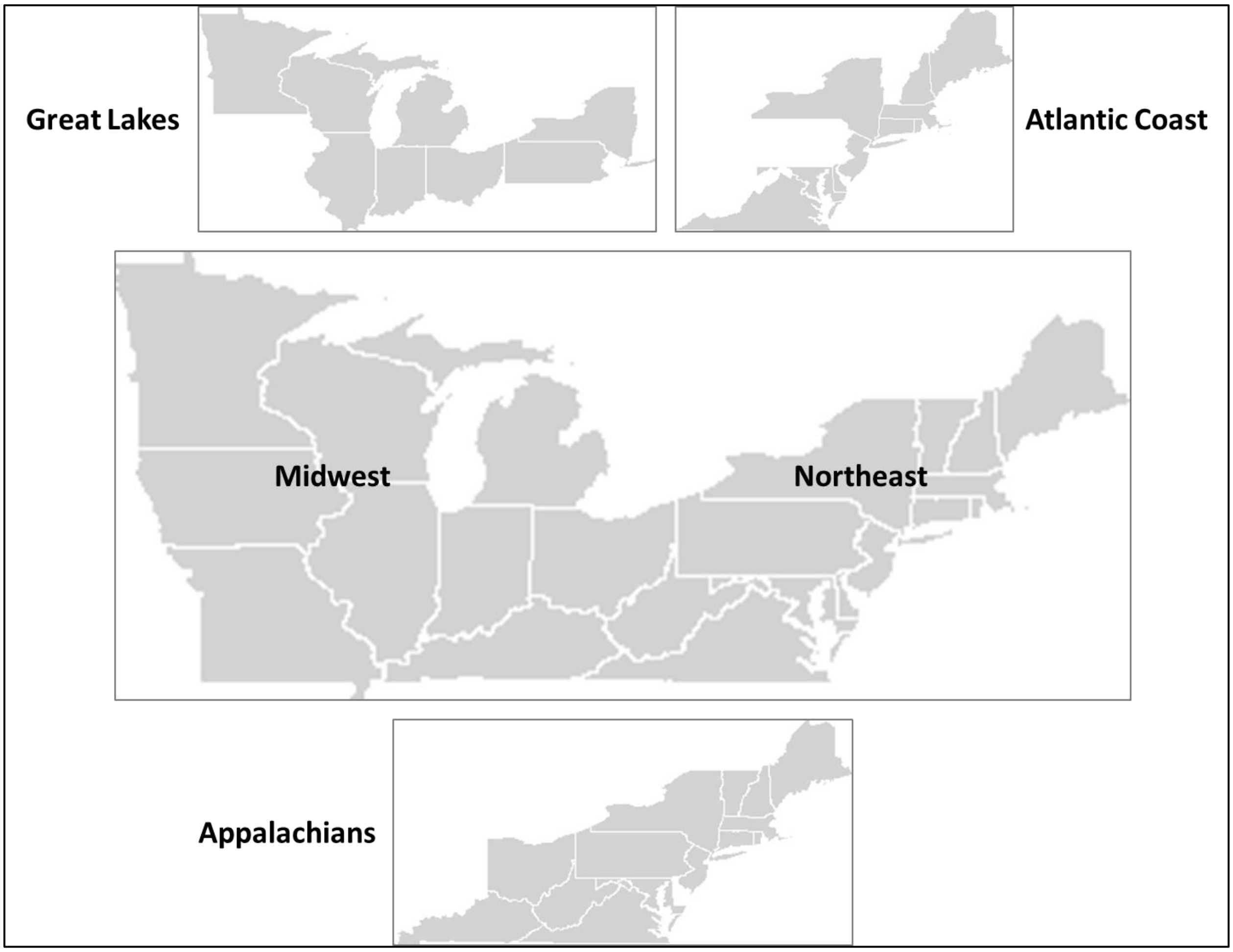


Figure 1: Geographical footprint and subregions of the DOI Northeast Climate Science Center (NE CSC), represented by this guide.

The goals of this section are to:

1. Characterize the greatest climate changes across the region;
2. Identify climate variables that are particularly difficult for many non-climate scientists to interpret and explain why;
3. Outline potential recommendations for managers in interpreting and taking action under these uncertainties; and

4. Identify where and when extreme climate conditions and intense storms have already occurred and are most likely to occur in the future.

We begin with some considerations for managers on how to interpret the information presented in this document, including discussions about uncertainty and approaches for coping with uncertainty. Next, we provide a summary of many of the climate trends that have been observed or are projected to occur in the region, particularly those relevant to wildlife and their habitats. Our discussion of climate trends begins with the widespread changes affecting the terrestrial landscape across the entire NE CSC region (e.g., long-term climatic warming, heavier rain events, and shifts in terrestrial surface hydrology). We conclude our synthesis with some regionally-specific changes pertaining to states along the Atlantic coast (e.g., sea level rise, storm surge, coastal flooding, and changing ocean acidification), surrounding the Great Lakes (e.g., lake levels, temperature, and quality, ice coverage, and lake-effect precipitation), and along the Appalachian Mountains (e.g., elevation-dependent warming, snowline, mountain hydrology).

II. MANAGING IN AN UNCERTAIN FUTURE: GUIDELINES FOR INTERPRETING THIS DOCUMENT

The climate is changing and already having visible consequences on our wildlife and their habitats (see **Chapters 2 and 3**). Emissions of carbon dioxide from human activity, particularly fossil fuel combustion, are largely responsible for the recent warming (Christensen et al. 2013; Cook et al. 2013; Fischer & Knutti 2015). Continued carbon emissions over the course of the 21st century will lead to further shifts in climate (Sillmann et al. 2013). Even if all carbon emissions ceased today, warming is very likely to continue (Frölicher et al. 2014). The Earth is currently warming faster than wildlife and ecosystems often are able to adapt, and thus climate change adaptation approaches are necessary to facilitate transitions of many climate-sensitive species if they are to be conserved. At the same time, climate change is still very much an area of active research, and thus many uncertainties and gaps in our knowledge exist. While these uncertainties and knowledge gaps pose challenges for planning, they can often prevent planners from attempting to plan and act. Amidst the uncertainty, there are many things that are certain for the Northeast and Midwest: the climate is warming, resulting in longer growing seasons, more extreme events, and many related impacts on wildlife and habitats (e.g., increased pests and disease, vegetation shifts). For these more certain aspects of climate change, plans and actions can be made with a high degree of confidence. For areas that are less certain (e.g., local scale changes in precipitation and its impact on surface hydrology, such as terrestrial drought, river and stream flows, vernal pool formation, etc.), planners can consider the actions they might take and whether they have the tools in place for the full range of projected outcomes.

This document presents observed and projected trends and our confidence in said trends for many climate variables that are relevant to wildlife and their habitats. When possible, we try to discuss variability across the Northeast and Midwest and time of year, as well as any other useful information, such as important considerations about uncertainty or results from particular case studies. All information presented here (unless noted otherwise) derives from the published scientific literature and has thus been thoroughly scrutinized for accuracy and legitimacy through the peer review process.

When discussing climate models and their output, we use terms that can be confusing to distinguish: projection, prediction, forecast, and scenario. *Projections* show a range of what *could* happen based on a range of future *scenarios*. In contrast, *predictions* describe what *will* happen assuming one particular scenario plays out. A *forecast* is a prediction used exclusively in predicting short-term (i.e., days to weeks) weather and thus not used in this report. Model projections (i.e., what could happen) are *not* predictions (i.e., what will happen) because the final outcome depends on how greenhouse gas emissions change over time as policies and human activities shift. Climate change projections are based on a standard set of 4-5 “emissions scenarios,” ranging from a worst-case scenario, in which emissions continue at present magnitudes (i.e., “business-as-usual”), to a low-emissions scenario under which global policies lead to major reductions in emissions (Nakićenović et al. 2000; Moss et al. 2010). Each scenario results in proportional differences in global climatic warming. In the short term (i.e., over the next 5-20 years), the direction and magnitude of warming in the global climate are mostly consistent across all emissions scenarios and with strong agreement across models. After approximately 20 years, the trends in global-scale warming from the different emissions scenarios begin to diverge. Models are run with each scenario, producing a suite of projected future conditions.

Climate models can produce varying results within the same emissions scenario. Several climate models have been developed out of many different institutions around the world. Although these models are built off of similar fundamental physical principles, they can predict different future conditions due to differences in how they represent more complex atmospheric processes (e.g., convection, cloud physics, surface-atmosphere interactions). Models also vary in resolution. Global models, used to simulate large-scale atmospheric motions, including the movement of air masses and jet streams, are run at a coarse spatial resolution (1-3° horizontal grid spacing; Flato et al. 2013). These models do not adequately capture local-scale climate features, as is necessary for most management planning applications, and thus fine scale (1-50 km) models have been developed for a subset of the globe using a variety of "downscaling" techniques. The downscaling approach used can also yield different model results. While downscaling is a necessary step for adequately representing the local climate, the technique does not necessarily reduce the uncertainty in the global projections, and may, in fact, introduce new uncertainties due to differences in how models capture fine-scale atmospheric processes.

When describing projected trends, we try to convey the approximate likelihood of possible future conditions using the terms defined in **Table 1**. Trends are considered likely (or greater) if model projections agree with each other, are supported by observed trends, or stand up to expert judgement. We use an assortment of phrases to elaborate on these sources of likelihood. For instance, an event "is projected to" occur if models consistently show a particular trend. If model projections are both consistent and supported by past observations, we say a trend *is* occurring (e.g., temperatures are increasing, rainfall is becoming more intense). We express the likelihood of future events through a variety of other terms. For instance, something that "may" happen means the outcome is plausible but about equally likely to occur as it is to not occur or see the opposite trend (33 – 66% probability). This applies most often to precipitation projections, which can show equal magnitudes of wetter or drier conditions in the future.

Table 1: Numerical definitions of terms used in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) to convey the likelihood of a given outcome (Adapted from Mastrandrea et al. 2010).

Term	Likelihood of the Outcome
Very likely	90 – 100% probability
Likely	66 – 100% probability
About as likely as not	33 – 66% probability
Unlikely	0 – 33% probability
Very unlikely	0 – 10% probability

Though many aspects of future climate are uncertain, there are approaches managers can take to cope with these uncertainties, such as scenario planning, structured decision-making, and adaptive management. **Chapter 4** of this document discusses how these and other tools can aid planning and decision-making in the face of uncertainty. If you wish to obtain guidance on how to interpret outputs and uncertainties related to climate model projections relative to your specific planning efforts, consult a qualified climatologist (e.g., the authors of this report).

III. WIDESPREAD CHANGES IN THE NORTHEAST AND MIDWEST

A) SURFACE AIR TEMPERATURE

Warming is occurring in all states and seasons.

Over the last century, mean temperature in the Midwest and Northeast regions has been observed to increase by approximately 1.4 and 1.6 °F, respectively (Hayhoe et al. 2007; Hayhoe et al. 2008; Kunkel 2013). In the Northeast, annual temperature has increased 0.16°F per decade during the period 1895-2011. Warming has been more pronounced during winter (0.24°F/decade), but statistically significant increasing trends are observed in all seasons. Over the Midwest states, the trend in annual temperature is positive over the period 1900-2010 with an increased rate of warming in the recent time period. However, only the spring season shows statistically significant increasing trends. Several studies suggest that the rate of climatic warming has been faster at higher elevations, though the availability of long-term meteorological data at high elevations is limited (Diaz et al. 2014; Pepin et al. 2015).

Future projections consistently show continued warming over the next century across the entire region, as shown in **Figure 2** (Hayhoe et al. 2007; 2008; Rawlins et al. 2012; Kunkel 2013; Ning et al. 2015). All models agree on the sign of the change, but vary in magnitude toward the end of the century depending on emissions scenario. The Midwest and Northeast are projected to see average temperature increases that exceed the global average, with potential warming of 4 – 5 °F annually by mid-century under a high emissions scenario (Kunkel 2013; Coffel & Horton 2015). The simulated annual changes increase with latitude and inland due to the regulating effects of the Atlantic Ocean and Great Lakes on air temperatures over the surrounding landscapes (Hayhoe et al. 2008; Notaro et al. 2013).

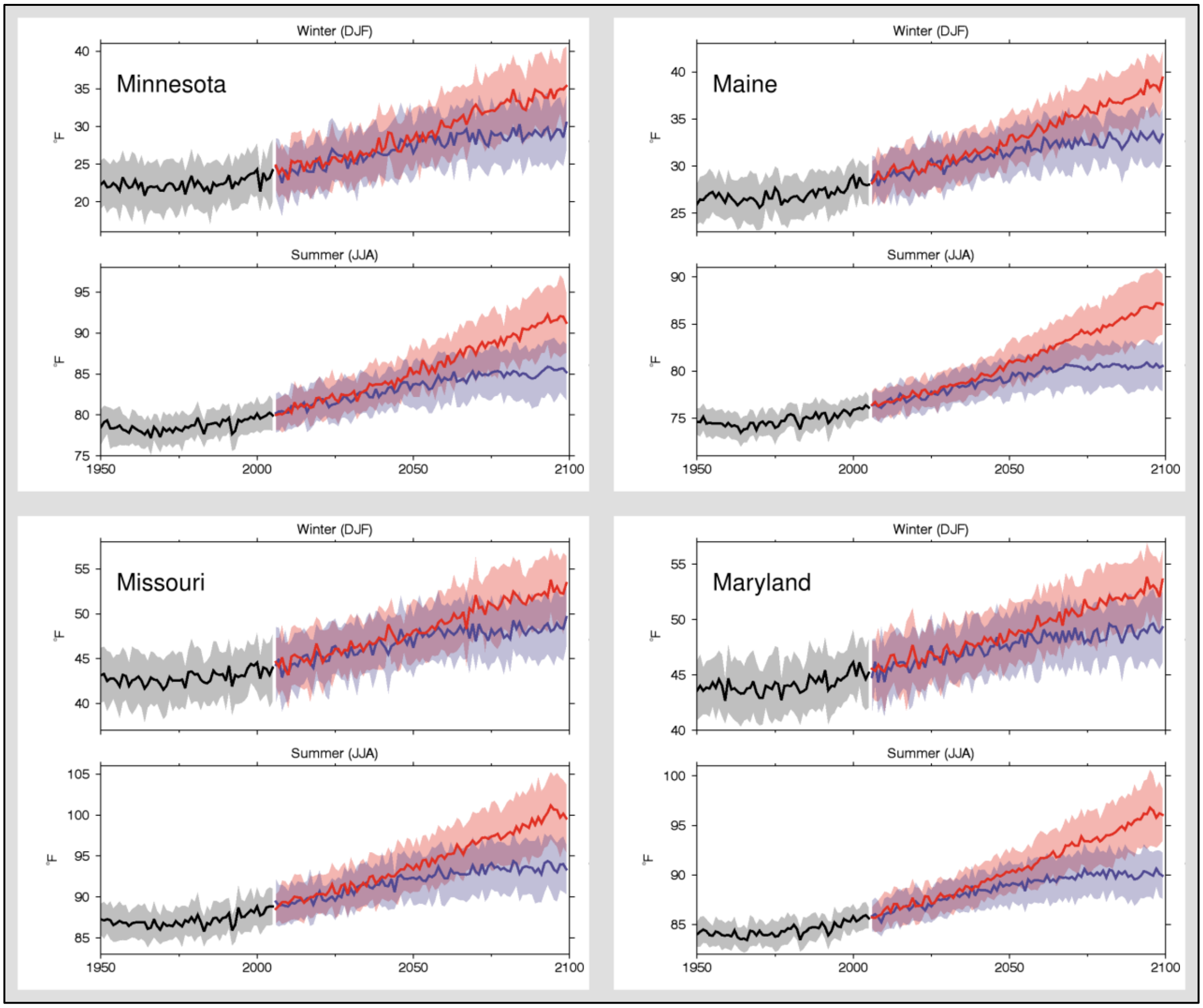


Figure 2: Trends in winter (December, January, and February) and summer (June, July, and August) average temperature from 1950 to 2100, courtesy of the USGS National Climate Change Viewer (Alder & Hostetler 2013). Both historical (black line with grey shading) and projected (colored lines and shading) trends derive from the NASA NEX-DCP30 data set (Thrasher et al. 2013), which includes 33 GCMs downscaled to a resolution of 800 meters. The solid line represents the mean of the 33 models. The red and blue curves represent the high and low emissions scenarios, respectively. The shading represents the range of one standard deviation.

Seasonal changes show more spatial variability (**Figure 3**, Kunkel 2013), with winter and spring showing higher increases in the north compared to the southern Midwest. The greatest warming is projected to occur in northwestern Minnesota and upper New England in winter (6°F) and in the Northeastern states in spring (4-4.5°F). Summer and fall show a reversed spatial pattern, with the greatest simulated increases to be in the southwestern part of the region and a north-south gradient ranging from 4.0 to 6.0°F.

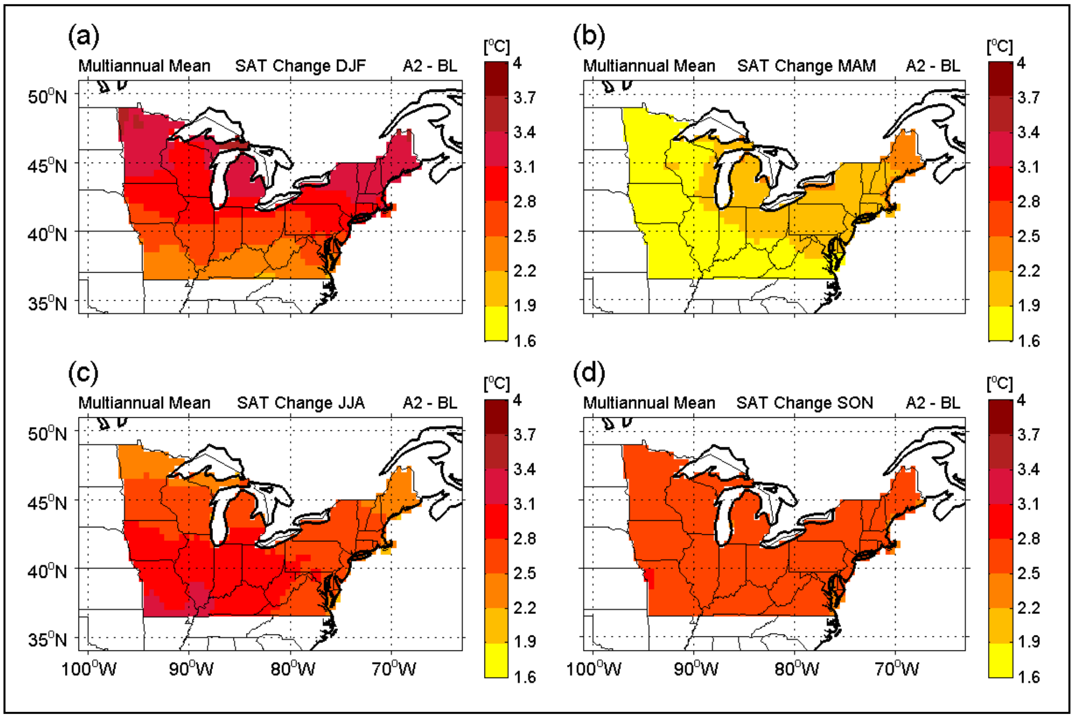


Figure 3: Projected warming across the NE CSC region by season: (a) winter (December, January, and February), (b) spring (March, April, and May), (c) summer (June, July, and August), and (d) autumn (September, October, and November). Values represent the differences between the 1979 – 2004 and 2041 – 2070 average temperatures for each season. Multi-model means from the North American Regional Climate Change Assessment Program (NARCCAP), based on a high emissions scenario, are used (Data and map for Northeast published by Rawlins et al. (2012); maps extended by F. Fan, written communication).

Heatwaves may become more frequent, more intense, and last longer.

Anthropogenic warming has led to more extreme heat events globally (Fischer & Knutti 2015). However, several studies point to a distinct "warming hole" over the past half century across the eastern U.S., where the number of warm days have been either stagnant or slightly decreasing (Alexander et al. 2006; Perkins et al. 2012; Donat et al. 2013). In addition, linear trends over the past half century indicate more cool days, albeit slight. While daytime extremes show cooler trends, nights have been getting warmer, with fewer cold nights and more warm nights. Long warm spells early in the spring season are particularly threatening to vegetation as such spells can trigger premature leaf-out and flowering (Cannell & Smith 1986; Inouye 2000), leaving the plant vulnerable to frost damage later in the season. Frost damage can affect the overall productivity of the plant for the entire growing season (Gu et al. 2008; Hufkens et al. 2012). However, recent analyses of trends over the past century indicate the last spring freeze is getting earlier at a faster rate than leaf-out, suggesting that damaging late-season spring freezes are becoming less likely (Peterson & Abatzoglou 2014).

Heatwave intensity, frequency, and duration are expected to increase over the U.S. in the 21st century, with the greatest increases projected toward the southwest portion of the Northeast and Midwest region (Meehl & Tebaldi 2004). Fewer cold days and nights, and more warm days and nights are expected over the next century (Sillman et al. 2013; Ning et al. 2015). Southern states in the region are projected to experience more additional warm days (days with maximum temperatures exceeding 90th percentile) than northern states, although the Great Lakes region is likely to see the greatest reductions in cold days (days with maximum temperatures below 10th percentile; Ning et al. 2015). The greatest increases in nighttime minimum temperatures are expected for inland areas and areas at higher latitudes due to reduced snow cover associated with warmer winters (Sillman et al. 2013; Thibeault & Seth 2014). The minimum temperature on the coldest night of the year is expected to increase by 11 °C by the end of the century from the Great Lakes northward, more than triple the expected increase for areas south of the Great Lakes (Sillman et al. 2013). Projected increases in the daily maximum temperatures are generally greatest inland (Sillman et al. 2013), with the exception of major urban centers along the coast due to heat island effects (Thibeault & Seth 2014). Higher elevations are also likely to see larger increases in the summer daily maximum temperatures, though past observations suggest greater increases in daily minimum temperatures (Diaz & Bradley 1997; Pepin & Lundquist 2008; Diaz et al. 2014; Thibeault & Seth 2014; Pepin et al. 2015). An increase in the inter-annual variability (in addition to the frequency) of extremes heat events is also anticipated under future climate (Ning et al. 2015).

B) PRECIPITATION

Annual precipitation is increasing, particularly in winter, though with less certainty in future projections than with temperature.

Annual total precipitation has increased over the past century on a global scale (Zhang et al. 2007). In the Midwest and Northeast, the last two decades (1991-2012) were wetter than the first 60 years of the twentieth century by about 10-15% (Walsh et al. 2014). According to a dense network of station observations from the National Climatic Data Center (NCDC), annual precipitation amounts across the NE CSC region have increased at a rate of over 1 inch per decade since 1895, with the greatest increases of nearly 2.5 inches per decade in Maine (NCDC 2015).

Over the next century, overall annual precipitation amounts are expected to increase over the NE CSC region (Schoof 2015), largely due to greater intensity in precipitation events (Thibeault & Seth 2014; see below). Further, precipitation events are expected to become less frequent (i.e., more consecutive dry days, or extreme dry spells), but last longer (i.e., more persistent; Schoof 2015; Guilbert et al. 2015). Heavy rainfall events occurring at a reduced frequency raises the risk for both flooding and drought (Horton et al. 2014).

Projections consistently predict wetter winters (**Figure 4**; Hayhoe et al. 2007; Rawlins et al. 2012; Kunkel 2013; Alder & Hostetler 2013; Schoof 2015), though with more rain than snow. Drier summers are projected, particularly for the southern Midwest, with some areas seeing little change or some increasing. Rainfall events in the summer are anticipated to become more intense and shorter with longer dry periods between events, hence little change in the seasonal total. More frequent severe thunderstorm activity may mean more frequent hail events in summer (Gensini & Mote 2015). In the Northeast, precipitation may become more persistent in summer and more intense in winter (Guilbert et al. 2015). For spring and fall, model projections agree on small positive changes in the Northeast, which are significant over much of the region in spring and within the level of natural variability in the fall (Rawlins et al. 2012).

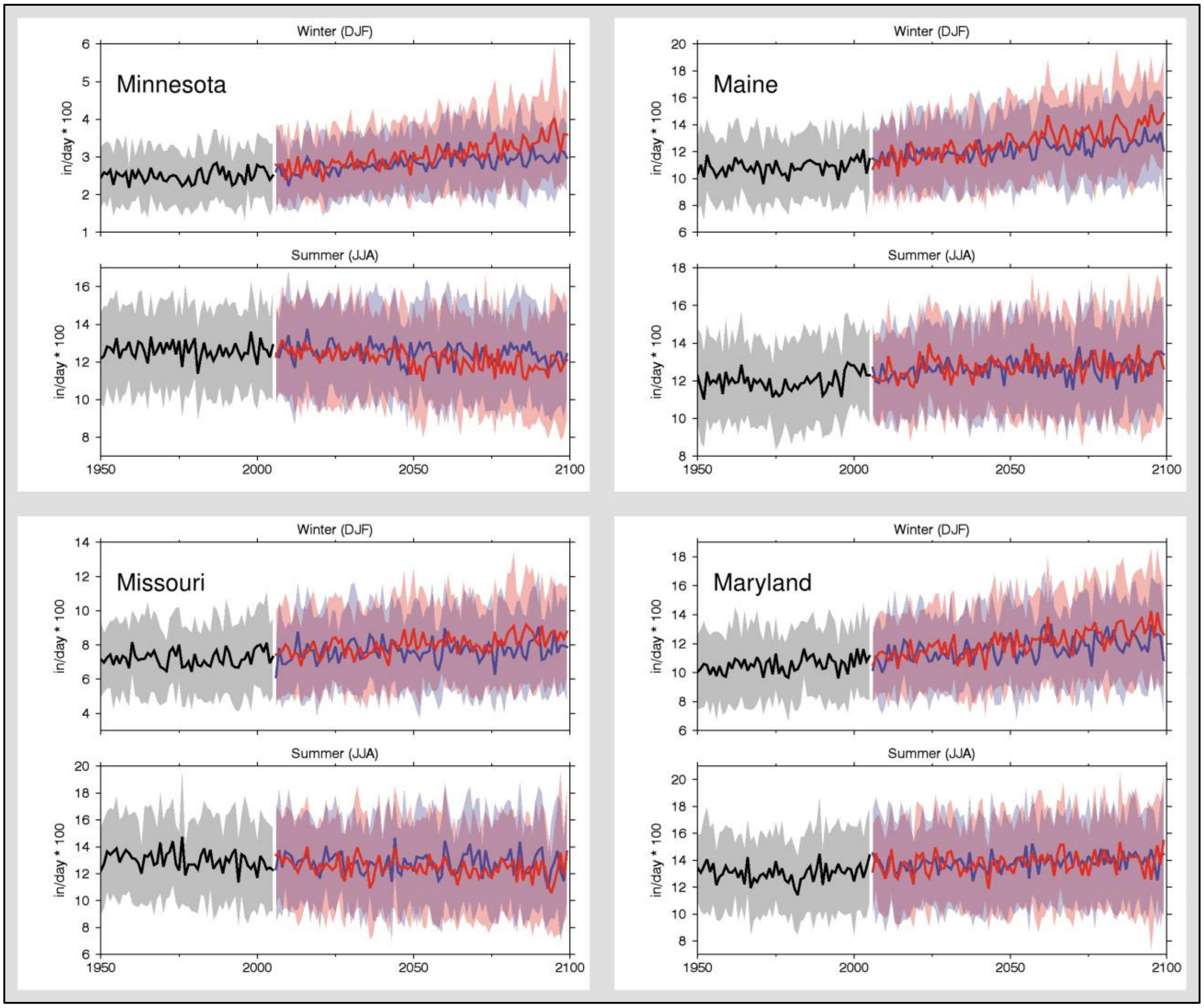


Figure 4: Simulated trends in winter (December, January, and February) and summer (June, July, and August) average precipitation, courtesy of the USGS National Climate Change Viewer (Alder & Hostetler 2013). Both historical (black line with grey shading) and projected (colored lines and shading) trends derive from the NASA NEX-DCP30 data set (Thrasher et al. 2013), which includes 33 GCMs downscaled to 800 meters. The solid line represents the mean of the 33 models, and the shading represents the range of one standard deviation. The red and blue curves represent the high and low emissions scenarios, respectively.

Changes in seasonal precipitation amounts vary regionally (**Figure 5**). Wetter conditions are projected for the Northeast and Midwest in winter, spring, and fall, with significant drying projected for the southern Midwest in summer. However, some projections show significant summertime drying in the upper Great Plains, as well, over the next century (Swain & Hayhoe 2015). In spring and fall, the largest increases are in the northern Midwest. Winter increases do not show a distinct regional gradient. We emphasize, however, the lack of confidence in the regional distribution of precipitation, as discussed below (Collins et al. 2013).

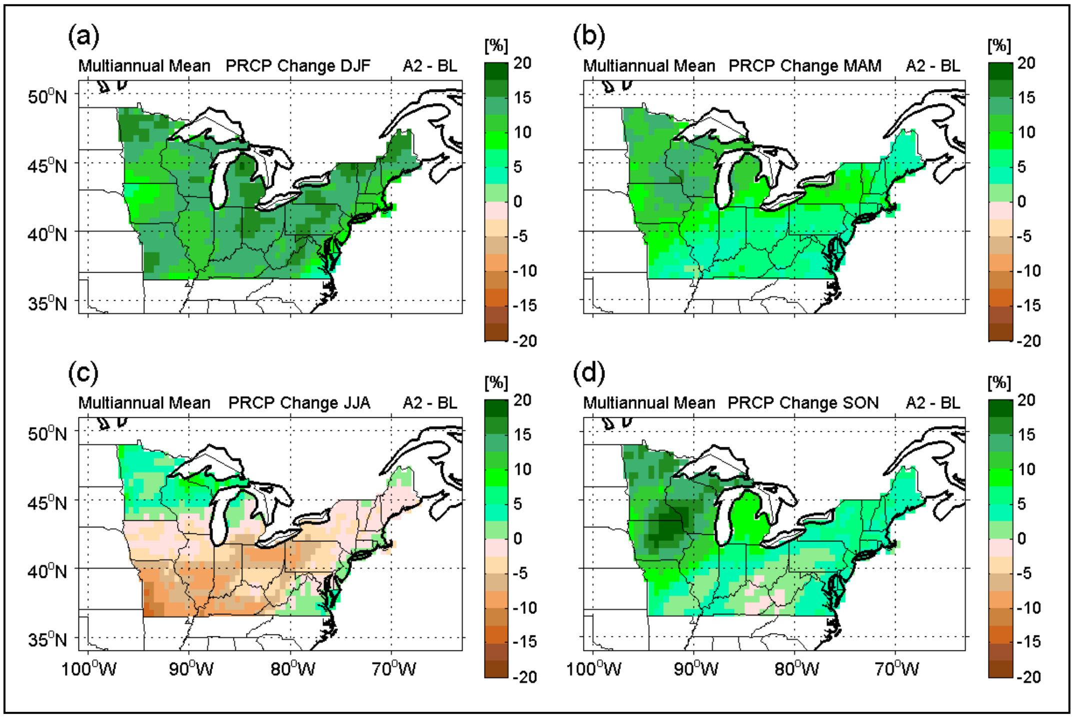


Figure 5: Projected precipitation changes across the NE CSC region by season: (a) winter (December, January, and February), (b) spring (March, April, and May), (c) summer (June, July, and August), and (d) autumn (September, October, and November). Percent change is calculated as (future – baseline) / (baseline) × 100% between the 1979 – 2004 and 2041 – 2070 average precipitation for each season. Multi-model means from the North American Regional Climate Change Assessment Program (NARCCAP), based on a high emissions scenario, are used (Data and map for Northeast published by Rawlins et al. (2012); maps extended by F. Fan, written communication).

Projections of changes in precipitation patterns are less robust than for temperature (Hawkins & Sutton 2011; Collins et al. 2013; Knutti & Sedláček 2013), particularly with respect to annual and seasonal totals (**Figure 4**). Not all models agree on the sign of the change for certain sub-regional averages. Part of the discrepancy comes down to challenges simulating cloud formation and convection due to the complex nature of these processes and difficulties representing them in the model. Additionally, not all models adequately capture large-scale climatic drivers of precipitation in the region, such as the Great Plains low-level jet or lake-effect precipitation. Consequently, models vary widely in the placement of precipitation maxima and minima. Therefore, planners should use caution when interpreting spatial distributions of precipitation in future projections. While one model may show more rainfall in one part of a state over another, another model may show the reverse. In conclusion, at present model projections are insufficiently reliable to be able to identify which part of a state or region may experience the most or least precipitation in the future.

Heavy rainfall events are intensifying, particularly in the Northeast.

The Northeast and Midwest have seen a pronounced increase in the frequency and intensity of extreme precipitation events in the past several decades (Groisman et al. 2005; 2013; Kunkel 2013; Schoof 2015; Guilbert et al. 2015), a trend which appears robustly simulated by the latest suite of GCMs (Scoccimarro et al. 2013; Toreti et al. 2013; Kendon et al. 2014; Wuebbles et al. 2014). Anthropogenic climate change is almost certainly a contributor of heavier precipitation events (Min et al. 2011; Fischer & Knutti 2015). The Northeast has seen the largest increases in heavy precipitation events over the rest of the country (a 74% increase in the heaviest 1% of all events since 1958; Groisman et al. 2013), with increases as high as 240% in the Connecticut River basin over the past 60 years (Parr & Wang 2014). Increases in the Midwest states are the second highest in the country at 46% (Groisman et al. 2013). The amount of rainfall falling in very heavy precipitation events in these states has increased by more than 20-30% in recent decades relative to 1901-1960 average. Over 30% of annual total precipitation at most stations in the Midwest occurs during the ten wettest days of the year. Therefore, changes in the magnitude and frequency of extreme precipitation events are of great importance.

Over the region as a whole, the occurrence of these intense precipitation events has risen substantially in recent decades. For example, the number of 24-hour storms with a 20% chance of occurrence in a given year has increased by about 4% per decade since the beginning of the 20th century. About 85% of the events occur during the warm season period of May through September. About 90% of the annual trend is due to increases during this warm season period. In other words, what would be expected to be a 100-year event based on 1950-1979 data occurs with an average return interval of 60 years when data from the 1978-2007 period are considered (DeGaetano 2009). Similarly, the amount of rain that constituted a 50-year event during 1950- 1979 is expected to occur on average once every 30 years based on the more recent data.

Intensity increases are projected for all seasons (Toreti et al. 2013), at a rate faster than the increase in annual mean precipitation (Kharin et al. 2013). The greatest increase in the number of heavy precipitation events are projected for northern latitudes, higher elevations, and coastal areas (Thibeault & Seth 2014). The Northeast, particularly along the Atlantic coast and Appalachians, should see the largest increase in number, intensity, and inter-annual variability of extreme precipitation events (Ning et al. 2015). Total wet-day precipitation amounts and the number of days with precipitation greater than 10mm are projected to increase in the Northeast, with models agreeing on the sign of the change (Sillman et al. 2013).

Less snow expected as events occur less frequently and shift to rain, though more intense snowfall events may lead to local increases in snowpack and totals.

Snowfall trends in response to climate change are complex and vary regionally. Climatic warming is resulting in a shift from snow to rain, leading to decreases in snow. However, areas that will remain cold enough for snow (e.g., northern latitudes and high elevations) may see localized increases in snowfall due to more intense precipitation events. For instance, lake-effect snow has increased in recent decades over the Great Lakes states due to warmer lake waters (Andresen et al. 2012) and is projected to continue to increase, particularly over Lake Superior where temperatures are likely to remain cold enough for snow (Notaro et al. 2015; see Great Lakes section below). In addition, increases in the amplitude of the jet stream in winter may have led to the observed increases in winter storms affecting the southeastern United States (Thompson et al. 2013).

Snowpacks are thinning and melting earlier, and thus shorter lived; the snowline may be retreating northward and upslope.

Climatic warming is expected to reduce snowpack depth across the Northeast and Midwest and lead to earlier snow melt (Mahanama et al. 2012). Climate projections for the 21st century indicate decreases in snow depth and the number of days with snow cover, as have already been observed (Hayhoe et al. 2007). Snow cover retreat is projected to occur earlier, shifting from spring to winter (Pierce & Cayan 2013; Maloney et al. 2014). Observed reductions in snow cover extent over the 2008 – 2012 period exceeded the decrease predicted by global climate model projections (Derksen and Brown 2012).

Snowpack textures may harden more often in many areas.

Some studies have observed changes in snow quality and characteristics of the snow pack, namely harder, crustier snow conditions (Klein et al. 2005; Chen et al. 2013). As the climate warms, temperatures are likely to cross above the freezing line more often during the winter. This will lead to more rain and freezing rain events, which alter the quality of the existing snowpack when the rain freezes upon the snow, resulting in an ice-like texture.

C) ATMOSPHERIC MOISTURE

More atmospheric moisture, higher cloud bases, and more frequent fog events are expected.

Climatic warming will increase the capacity of the atmosphere to hold water, yet future projections do not show substantial change in relative humidity. This implies that the amount of atmospheric water vapor will increase with warming temperatures in order to maintain a constant relative humidity (Shi & Durran 2014). There is some evidence that cloud base heights have increased in the northeast over the last 30 years (Richardson et al. 2003) and that fog cover has become more frequent in spring and fall on Mt. Washington in New Hampshire (1934-2004; Seidel et al. 2007).

D) WIND

Wind speeds are declining, though stronger wind gusts are possible.

Winds can be described in terms of sustained winds (long-lasting winds that occur in the background with little fluctuation over time) and wind gusts (short bursts of high-speed winds). Past observations and future projections both indicate decreases in overall wind speed (sustained plus gusts) under climate change cross the country (Pilson 2008; Pryor et al. 2009; 2012). Modeling studies over the continental U.S. indicate no change in extreme wind events with climate change (Pryor et al. 2012). However, one modeling study simulating Ontario, Canada, projected increases in the number of 45-mph wind gusts by up to 20-30% (Cheng et al. 2014). High winds often accompany severe weather, such as thunderstorms, tornadoes, and hurricanes, which are expected to increase in intensity with climate change (Holland & Bruyère 2014; Gensini & Mote 2015; see **Section F**) .

E) SURFACE HYDROLOGY

This section discusses changes in hydrology on the terrestrial surface (e.g., soil moisture, evapotranspiration, streamflow and temperature, surface runoff, and groundwater levels). Changes in hydrology pertaining to the Atlantic Ocean and Great Lakes are discussed in later sections.

Soil moisture trends are uncertain.

Observations over the Connecticut River Basin indicate wetter soils since 1950 due to more extreme precipitation events (Parr & Wang 2014). However, many habitats across the U.S. are predicted to experience net drying during the next 50 years, even in areas where precipitation is predicted to increase (Brooks 2009; Wuebbles et al. 2014). Trends in soil moisture are difficult to predict given that rainfall events are both becoming less frequent (suggesting drier soils), yet more intense and longer lasting (suggesting wetter soils). The Northeast and Midwest are especially problematic given that the increases in annual precipitation and heavy precipitation events predicted for them are stronger than any other region in the country.

Evapotranspiration rates are also inconclusive.

Many studies indicate increasing trends in evapotranspiration as the climate warms and is thus able to contain more water vapor, and as precipitation increases moisture availability (Hayhoe et al. 2007; Wuebbles et al. 2014; Pan et al. 2015). Some trends in the Northeast are statistically significant (Hayhoe et al. 2007). However, there is generally a lot of uncertainty about how the hydrologic environment will shift and impact evapotranspiration rates. There is also debate as to whether precipitation increases or decreases will feed back to increased evapotranspiration (Abtew & Melesse 2013; Wuebbles et al. 2014). Higher carbon dioxide concentrations may lead plants to close their stomata, resulting in less transpiration, whereas increased leaf temperature increases transpiration rates. No trend has been seen in evapotranspiration measurements in the Connecticut River Basin since 1950 (Parr & Wang 2014), though there appears to be wide spatial variability in trends (Abtew & Melesse 2013).

Streamflow is intensifying, but varies by season and sub-region, and is not proportional to increases in extreme rainfall.

Climate change will have significant impacts on the flows of rivers and streams throughout the Northeast and Midwest. The most direct sources of these changes are projected shifts in temperature, rainfall, and evapotranspiration. These changes are unlikely to be uniform across the region and will be altered by the specific characteristics of the individual basins. Basin characteristics that are very likely to have particular impacts include the basin’s vegetation, degree of urbanization, underlying geology, longitude, latitude, elevation, the contribution of groundwater, and basin slope.

Annual flows have increased during the last part of the 20th century in the Northeast (Collins 2009; Hodgkins et al. 2005; McCabe & Wolock 2011). However, despite recent intensification of precipitation events, observed maximum annual flows have not increased (Douglas et al. 2000; Lins & Slack 1999; 2005; Villarini & Smith 2010; Villarini et al. 2011). More precipitation during the summer in New England and during the fall in the upper Mississippi basin and upper Midwest have been linked to positive trends in low flows linked to groundwater contribution (Hodgkins et al. 2005; Small et al. 2006). Low flows play a crucial role in maintaining aquatic ecosystems since they provide a minimum flow during the warm summer months and control stream water temperatures.

Step changes in the mean and variance of observed mean and minimum annual streamflows around the year 1970 have been documented for the continental U.S. by McCabe & Wolock (2002). Similarly, step changes in maximum annual values were identified around the same time in 23 (out of 28) basins in New England and attributed to the natural variability of the North Atlantic Oscillation (Collins 2009). Conversely, step changes in the mean and variance of flood peaks were observed in 27% and 40% of the stations in the Eastern and Midwest states, respectively, and linked to changes in land use-land cover practices in the region and not to external climatic conditions (Villarini & Smith 2010; Villarini et al. 2011).

Projected warmer summers along with reduced precipitation may impact soil moisture conditions in the region if evapotranspiration increases. Additionally, diminished groundwater reserves, linked to declining snow pack, will impact base flows in streams (Hayhoe et al. 2008).

Earlier winter-spring peak flows in the range of 6-8 days have also been observed in the Northeast and Midwest and thought to be linked to increased snowmelt and rain-on-snow episodes (Hodgkins & Dudley 2006). This trend is projected to continue during the 21st century (Campbell et al. 2011). A shift toward higher winter flows and lower spring flows has been documented for two Northeastern watersheds (Connecticut River Basin, and a small forest site in New Hampshire) using climate-driven streamflow simulations (Campbell et al. 2011; Marshall & Randhir 2008). Changes in the timing and the magnitude of spring snowmelt in eastern U.S. are crucial to maintain ecosystem functions since some aquatic species rely on the time and volume of streamflows for vital life cycle transitions (Comte et al. 2013; Hayhoe et al. 2007). Larger peak flows can contribute to increases in river scour magnitude and frequency and affect egg burial depths of some salmon species (Goode et al. 2013). Additionally, larger flow velocities in river channels can impede the natural displacement of some small fish (Nislow & Armstrong 2012).

Stream temperatures are rising.

Warming has been observed in many streams across the continent (Webb 1996; Bartholow 2005), as also seen in future projections (Mohseni et al. 1999). Warming stream temperatures seem to be more a function of warmer nights than warmer days or daily averages (Diabat et al. 2013).

F) EXTREME EVENTS

Severe thunderstorms may become more severe, whereas tornadoes may decrease in annual number and increase in daily number.

Only a few studies have attempted to examine observed and projected trends in severe weather, and with much difficulty due to a limited observational record and inconsistent metrics to describe weather events (e.g., structural damage, storm reports; Walsh et al. 2014). Studies reporting reliable estimates in observed trends in severe thunderstorm activity could not be located. One study reported increases in damage costs from storms over recent decades; however, this trend was not statistically significant and may owe more to population and wealth increases than severe activity (Kunkel 2013). The number of tornadoes per year has not changed since 1970; however, one study found that the number of days with tornadoes is decreasing while the number of tornadoes per day is increasing (Brooks et al. 2014). Some studies suggest that climatic warming may increase the frequency of severe storms (Del Genio et al. 2007). Some future projections indicate an increase in the occurrence of hazardous events, such as tornadoes, damaging wind, and hail (Gensini & Mote 2015), with the greatest increases estimated for the Great Plains in March, and southern Illinois and Indiana in April. Brooks (2013) projected more severe thunderstorms due to increased available convective energy, though lower probability of tornadoes due to decreased wind shear. Little change in severe activity is projected for the Northeast; however, trends show an increase in Atlantic hurricanes making landfall in the northern coastal states (see U.S. Atlantic Coast section below).

Floods are becoming more intense.

Increasing trends in floods have been observed in the Northeast and the Midwest, associated with increases in annual precipitation (Peterson et al. 2013; Wuebbles et al. 2014). Across the United States, the NE CSC region is most susceptible to increases in flood events (Wuebbles et al. 2014). It is expected that overall annual precipitation totals will increase over the Northeast region throughout the century, but that precipitation events will become less frequent. As a consequence, the events that do occur are projected to be more intense, raising the risk for both flooding and drought (Horton et al. 2014).

Droughts are becoming more frequent.

The average number of consecutive dry days over the region is projected to increase by 1-5 additional days (Sillman et al. 2013; Ning et al. 2015), suggesting a potential increase in drought frequency. However, simultaneous increases in annual precipitation (Schoof 2015), particularly extreme rain events, may help minimize the severity of droughts. Thus, statistically significant increases in the frequency of short-term (lasting 1-3 months) droughts are projected with minimal threat of increased long-term droughts (Hayhoe et al. 2007).

More frequent droughts are expected in the future for all states in the Northeast and Midwest. Maine, New Hampshire, Vermont, western Massachusetts, Connecticut, Rhode Island, and the Adirondacks may see the greatest increases in short-term (lasting 1-3 months) droughts (one every year, up from one every 2-3 years), while more long-term (lasting 6+ months) droughts are expected predominantly in western New York. We note again, however, that projections are not very reliable at capturing regional distributions in precipitation, and that long-term trends in drought events have yet to be observed (Hayhoe et al. 2007; Karl et al. 2012). In fact, droughts may be occurring less frequently than in the past in the Northeast (Peterson et al. 2013) due to amplifications in precipitation, particularly in extreme events. Nonetheless, warming and less frequent precipitation events favor an increase in drought intensity.

Blizzards and ice storms are occurring more frequently.

Severe snow and ice storms have more than doubled over the last 55 years relative to the previous 60 years (Kunkel 2013). This suggests that, while most areas are seeing reduced snow pack due to warming and shifts in precipitation from snow to rain, some localized areas that experience severe storms may exhibit an increase in annual total snowfall.

G) BIOLOGICAL INDICES

Growing seasons are getting longer.

Growing season length is generally defined as the number of days between the dates of the last spring frost and the first autumn frost. Frosts occur when the minimum daily temperature drops below freezing (32 °F). Over the entire time period of 1895-2011, there is a statistically significant upward trend in freeze-free season length in the Northeast (Hayhoe et al. 2007; Kunkel 2013), indicative of shorter winters and longer summers. The average freeze-free season length in the Northeast during 1991-2010 was about 10 days longer than during 1961-1990 (Kunkel 2013). The average date of the last frost in spring has been getting earlier each year, and the date of the first frost in autumn has been getting later across the Northeast (Hayhoe et al. 2007), though the magnitude of change varies spatially. In Vermont over the past half century, the average date of the last spring freeze has been getting earlier by 2.3 days every decade, while the first autumn freeze has gotten later by only 1.5 days per decade (Betts 2011). This finding suggests the impact of climate change is greatest during the early growing season when vegetation is most vulnerable to extreme climate (e.g., extreme heat and cold, drought). For example, late-season spring freezes following an early leaf-out can damage leaves and decrease their productivity for the remainder of the warm season (Norby et al. 2003; Inouye 2008; Gu et al. 2008; Martin et al. 2010; Hufkens et al. 2012). While the average date of the last spring freeze is getting earlier, fluctuations in temperature in a given season are getting wider (Rigby & Porporato 2008; Augspurger 2013), implying that climate change is likely to result in more frequent frost damage on plants.

Projections show continued lengthening of the freeze-free season across the Northeast by at least 19 days by 2055 relative to 1980-2000 for the high emissions scenario (Kunkel 2013). By the end of the century, the growing season may lengthen by as much as 1-2 months depending on the emissions scenario (Hayhoe et al. 2007; Ning et al. 2015). In the Midwest, increases of up to 26 more days in the length of the annual freeze-free season are simulated across most of the Midwest by 2055 relative to 1980-2000 for the high emissions scenario (Kunkel 2013). Anticipated increases are greatest from 40-50 °N, the latitude band covering the Great Lakes region, and along the Appalachian Mountains (**Figure 6**).

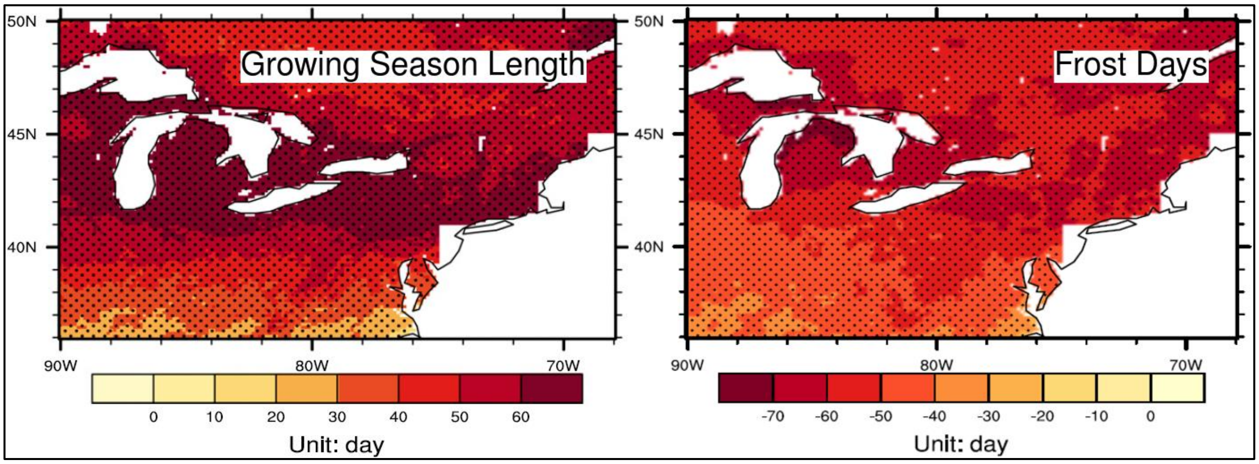


Figure 6: Change in the number of days in the growing season (left) and number of frost days (right) by the end of century (2050-2099) relative to the 1950-1999 average, following a "business-as-usual" greenhouse gas emissions scenario (Used with permission from Ning et al. 2015).

More growing degree days are expected.

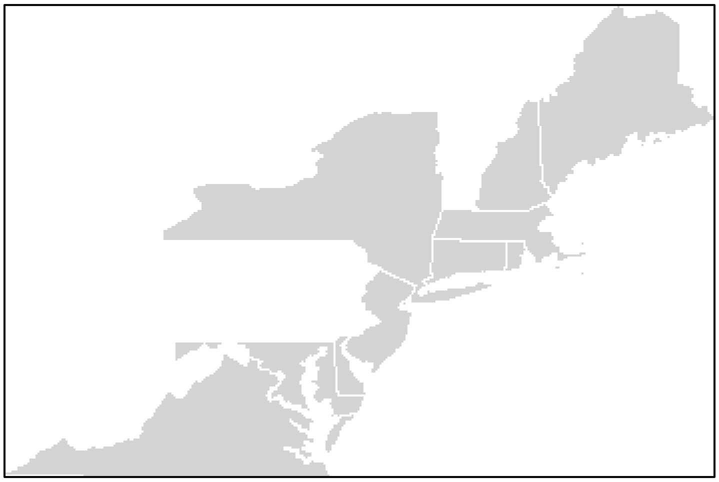
Growing degree days (GDD) is an index that is used to estimate the timing of certain events in the phenology of plants and animals, such as leaf-out and pest invasions. GDD for a given day is the average of the daily minimum and maximum temperature minus some base temperature above which biological events (e.g., blooming, leaf-out) are triggered. For example, a high of 70 °F and a low of 40 °F with a base temperature of 50 °F indicate a daily yield of 5 GDDs. An average temperature below the base temperature yields 0 GDDs. GDDs are additive, and so they accumulate day after day throughout the growing season. GDDs begin accumulating on March 1 each year. GDDs eventually reach a certain threshold that has biological significance. Though the base temperature varies by species, a standard reference temperature (often either 50 °F or 65 °F) is generally used in weather reports. Projections estimate an increase in GDD of over 32-33% and 35-41% in the Midwest and Northeast, respectively, over the next half century, with strong agreement among the models (Kunkel 2013). More important than the increase in GDD is the shift in timing of when GDD becomes large enough to trigger certain events. As the climate warms, the date at which GDD begins accumulating is very likely to be earlier. This may provide opportunities for some warm climate vegetation while negatively impacting cold-adapted species.

Winters are becoming less severe.

The Winter Severity Index (WSI) is a measure of the combined influence of the intensity and duration of severe cold and snow cover (Notaro et al. 2014). This indicator is a useful metric for tracking wildlife populations (e.g., deer expansion or waterfowl migration). For instance, Schummer et al. (2010) found that southward migration of ducks generally begins when WSI exceeds 7.2. Notaro et al. (2014) estimate a 20-40% decrease in the probability of a 7.2 or greater WSI in December across the Northeast and Midwest, suggesting that waterfowl migration may occur later in the winter. Changing WSI patterns are largely attributed to a 40-50% decrease in snowfall. Severe winters, with heavy snow and extreme cold, also negatively impact deer (Verme 1968), and thus deer populations and some other wildlife populations are likely to expand northward as decreases in WSI allow regions that were unsuitable for deer to become suitable.

IV. SUB-REGIONAL ANALYSES

A) U.S. ATLANTIC COAST



Sea level is rising at an accelerating rate.

The coastal region of the Northeast has high, and growing, vulnerability to coastal flooding (Horton et al. 2014). It combines low slope coastal areas, especially in southern parts of the region, with the potential for faster regional sea level rise than the global average (Yin et al. 2009). While global sea levels have risen by about 8 inches since 1900, much of the Northeast has experienced approximately 1 foot, whereas the Mid-Atlantic states have experienced approximately 1.5 feet during that same time period (Horton et al. 2014) of sea level rise. Sea level rise threatens coastal environments, through more frequent coastal erosion, flooding, and salt water intrusion (Kane et al. 2015), as well as more severe flooding during storms (Horton et al. 2014). Storms are likely to become more destructive in the future as sea level rise contributes to higher storm surges (Anthes et al. 2006).

Sea level rise is uniquely threatening to the U.S. Atlantic coast, both due to the more rapid than average rate of increase expected in the area as well as the particular vulnerability of developed coastal areas, including New York City (NYC). Sea level rise is much less responsive to emissions reductions than temperature (Solomon et al. 2009); therefore, even under an aggressive climate change mitigation policy, sea level will continue to rise for the rest of the 21st century and beyond. Due to the near certainty of continued sea level rise, coastal adaptation is essential if society is to prevent increasing damage from flooding events.

Sea level rise is projected to accelerate in the future. By mid-century, much of the region could see between 8 inches and 2.5 feet of sea level rise relative to 2000-2004 levels; by the end of the century, anywhere between 1.5 and 6 feet of sea level rise is possible (Collins et al. 2013; Horton et al. 2015). While the worst case projections would require rapid acceleration of land-based ice melt in Greenland and West Antarctica, such rapid melting cannot be ruled out (Joughin et al. 2014). Faster-than-expected slowdown in the Atlantic meridional overturning circulation also contributes to high-end projections in sea level rise (Rahmstorf et al. 2015). Even at the mid-range of the projections for late in the century—say 2.5 feet—coastal flood frequency would increase dramatically, even if storms remain unchanged. In the NYC region, for example, the current 1 in 100 year flood level could become a 1 in 20 year event under such a sea level scenario (Horton et al. 2015). We note high uncertainties in projections of the magnitude of future sea level rise, particularly in the high emissions scenario. However, there is no uncertainty that the sea level has risen and will continue to rise.

Coastal storms, such as tropical cyclones, hurricanes, and Nor'easters, may be intensifying.

Changes in the frequency and intensity of tropical cyclones (warm season coastal storms) or Nor'easters (cool/cold season coastal storms) would modify coastal flood risks. The balance of evidence suggests that the strongest tropical cyclones may become more intense due to climate change and warming of the upper oceans (Knutson et al. 2010; Christensen et al. 2013), as has already been observed over the past 40-45 years (Emanuel 2005; Webster et al. 2005). In addition, tropical cyclones may track further north toward the poles over the course of the 21st century (Yin 2005). However, confidence in how tropical cyclones may change is relatively low, due to high natural variability, short observed record, and uncertainty in how other climate variables that are important for tropical cyclones may change (e.g., wind shear, vertical temperature gradients in the atmosphere, and warming in the tropical Atlantic ocean relative to the tropical oceans as a whole). Hurricane intensity is also projected to increase (Emanuel et al. 2008; Ting et al. 2015). It is also unclear how Nor'easters may change (Horton et al. 2015), although some research suggests growing risk for the northern-most parts of the U.S. Atlantic coast, and decreasing risk for southern parts (Colle et al. 2010).

While it is unclear exactly how storms may change in the future, it is certain that our coasts are highly vulnerable today. Sea level rise, even at the low end of the projections, are very likely to dramatically increase flood risk. It should be noted that sea level rise impacts can penetrate far inland in our tidal estuaries. Saltwater intrusion into coastal ecosystems and aquifers are very likely to be an issue of increasing concern. Furthermore, in low lying areas, rainfall flooding may become worse due not only to heavier rain events, but because high sea levels will reduce drainage to the ocean (Horton et al. 2014). This may enhance pollution issues, especially in (formerly) industrial sites.

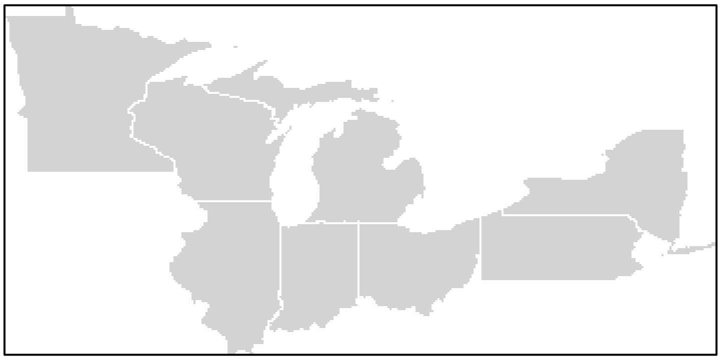
Oceans are warming.

Warming of the ocean waters has been observed in recent decades, with many of the records collected within the last 10 years (Mann & Emanuel 2006; Holland & Webster 2007; Domingues et al. 2008; Rhein et al. 2013). This suggests a direct link with anthropogenic climate change. Changes in coastal water ecology have been observed along the northern Atlantic coast (Oviatt 2004; Nixon et al. 2009). Other examples of how warming ocean waters will impact marine species and ecosystems are presented in **Chapter 3**.

The ocean is becoming more acidic.

With more carbon in the atmosphere from human activity (Sabine et al. 2004), and thus greater absorption of carbon by the Earth’s oceans (Feely et al. 2004; Canadell et al. 2007; Cooley & Doney 2009), the oceans and coastal waters are becoming more acidic (Walsh et al. 2014). The pH level of the oceans and coastal waters will continue to drop as atmospheric carbon continues to rise (Rhein et al. 2013). Ocean acidity has not changed in the last 300 million years with the exception of a few rare events (Caldeira & Wickett 2003), highlighting the impact of recent anthropogenic climate change. More importantly, these changes in ocean acidity are irreversible over the next several thousand years and thus will have prolonged impacts on marine and aquatic ecosystems.

B) GREAT LAKES



Like other parts of the NE CSC region, warmer conditions and more extreme temperature and precipitation events are expected for the Great Lakes basin (Bartolai et al. 2015). However, there are a number of changes that specifically impact the states that are adjacent to the lakes.

The lakes are warming.

Warming of water in the Great Lakes has already been observed (McCormick & Fahnenstiel 1999; Jones et al. 2006; Austin & Colman 2007; Dobiesz & Lester 2009), and is expected to continue (Trumpickas et al. 2009; Music et al. 2015). Observations indicate warming by 1-3 °C over the past 40 years (Dobiesz & Lester 2009). Lake Erie is warming, but at a slower rate than the other lakes (Dobiesz & Lester 2009). Lake temperatures are warming faster than surrounding air due to reductions in ice cover (Austin & Colman 2007). Given the influence of the lakes on regional climate, particularly their role in moderating air temperatures (Notaro et al. 2013), warming of the Great Lakes is very likely to lead to warmer air over the surrounding landscape compared to areas far away from the lakes. Since ice cover reduces the ability of the lakes to regulate temperatures, reductions in ice cover due to warmer lake temperatures may lead to faster warming of air temperatures immediately surrounding the lakes than other parts of the adjacent states.

Lake ice is decreasing in areal extent.

Long-term decreases in ice cover extent have already been observed (Assel 2005; Austin & Colman 2007; Wang et al. 2012; Bartolai et al. 2015) and are likely to continue to decline dramatically as a result of long-term climatic warming (Notaro et al. 2015). Ice cover extent varies interannually associated with the phases of large-scale climatic phenomena, such as the El Niño/La Niña cycle (Bai et al. 2015). Specifically, low ice cover tends to occur under strong positive phases of the North Atlantic Oscillation (NAO) and the La Niña phase of the El Niño-Southern Oscillation pattern. It is uncertain how climate change will impact these oceanic oscillations, let alone their influence on Great Lakes ice cover.

Lake evaporation rates are increasing.

Lake ice acts as a barrier that inhibits evaporation from the lakes. As ice cover extent decreases and waters warm, enhancements in lake evaporation are expected. Increases in lake evaporation rates have already been observed over the past 50 years due to warmer waters and decreasing ice coverage (Gronewold et al. 2013). Future projections anticipate continued increases in evaporation from the lakes as ice cover extent continues to decrease (Notaro et al. 2015). Due to the enormous size of the lakes and the ability of water to store heat, lake temperatures, and thus evaporation rates, have an offset seasonal cycle relative to land surface temperatures and evapotranspiration (Bryan et al. 2015). Specifically, most lake evaporation tends to occur in the winter when waters heated from the previous summer are much warmer than the overlying air. Accordingly, warmer lakes under a changing climate may lead to proportionally greater enhancement of evaporation in the winter season.

Lake-effect snow events are likely to shift to rain, become more severe, last longer, but occur less often.

During winter lake-effect snow is driven by intense evaporation from the lakes which occurs when lake waters are significantly warmer (by 13 °C or more, typically) than the overlying air (Wright et al. 2013). As lake waters warm, this temperature gradient between the lake and air may become stronger, leading to shifts in lake-effect snow. Ice cover inhibits lake-effect snow (Vavrus et al. 2013; Wright et al. 2013), so decreases in ice cover extent may also contribute to more intense lake-effect snow events. Given projected increases in future global temperature, areas downwind of the Great Lakes may experience increased lake-effect snowfall for the foreseeable future.

Lake-effect snow has been observed to increase in the twentieth century (Andresen et al. 2012), and model projections indicate continued increases in the future (Notaro et al. 2015). In particular, lake-effect events are expected to become more intense and longer lasting, but less frequent than at present. As the climate warms, however, lake-effect snow is likely to transition to lake-effect rain, which is predicted for four of the five Great Lakes (Notaro et al. 2015). Given its high latitude, Lake Superior is expected to be cold enough over the next century to support lake-effect snow. However, as warming continues into the next century, lake-effect rain may occur as far north as the Lake Superior region.

Water levels have been decreasing slightly, but future projections and the link to anthropogenic climate change is uncertain.

Slight decreases in lake levels in the Great Lakes have been observed over the past 30 years (Gronewold et al. 2013), coinciding with increased warmer waters, increased evaporation, and decreased areal ice coverage. Decreases have varied in magnitude depending on the lake (**Figure 7**). Future projections indicate slight decreases to no change over the next century (Angel & Kunkel 2010; Hayhoe et al. 2010). However, lake-level predictions are not very robust, and the hydrological drivers of lake levels are quite complex, thus the impact of climate change on lake levels is not fully understood or well predicted (Gronewold et al. 2013).

Higher evaporation rates from warmer lake waters implies a loss of water from the lakes resulting in lower lake levels. However, a net reduction in lake water requires evaporated water to escape the Great Lakes watershed basin before precipitating back to the surface; additionally, the entry of new water transported from long distances must not make up for the loss of water evaporated from the lake (Bryan et al. 2015). It is unclear how these various aspects of the Great Lakes hydrologic budget will change with climate change (i.e., whether there will be a net loss or gain to the system). It is also unclear how much the slight decrease in water levels observed recently is due to anthropogenic climate change or more natural, longer-term causes. As shown in **Figure 7**, lake levels in Lakes Michigan and Huron have been decreasing since before anthropogenic warming began. Even if the net water content remains constant and lake levels remain unchanged with climate change, it is likely the hydrologic cycle in the region will manifest more intense evaporation and convection combined with more intense precipitation events (Grover 2015).

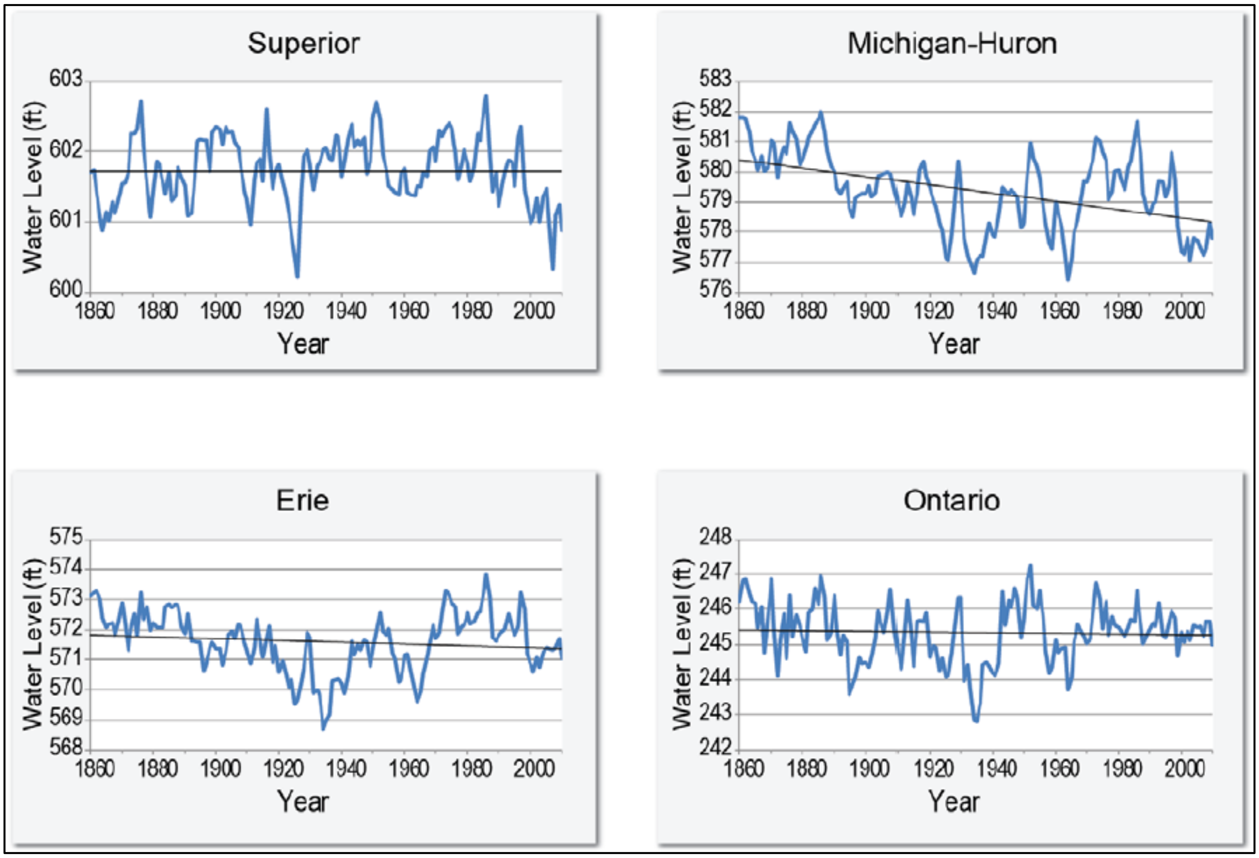
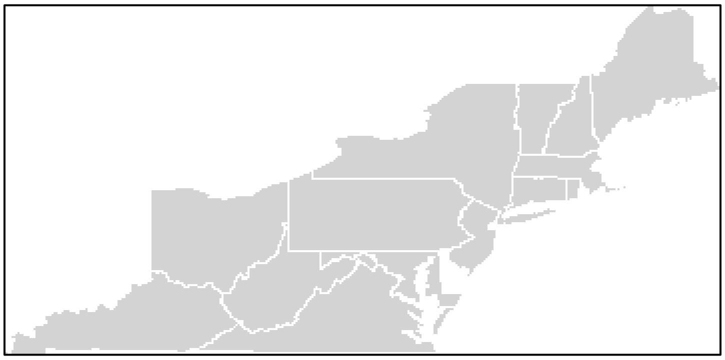


Figure 7: Recent trends in Great Lakes water levels (Used with permission from Kunkel 2013). Linear regressions for the 1860 – 2010 period are shown in black.

C) APPALACHIANS



Warming may be occurring at a faster rate at higher elevations.

Though the observational networks at the tops of mountains are limited, there is evidence on several mountain peaks around the world that temperatures are increasing at a faster rate at the top of mountains than at the bases (Diaz & Bradley 1997; Pepin & Lundquist 2008; Rangwala & Miller 2012; Diaz et al. 2014; Pepin et al. 2015). Based on model simulations, under future warming, the magnitudes of temperature increases over mountain regions are also larger than over low-elevation regions (Bradley et al. 2004; Bradley et al. 2006; Diaz et al. 2014). The potential physical mechanisms that contribute to elevation-dependent warming include: a) snow albedo and surface-based feedbacks; b) water vapor changes and latent heat release; c) surface water vapor and radiative flux changes; d) surface heat loss and temperature change; and, e) aerosols (Pepin et al. 2015).

Consistent with these model results, future projections indicate a more rapid increase in summer daily highs (Thibeault & Seth 2014) and lengthening of the growing season (**Figure 6**; Ning et al. 2015) in the Appalachians than for the surrounding landscape. A further consequence of this warming may be an accelerating decrease in snow pack and upslope regression of the snowline (Cohen et al. 2012). No matter the variability in rate with elevation, warming in general will likely lead to decreased depths and earlier melting of snow in mountain regions (Barnett et al. 2005), as have already been observed since the start of the century (Dedieu et al. 2014). Wildlife or habitats that depend on specific timing and magnitude of snow melt and thicknesses of winter snow cover will be most vulnerable to these changes. For example, some species rely on snow cover for camouflage, and as snow packs melt away earlier, there may be a mismatch in timing with changes in seasonal coat (e.g., snowshoe hare; Mills et al. 2013). Additionally, upslope progression of the temperate-boreal transition zone may accelerate with future warming.

The Appalachians may see greater intensification of extreme precipitation.

The precipitation environment along mountain slopes is distinct from flat terrain due to the influence of orographic lift on the windward side and subsidence on the leeward side (Roe 2005). Overall, precipitation amounts and frequency of extreme events on mountain slopes are likely to increase and the shift from snow to rain under warming climate points to heavier runoff and flooding (Shi & Durran 2015). Projections suggest that the Appalachians, in addition to the U.S. Atlantic coast, may see greater increases in the number, intensity, and inter-annual variability of extreme precipitation (Ning et al. 2015). The windward side of mountains is particularly sensitive to climatic warming due to the influence of orographic lift in producing high amounts of precipitation in that region (Shi & Durran 2014). Warming may increase both the intensity and duration of orographic precipitation due to elevation-varying changes in the moist adiabatic lapse rate, winds along the slope, and orographic lift. Changes in the progression of mid-latitude storms may also impact precipitation on the slopes of the Appalachians.

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

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

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**).

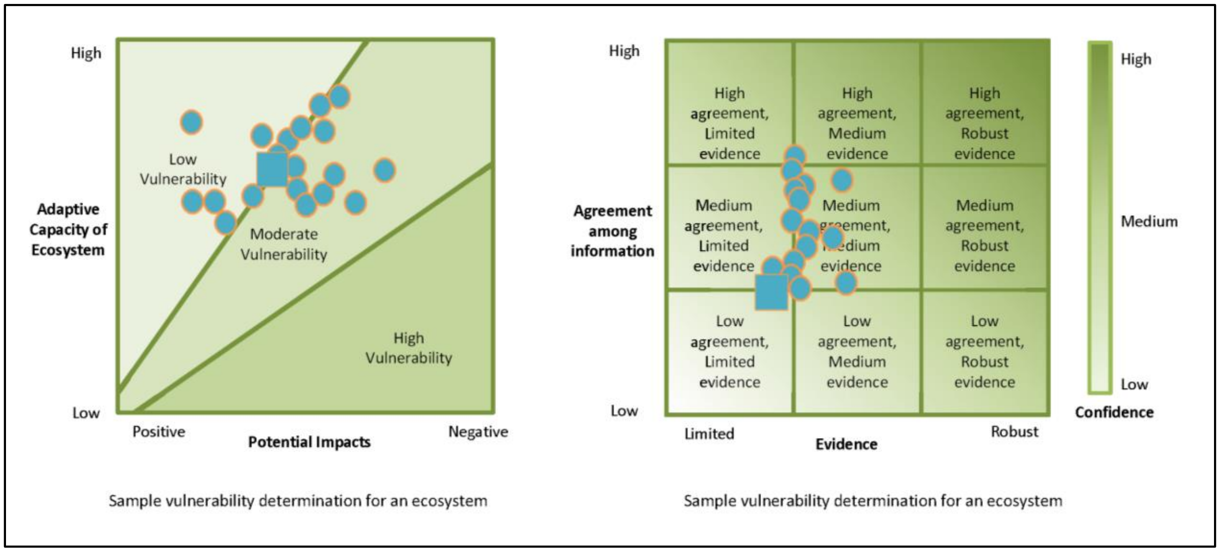

Figure 1: An example of how expert panelists assess vulnerability (left panel) and confidence (right panel) for forest ecosystems in CCRF vulnerability assessments. Each panelist provides an individual determination of ecosystem vulnerability and rate confidence in that determination (circles). The group 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.

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

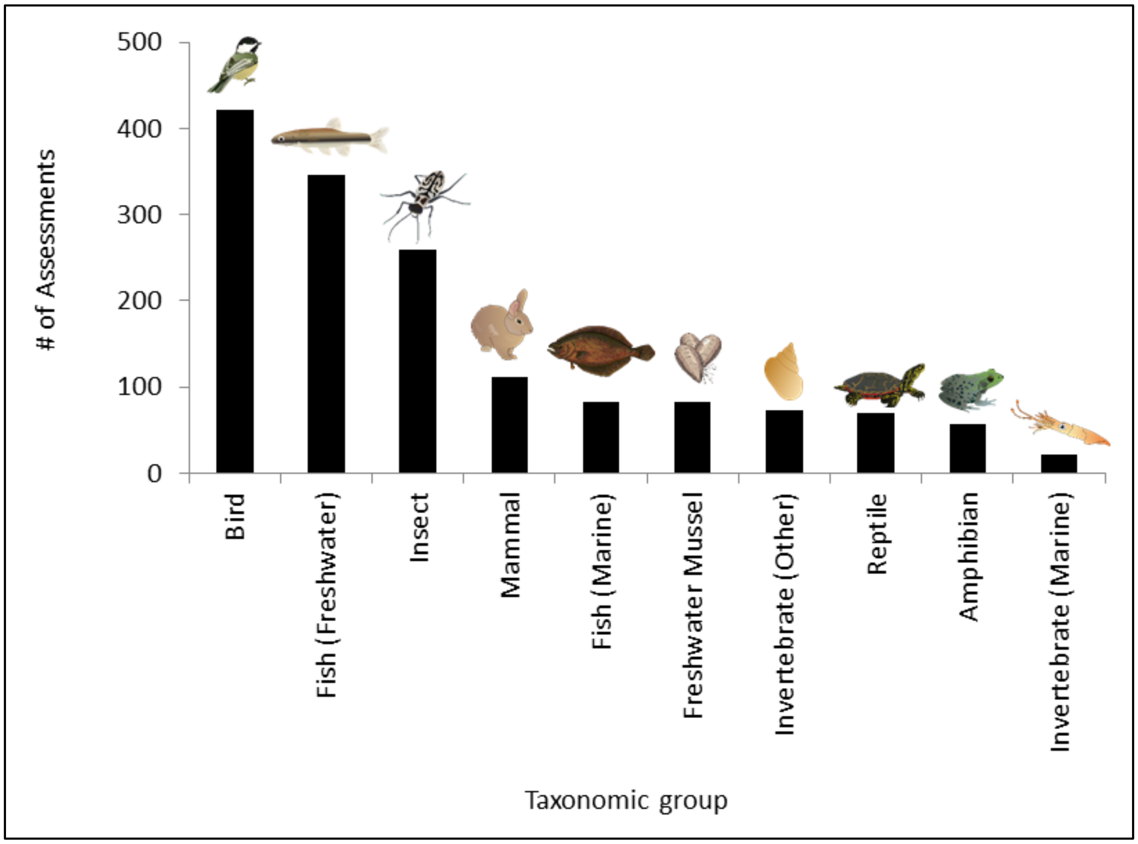

Figure 2: Number of vulnerability assessment rankings by major taxonomic groups across 16 regional studies. Icons courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

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.

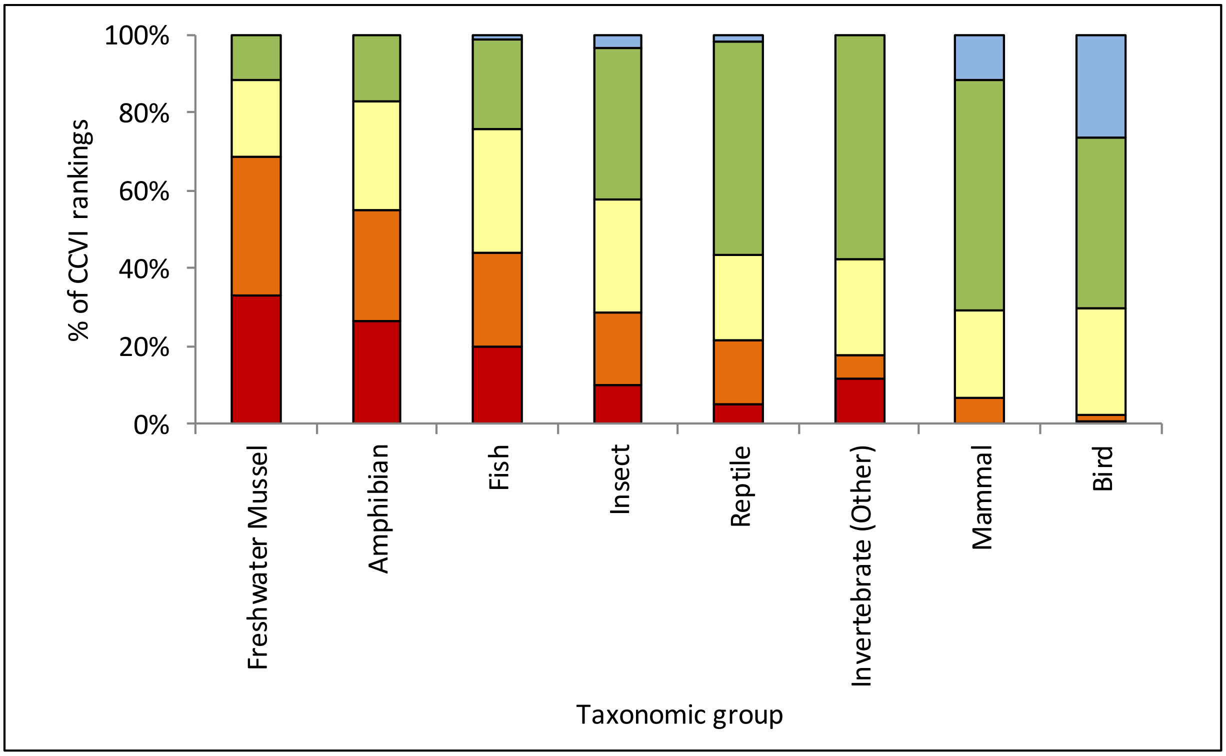

Figure 3: Count of vulnerability rankings using the NatureServe CCVI method broken down by taxonomic group. Bars show the distribution of vulnerability ranking scores of extremely vulnerable (red), highly vulnerable (orange), moderately vulnerable (yellow), presumed stable (green) and increase likely (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.

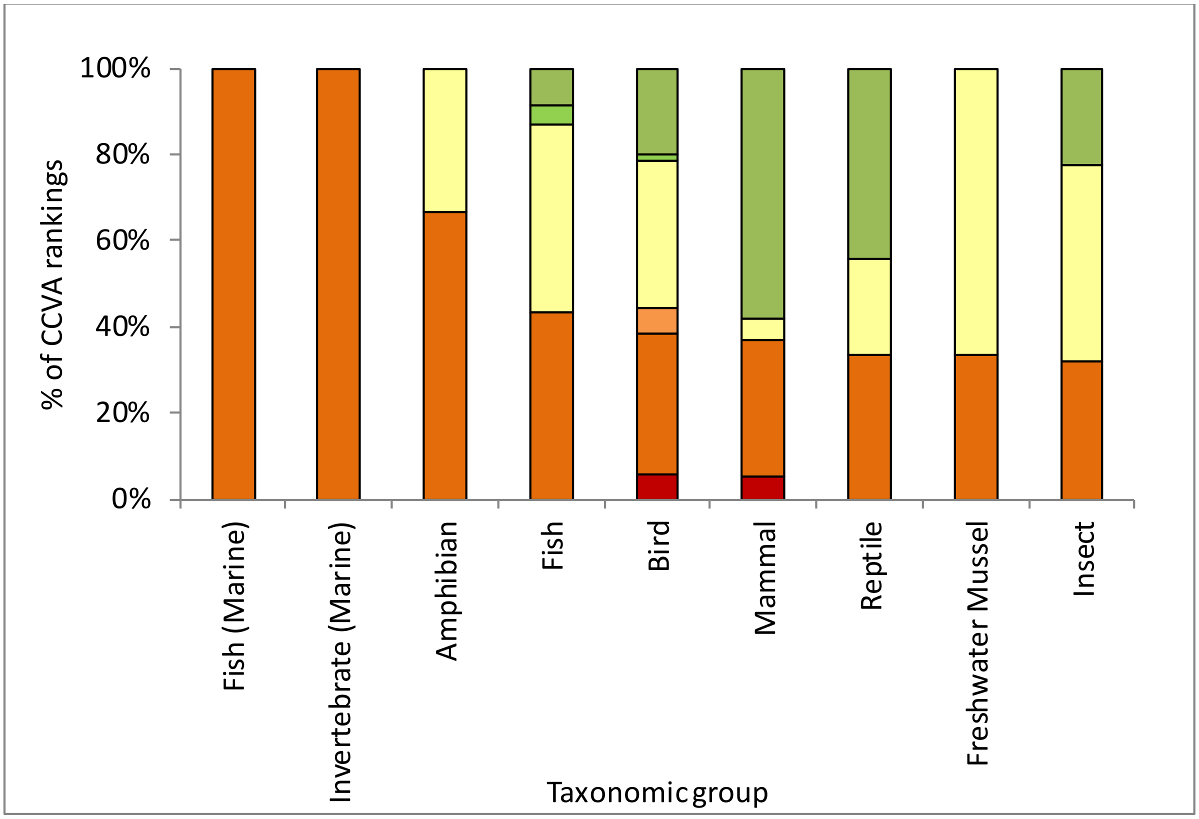

Figure 4: Count of vulnerability rankings using methods other than the NatureServe CCVI method broken down by taxonomic group. Bars show the distribution of vulnerability ranking scores of extremely vulnerable (red), highly vulnerable and high concern (orange), moderately vulnerable (yellow), low concern 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).

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[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.

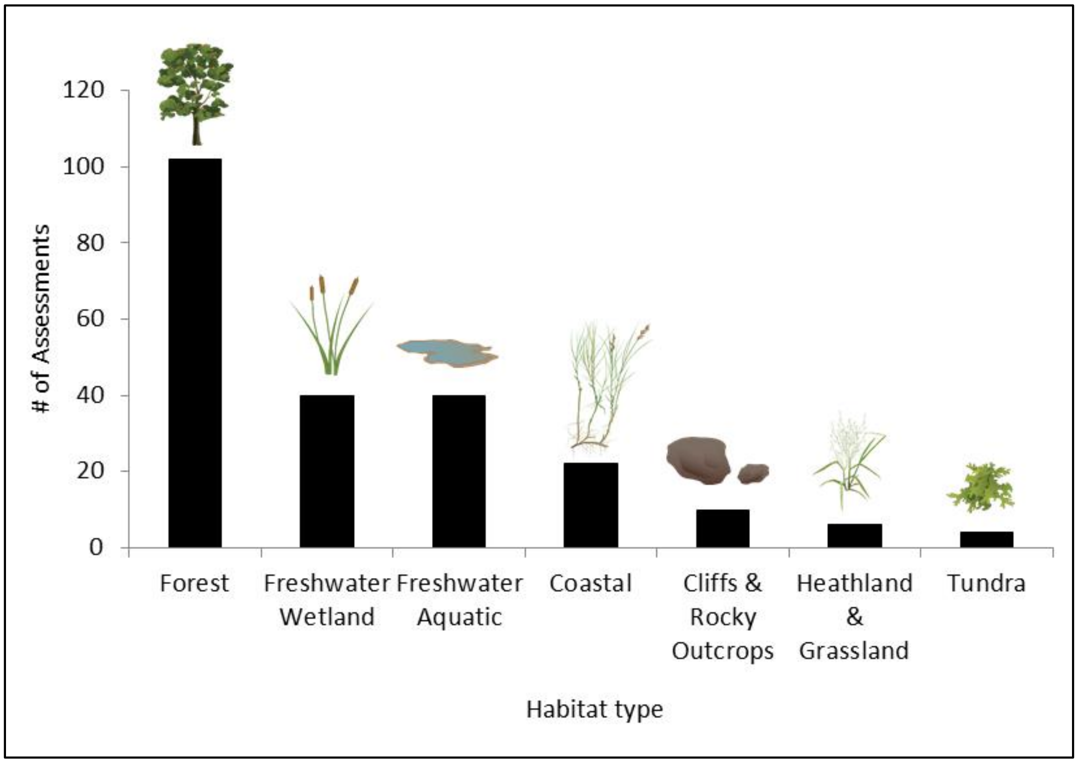

Figure 5: Number of vulnerability assessment rankings by habitat type across 11 regional studies. Icons courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

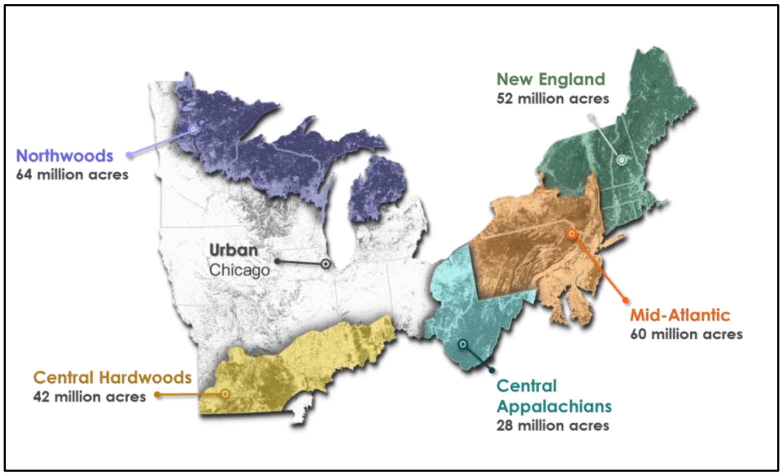

Figure 6: Areas assessed and anticipated (in 2016) for climate change vulnerability through the CCRF.

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.

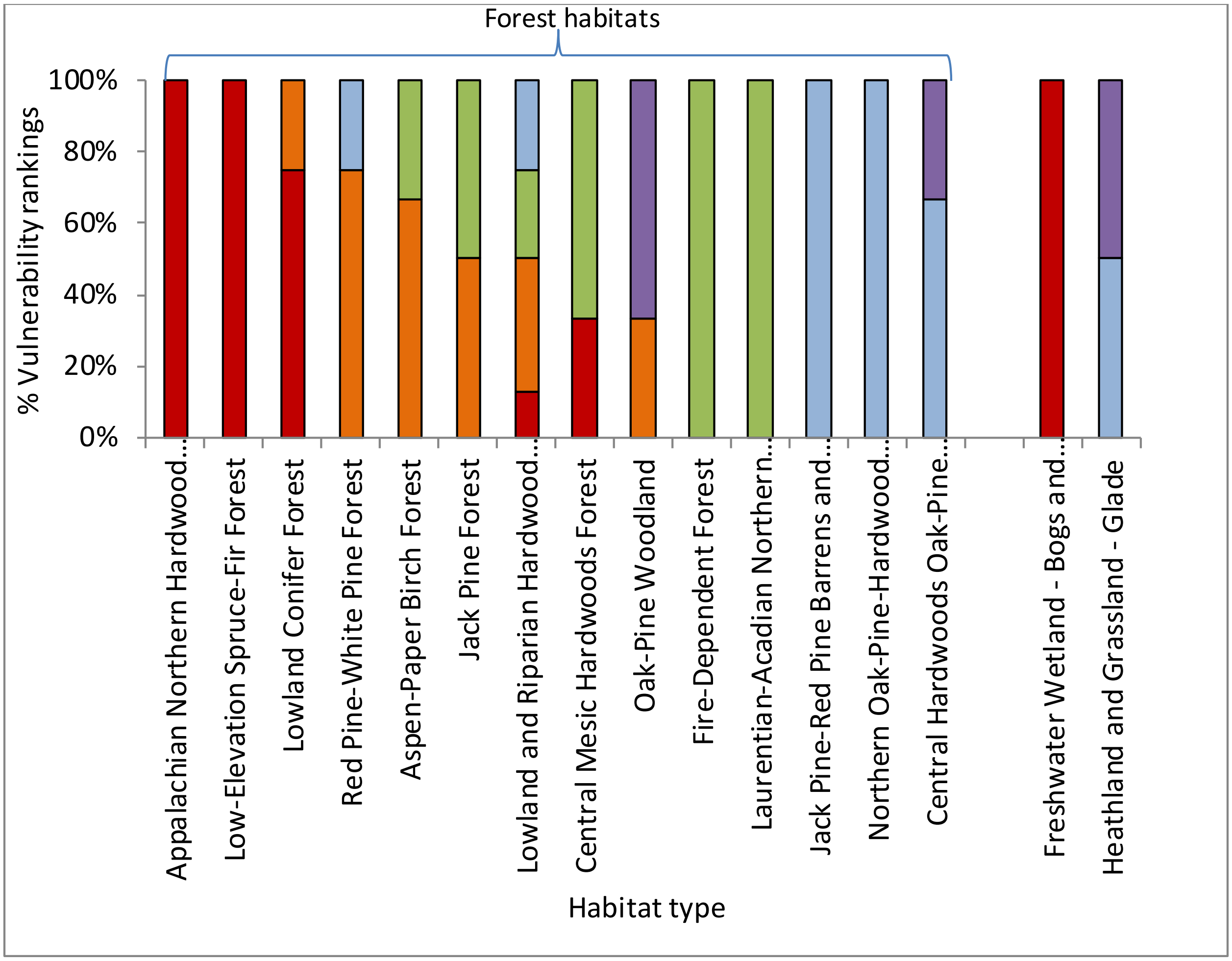

Figure 7: Count of vulnerability rankings using the CCRF framework broken down by habitat. Bars show the distribution of vulnerability ranking scores of High (red), Moderate-High (orange), Moderate (green) and Low-Moderate (blue), and Low (purple) vulnerability. Results show combined rankings across 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.

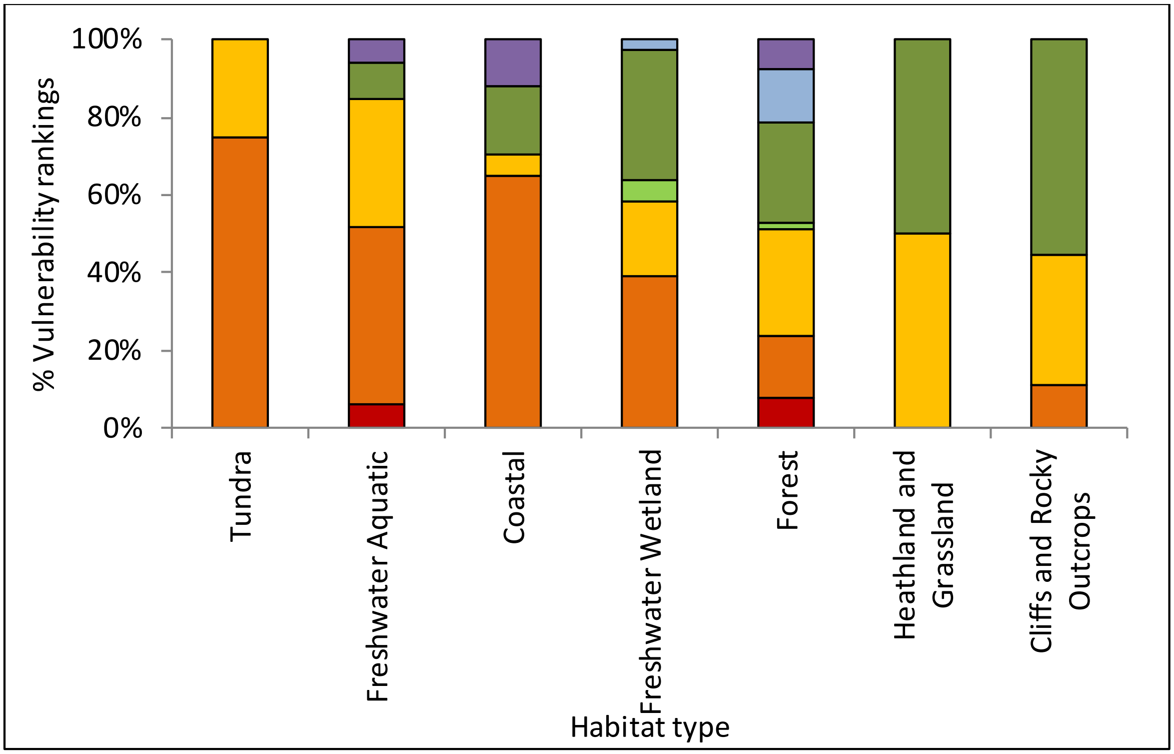

Figure 8: Percentage of counts of vulnerability rankings in non-CCRF studies by habitat type. Bars show the distribution of vulnerability ranking scores of extremely vulnerable (red), highly vulnerable and high concern (orange), moderately vulnerable (yellow), low concern and presumed stable (green), 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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CHAPTER 3: BIOLOGICAL RESPONSES TO CLIMATE IMPACTS WITH A FOCUS ON NORTHEAST AND MIDWEST REGIONAL SPECIES OF GREATEST CONSERVATION NEED (RSGCN)

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CHAPTER 3: BIOLOGICAL RESPONSES TO CLIMATE IMPACTS WITH A FOCUS ON NORTHEAST AND MIDWEST REGIONAL SPECIES OF GREATEST CONSERVATION NEED (RSGCN)

Summary Points

- Climate change will have cascading effects on ecological systems.
- These changes are expected in the form of shifts in timing, distribution, abundance, and species interactions.
- Some wildlife groups in the Northeast and the Midwest, including montane birds, salamanders, cold-adapted fish, and freshwater mussels, could be particularly affected by changing temperatures, precipitation, sea and lake level, and ocean processes.
- Interspecific interactions and land use change could exacerbate the impacts of climate change.
- A focus on habitat connectivity, water quality, and invasive species is among the many options to increase resilience for wildlife populations in the face of climate change.

This chapter reviews the responses to climate change on the 367 Regional Species of Greatest Conservation Need (RSGCN) identified by the Northeast Fish and Wildlife Diversity Technical Committee (NEFWDTC), technical experts from states’ natural resource agencies (**Appendix 3.1**). These species were chosen based on their conservation status, listing in SWAPs, and the percentage of their range that occurs in the Northeast. The objectives of this chapter are to: summarize how regional biodiversity has already responded and is expected to respond to climate change; summarize information on specific RSGCN species responses to climate change to date and anticipated under future scenarios; characterize the greatest uncertainties about how biodiversity and RSGCN species will respond to climate change in the future; and highlight where other factors are expected to exacerbate the effects of climate change. This information was obtained through a systematic review of the peer-reviewed literature, primarily using the ISI Web of Knowledge to search for papers on each species related to “climate”, “temperature”, or “precipitation”. Although we undoubtedly missed some sources, the following allows us to review some of the ways climate change will affect regional species of conservation concern.

I. INTRODUCTION

As was laid out in **Chapter 1**, the Northeast and Midwest are experiencing, and will continue to experience, an altered climate as a consequence of human-induced global climatic warming. Warming is occurring in all seasons, particularly in the winter and at higher latitudes and elevations. Winters are getting wetter, with snow shifting to rain, resulting in lower snowpack in all areas except downwind coasts along the Great Lakes, where warming lake water are enhancing lake-effect precipitation. In summer, rainfall events are becoming more intense but occurring less often, resulting in little net change in annual precipitation totals in the Northeast and upper Midwest. Along the Atlantic coast, the sea level is rising at an accelerating rate, and tropical storms and storm surges may be intensifying. These changes are expected subsequently to influence lake levels, hydrological flows, storm frequency, distributional shifts in vegetation, and, ultimately, ecosystem structure and function.

Climate change might have cascading effects on ecological systems. Some species' distributions are already shifting northward, upslope, upstream, and to deeper depths (Melillo et al. 2014; Staudinger et al. 2013) and interdependent species will shift in response, adapt in place, or be unable to cope with the changes. Species distributional shifts will likely not be synchronized, as species respond to different cues and at different rates. For some species, shifts could be hindered by lack of connectivity as well as life history traits or lack of diversity that prevent movement or adaptation. Changes in species abundance and distribution are more likely to occur at the edge of a species range than in its center (Morelli et al. 2012; Trumbo et al. 2011). Increased disturbance related to climate change could increase establishment of invasive or pest species, which could in turn lead to more ecological disturbance. These changes will likely result in community turnover, with novel species assemblages, including complex interactions between species and new predators (Herstoff & Urban 2014).

Biological responses to climate change can already be seen across taxa in the Northeast and Midwest. Some species, like most small mammals, have broad distributions across the region and thus may be able to adapt to shifting temperatures and precipitation. Some montane birds, on the other hand, rely on habitats that are at the southern edge of their distribution in the northern U.S.; for example, the Bicknell's thrush (*Catharus bicknelli*) are predicted to severely contract their ranges northward and upslope in response to shifts in the spruce-fir ecosystems they rely on for breeding (Rodenhouse et al. 2008). High temperatures will likely negatively affect insects and amphibians due to desiccation stress. On the other hand, high temperatures coupled with high humidity could cause thermal stress to moose (*Alces alces*) at the southern edge of their range (Murray et al. 2006). Low snowpack will affect the thermoregulation of hibernating mammals and other species (Morelli et al. 2012).

Life history traits are a key determinant of how species will respond to climate change. Turtles, with their temperature-dependent sex determination, may have particularly strong population responses to warming. Some species, like some small mammals and grassland birds, are expected to be more affected by changes in precipitation than temperature. Low mobility species, like freshwater mussels, are highly threatened by both warming and drying waters as well as habitat conversion and pollution (Furedi 2013). On the other hand, some large mammals and fish species may be able to track their climate niche, as long as habitat connectivity allows.

Phenological shifts are already occurring. For example, anadromous species like American shad (*Alosa sapidissima*) appear to be changing the timing of reproduction (Kerr et al. 2009). However, detecting the full consequences of these changes is complicated by delayed responses, compounding effects of other stressors such as land use and harvest, and by interactions with competitors, predators, invasive species, disease, pests, and prey.

II. VERTEBRATES

A. MAMMALS

Small Mammals

Small mammals play an important role in their respective ecosystems as seed and fungal spore dispersers and prey for birds and other mammals. They also have the potential to play an important role in climate adaptation, particularly in more arid ecosystems, where they can mediate vegetation change (Curtin et al. 2000). These roles may be affected by the shifting patterns of precipitation and temperature across the United States.

Many small mammals in the Northeast and Midwest have broad temperature tolerances. Thus, climate change will likely be mediated through indirect effects on their life history and distribution. For example, the American red squirrel (*Tamiasciurus hudsonicus*), an important predator on eggs and nestlings in the spruce-fir ecosystem of northern New England and the upper Midwest, appears to be expanding its range upslope (T.L. Morelli, unpublished data), possibly in response to reduced snowpack or more food availability. However, there are examples of geographically-limited species that could be highly vulnerable to warming temperatures, such as the Allegheny woodrat *(Neotoma magister*, Manjerovic et al. 2009).

Precipitation patterns, which can drive small mammal abundance and distribution, are changing across the Midwest and Northeast. Some small mammals, such as smoky shrews (*Sorex fumeus*), move more when it rains (Brannon 2002), especially in dry environments. Star-nosed moles (*Condylura cristata*) are dependent on rain events for dispersing, and thus may be adversely affected in areas where rainfall events are projected to become less common (McCay et al. 1999). Extreme events can also have a detrimental effect on small mammal populations, and thus overall diversity, favoring particular species (Pauli et al. 2006).

Not all effects of climate change will be negative. The New England cottontail (*Sylvilagus transitionalis*) may benefit from decreased snow cover and forest disturbance in the Northeast. But indirect effects through changing relationships with other species such as predators and competitors are hard to predict. For example, if climate change affects eastern cottontails positively, there may be increased competition for New England cottontails (Fuller & Tur 2012).

Northern flying squirrels (*Glaucomys sabrinus*) are an example of a species threatened by the indirect effects of climate. Their northern forest habitat is shifting northward (Iverson et al. 2008). Moreover, climate change may decrease the fungi and lichen that are important food sources for the northern flying squirrel. Most notably, habitat and temperature changes are already allowing southern flying squirrels (*Glaucomys volans*) to expand northward, with a subsequent decline of northern flying squirrels associated with disease transmission and competition (Smith 2012). Furthermore, climate-induced hybridization was detected between southern and northern flying squirrels in the Great Lakes region and Pennsylvania as a result of increased sympatry after a series of warm winters (Garroway et al. 2010).

Climate change is expected to shift the ranges of boreal species, such as the snowshoe hare (*Lepus americanus*), northward; fragmentation and loss of southern populations are anticipated (Cheng et al. 2014). In addition, snowshoe hare exhibit seasonal changes to pelage color that help them to evade detection by predators. The timing of molting exhibits limited response to snow conditions within a given location and appears to be fixed by photoperiod; thus, as the number of snow-free days increases, snowshoe hares will likely experience longer mismatches between coat color and ground cover, leading to increased vulnerability to predators (Zimova et al. 2014). Hares do not appear to recognize this discrepancy as they show no behavioral changes when coat color is mismatched to ground cover (Zimova et al. 2014).

Bats

Climate change induced habitat loss may lead to losses of wildlife, including bats. For example, hoary bats (*Lasiurus cinereus*) in the Northeast have been known to roost exclusively in eastern hemlock (*Tsuga canadensis*) trees (Veilleux et al. 2009). The eastern hemlock, however, is expected to be substantially reduced by the hemlock wooly adelgid (*Adelges tsugae*), a tree pest that seems to be increasing due to climate change (Paradis et al. 2008).

Increasing climate variability may have a large effect on some bat species, with both increases and decreases in precipitation having potentially negative impacts. Some species, such as big brown bats (*Eptesicus fuscus*, O'Shea et al. 2011), have shown higher mortality in response to the extreme droughts that may increase in the future, especially for some areas of the Midwest. Lower weight gain for juvenile and adult female big brown bats was associated with years with lower rainfall and higher temperatures in the spring and summer (Drumm et al. 1994). Decreased summer precipitation may even lead to higher mortality (e.g., little brown myotis, *Myotis lucifugus*; Frick et al. 2010).

On the other hand, increases in precipitation at the right time may bode well for insectivorous bat species (Moosman et al. 2012). Moreover, climate change may increase riparian habitat in some areas of the Northeast and Midwest in coming decades, which has been shown to be important for bat foraging (e.g., hoary bats and big brown bats; Menzel et al.

2005). Even heavy rains in spring may have a positive effect on reproduction, as shown in big brown bats in Indiana, which otherwise seemed resilient to natural fluctuations in climate (Auteri et al. 2012).

The eastern red bat *(Lasiurus borealis)* is an example of a species that may be expanding its range in response to climate change, in this case into Canada (Willis & Brigham 2003). Bats are not as active in very cold climates and thus may begin to become more active in the future. However, cold-adapted species at the southern edge of their distribution, like the eastern red bat, might disappear out of the Northeast and Midwest (Arndt et al. 2012). Increased temperatures have also been shown to have a negative effect on northern myotis (*Myotis septentrionalis*; Johnson et al. 2011).

Disease is an important consideration when discussing bats in the Northeast and Midwest. The connection between white-nosed syndrome and climate change is still unclear, but warming climates could ultimately reduce vulnerability of little brown myotis and other bats to this fungal pathogen (Ehlman et al. 2013).

Carnivores

Carnivores in the Northeast and Midwest could see a mix of effects from climate change, especially if the region is at the southern edge of their distribution. Snowpack, competition, and prey availability may be the key drivers of these effects. For example, Canada lynx (*Lynx canadensis*) have been shown to be negatively affected by increased rain and decreased snow (Stenseth et al. 2004; Yan et al. 2013), as is projected for much of the Northeast and Midwest (See **Chapter 1**). Moreover, bobcat (*Lynx rufus*) will likely outcompete Canada lynx in this new habitat (Peers et al. 2013) and bobcat range expansion could result in increased interspecific hybridization

Climate change is interacting with human activities such as logging and trapping to cause declines in mammal populations. For example, Canada lynx and American marten (*Martes americana*) are being negatively affected in some U.S. forests (Carroll 2007). Models show that American marten populations in the western U.S. could be isolated due to climate change (Wasserman et al. 2012), although it is unclear how this research applies to species in the eastern U.S. (Koen et al. 2014).

Generalist species like the coyote (*Canis latrans*) are more likely to persist during periods of rapid environmental change than specialist species (Koblmüller et al. 2012; Malcolm et al. 2002). Martínez-Meyer et al. (2004) found that climatic variables were poor predictors of coyote distributions through past periods of climate change and suggested that distributions were determined by factors not directly related to climate. Effects of climate change on abundance are unclear, although coyote abundance is typically tied to the abundance of its prey species (Knowlton & Gese 1995; O'Donoghue et al. 1997; Todd & Keith 1983). An observed trend toward greater coyote abundances at lower latitudes has been interpreted by some as resulting from greater food availability in the southern U.S. during the critical winter months (Windberg 1995). If this interpretation is correct, milder winters may result in higher abundances in the Midwest and Northeast. However, as with many other carnivores in the region, potential climate-related impacts on coyote abundance will likely depend upon climate-related impacts to prey species abundances.

Marine Mammals

Not much is known about how most marine mammals are responding to climate change, although one study predicted that warming oceans and changes in sea ice cover would affect distributions, including decreases in pinniped and cetacean richness at lower latitudes and potential increases in cetaceans at higher latitudes (Kaschner et al. 2011).

Whales will likely be affected by several indirect changes in the oceans. For example, climate and oceanographic change is expected to affect habitat and food availability of sei whales (*Balaenoptera borealis*); migration, breeding locations, and prey availability are influenced by ocean currents and water temperature (National Marine Fisheries Service 2011). For baleen whales, loss of sea ice may lead to a decrease in krill populations; a severe decrease has been modeled for blue whale (*Balaenoptera musculus*) populations (Wiedenmann et al. 2011). Furthermore, climate change may be leading to hybridization in blue whales and other species (Attard et al. 2012). On the other hand, changes in prey populations are correlated with increases in some populations. Northern right whales (*Eubalaena glacialis*) have increased over the last decade, apparently in response to increased populations of their primary copepod prey in the Gulf of Maine, which in turn is likely due to changes in large-scale climate-related circulation patterns (Meyer-Gutbrod & Greene 2014), although this trend is confounded by population expansion as protection has aided recovery.

Other Mammals

The moose is a cold-adapted species at its southern limit in the Northeast and Midwest. Several southern populations are currently declining, including populations in Minnesota (Murray et al. 2006). Studies have linked these declines to changes associated with climate change, including milder winters resulting in increased densities of winter tick (*Dermacentor albipicuts*). Moose are susceptible to infestation by winter ticks and extreme infestations are associated with substantial mortality (Musante et al. 2007). Moose burdened by tick infestations rub against objects to relieve irritation, resulting in hair loss. Mortality occurs chiefly in winter as the energetic costs of compensating for blood loss exacerbate the effects of the resulting hypothermia (Musante et al. 2007; Rodenhouse et al. 2009). Other pathogenic parasites may have an advantage with climate change, such as meningeal worm or brainworm (*Parelaphostrongylus tenuis*), which is carried by growing white-tailed deer (*Odocoileus virginianus*) populations. Thermoregulatory stress associated with rising temperatures may also play an important role (Dou et al. 2013; Murray et al. 2006), although moose can use behavioral adaptations to cope with elevated temperatures (Broders et al. 2012; van Beest et al. 2012).

Land cover and forest dynamics play a large role in moose distribution. Moose abundance appears to be increasing in southern New England (Kilpatrick et al. 2002; Wattles & DeStefano 2013). Conditions there are currently favorable for moose because thermal refuges such as wetlands and closed canopy forest are well interspersed with young, vigorously growing forest, which is their main forage habitat. In addition, white-tailed deer populations are not particularly dense and there are no significant predators (Wattles & DeStefano 2013). However, given increased temperatures associated with climate change, several authors predict moose distributions will retreat northward (Dou et al. 2013; Lenarz et al. 2010; Rempel 2011).

American beavers (*Castor canadensis*) are habitat specialists, requiring streams with gentle gradients and at least intermittent flow and lakes or ponds with standing water (Baker & Hill 2003; Howard & Larson 1985). Climate projections for the Northeast and Midwest generally predict that increased temperatures will lengthen the growing season and increase the frequency of short-term drought and decreased soil moisture, resulting in some reduction of suitable habitat for beavers. If so, decreases in beaver populations could exacerbate climate effects as the presence of beavers has been associated with increased groundwater recharge, higher summer stream flows, and refugia for cold-adapted species such as moose and some amphibians (Gurnell 1998; Popescu & Gibbs 2009; Westbrook et al. 2006).

B. BIRDS

In addition to the information below, **Table 1** lays out the predicted shift in preferred habitat for 147 bird species in the Northeast and Midwest due to climate change, highlighting the amount of agreement across 8 model/scenario combinations, species-specific model reliability, and degree of change predicted for each species' habitat. It is modified from the Climate Change Bird Atlas (Matthews et al. 2007, 2011; http://www.fs.fed.us/nrs/atlas).

Grassland Birds

Changing precipitation regimes could have large effects on grassland bird populations. One study found that spring densities of Baird's sparrows (*Ammodramus bairdii*) were negatively correlated with the previous winter's snowfall, whereas grasshopper sparrow (*Ammodramus savannarum*) densities were positively correlated with May precipitation (Ahlering et al. 2009). Climate appears to drive the abundance of at least some grassland bird species, especially the grasshopper sparrow but also the bobolink (*Dolichonyx oryzivorus*), Henslow's sparrow (*A. henslowii*), sedge wren (*Cistothorus platensis*), and upland sandpiper (*Bartramia longicauda*) (Thogmartin et al. 2006).

A study of the effect of a drought in North Dakota on grassland birds showed a decline in species richness and abundance, with detrimental (although primarily short-term) effects on nearly all species studied: Baird's Sparrow, grasshopper sparrow, upland sandpiper, sharp-tailed grouse (*Tympanuchus phasianellus*), mourning dove (*Zenaida macroura*), eastern kingbird (*Tyrannus tyrannus*), Sprague's pipit (*Anthus spragueii*), clay-colored sparrow (*Spizella pallida*),

Table 1. Predictions of Species-Specific Habitat Shift due to Climate Change in the Northeast. Modified from the Climate Change Bird Atlas, Matthews et al. 2007, http://www.fs.fed.us/nrs/atlas/

Regional Predictions of Species-Specific Habitat Shift due to Climate Change

(Modified from the Climate Change Bird Atlas, Matthews et al. 2007 - http://www.fs.fed.us/nrs/atlas/)

Common Name	Scientific Name	Model Predictions
Common Loon	*Gavia immer*	**↓**
Mallard	*Anas platyrhynchos*	**↓↓**
Blue-winged Teal	*Anas discors*	↑
Canada Goose	*Branta canadensis*	↓
White Ibis	*Eudocimus albus*	**↑**
American Bittern	*Botaurus lentiginosus*	**↓**
Great Blue Heron	*Ardea herodias*	↓
Great Egret	*Ardea alba*	**↑↑**
Snowy Egret	*Egretta thula*	↑
Little Blue Heron	*Egretta caerulea*	**↑↑**
Cattle Egret	*Bubulcus ibis*	**↑↑**
Green Heron	*Butorides virescens*	**↑↑**
Yellow-crowned Night-Heron	*Nyctanassa violacea*	**↑**
Sora	*Porzana carolina*	**↓**
American Coot	*Fulica americana*	↑
Common Snipe	*Gallinago gallinago*	**↓↓**
Spotted Sandpiper	*Actitis macularia*	**↓**
Killdeer	*Charadrius vociferus*	↑
Gray Partridge	*Perdix perdix*	↑
Northern Bobwhite	*Colinus virginianus*	**↑↑**
Ruffed Grouse	*Bonasa umbellus*	**↓**
Ring-necked Pheasant	*Phasianus colchicus*	**↓↓**
Rock Dove	*Columba livia*	**↓↓**
Mourning Dove	*Zenaida macroura*	**↑**
Common Ground-Dove	*Columbina passerina*	**↑**
Turkey Vulture	*Cathartes aura*	**↑↑**
Black Vulture	*Coragyps atratus*	**↑↑**
Mississippi Kite	*Ictinia mississippiensis*	**↑↑**
Northern Harrier	*Circus cyaneus*	**↓**
Red-tailed Hawk	*Buteo jamaicensis*	**↑↑**
Red-shouldered Hawk	*Buteo lineatus*	**↑↑**
Broad-winged Hawk	*Buteo platypterus*	**↑**
American Kestrel	*Falco sparverius*	**↓**
Great Horned Owl	*Bubo virginianus*	**↑↑**
Yellow-billed Cuckoo	*Coccyzus americanus*	**↑↑**
Black-billed Cuckoo	*Coccyzus erythropthalmus*	**↓↓**
Downy woodpecker	*Picoides pubescens*	↑
Yellow-bellied Sapsucker	*Sphyrapicus varius*	**↓↓**
Pileated Woodpecker	*Dryocopuc pileatus*	**↑↑**
Red-headed Woodpecker	*Melanerpes erythrocephalus*	**↑↑**
Red-bellied Woodpecker	*Melanerpes carolinus*	**↑↑**
Chuck-Wills Widow	*Caprimulgus carolinensis*	**↑↑**
Whip-poor-will	*Caprimulgus vociferus*	**↑↑**
Common Nighthawk	*Chordeiles minor*	**↑↑**
Chimney Swift	*Chaetura pelagica*	↑
Ruby-throated Hummingbird	*Archilochus colubris*	**↑↑**
Scissor-tailed Flycatcher	*Tyrannus forficatus*	**↑↑**
Eastern Kingbird	*Tyrannus tyrannus*	**↑↑**
Eastern Phoebe	*Sayornis phoebe*	**↑↑**
Eastern Wood-Pewee	*Contopus virens*	**↑↑**
Acadian Flycatcher	*Empidonax virescens*	**↑↑**
Willow Flycatcher	*Empidonax traillii*	↓
Least Flycatcher	*Empidonax minimus*	**↓↓**
Horned Lark	*Eremophila alpestris*	**↑↑**
Blue Jay	*Cyanocitta cristata*	↑
American Crow	*Corvus brachyrhynchos*	↑
Fish Crow	*Corvus ossifragus*	↑
European Starling	*Sturnus vulgaris*	↓
Bobolink	*Dolichonyx oryzivorus*	**↓↓**
Brown-headed Cowbird	*Molothrus ater*	**↑**
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	↑
Eastern Meadowlark	*Sturnella magna*	**↑↑**
Orchard Oriole	*Icterus spurius*	**↑↑**
Baltimore Oriole	*Icterus galbula*	**↓↓**
Brewers Blackbird	*Euphagus cyanocephalus*	↓
Evening Grosbeak	*Coccothraustes vespertinus*	**↓**
Purple Finch	*Carpodacus purpureus*	**↓↓**
House Finch	*Carpodacus mexicanus*	**↓↓**
American Goldfinch	*Carduelis tristis*	**↓↓**
Vesper Sparrow	*Pooecetes gramineus*	**↓↓**
Savannah Sparrow	*Passerculus sandwichensis*	**↓↓**
Grasshopper Sparrow	*Ammodramus savannarum*	**↑↑**
White-throated Sparrow	*Zonotrichia albicollis*	**↓↓**
Chipping Sparrow	*Spizella passerina*	**↓↓**

Common Name	Scientific Name	Model Predictions
Clay-colored Sparrow	*Spizella pallida*	**↓**
Field Sparrow	*Spizella pusilla*	**↑↑**
Dark-eyed Junco	*Junco hyemalis*	**↓↓**
Bachmans Sparrow	*Aimophila aestivalis*	**↑**
Song Sparrow	*Melospiza melodia*	**↓↓**
Lincolns Sparrow	*Melospiza lincolnii*	**↓**
Swamp Sparrow	*Melospiza georgiana*	**↓↓**
Eastern Towhee	*Pipilo erythrophthalmus*	↑
Northern Cardinal	*Cardinalis cardinalis*	**↑↑**
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	**↓↓**
Blue Grosbeak	*Guiraca caerulea*	**↑↑**
Indigo Bunting	*Passerina cyanea*	**↑**
Painted Bunting	*Passerina ciris*	**↑↑**
Dickcissel	*Spiza americana*	**↑↑**
Summer Tanager	*Piranga rubra*	**↑↑**
Purple Martin	*Progne subis*	**↑↑**
Cliff Swallow	*Petrochelidon pyrrhonota*	**↓↓**
Barn Swallow	*Hirundo rustica*	↑
Tree Swallow	*Tachycineta bicolor*	**↓↓**
Bank Swallow	*Riparia riparia*	**↓↓**
Cedar Waxwing	*Bombycilla cedrorum*	**↓↓**
Loggerhead Shrike	*Lanius ludovicianus*	**↑↑**
Red-eyed Vireo	*Vireo olivaceus*	**↓↓**
Warbling Vireo	*Vireo gilvus*	**↓**
Yellow-throated Vireo	*Vireo flavifrons*	**↑↑**
Blue-headed Vireo	*Vireo solitarius*	**↓↓**
White-eyed Vireo	*Vireo griseus*	**↑↑**
Black-and-white Warbler	*Mniotilta varia*	**↓↓**
Prothonotary Warbler	*Protonotaria citrea*	**↑↑**
Worm-eating Warbler	*Helmitheros vermivorus*	**↑**
Blue-winged Warbler	*Vermivora pinus*	↑
Golden-winged Warbler	*Vermivora chrysoptera*	**↑**
Nashville Warbler	*Vermivora ruficapilla*	**↓↓**
Northern Parula	*Parula americana*	**↑↑**
Yellow Warbler	*Dendroica petechia*	**↓↓**
Black-throated Blue Warbler	*Dendroica caerulescens*	**↓↓**
Yellow-rumped Warbler	*Dendroica coronata*	**↓↓**
Magnolia Warbler	*Dendroica magnolia*	**↓↓**
Cerulean Warbler	*Dendroica cerulea*	**↑**
Blackburnian Warbler	*Dendroica fusca*	**↓↓**
Yellow-throated Warbler	*Dendroica dominica*	**↑↑**
Black-throated Green Warbler	*Dendroica virens*	**↓↓**
Pine Warbler	*Dendroica pinus*	**↑↑**
Prairie Warbler	*Dendroica discolor*	**↑↑**
Ovenbird	*Seiurus aurocapillus*	**↓↓**
Northern Waterthrush	*Seiurus noveboracensis*	**↓↓**
Kentucky Warbler	*Oporornis formosus*	**↑↑**
Mourning Warbler	*Oporornis philadelphia*	**↓↓**
Common Yellowthroat	*Geothlypis trichas*	**↓↓**
Yellow-breasted Chat	*Icteria virens*	**↑↑**
Hooded Warbler	*Wilsonia citrina*	**↑↑**
Canada Warbler	*Wilsonia canadensis*	**↓↓**
American Redstart	*Setophaga ruticilla*	**↓↓**
House Sparrow	*Passer domesticus*	↑
Northern Mockingbird	*Mimus polyglottos*	**↑↑**
Gray Catbird	*Dumetella carolinensis*	**↓↓**
Brown Thrasher	*Toxostoma rufum*	**↑↑**
Carolina Wren	*Thryothorus ludovicianus*	**↑↑**
House Wren	*Troglodytes aedon*	**↓↓**
Winter Wren	*Troglodytes troglodytes*	**↓↓**
Sedge Wren	*Cistothorus platensis*	↑
Brown Creeper	*Certhia americana*	**↓**
White-breasted Nuthatch	*Sitta carolinensis*	↑
Red-breasted Nuthatch	*Sitta canadensis*	**↓↓**
Brown-headed Nuthatch	*Sitta pusilla*	**↑**
Tufted Titmouse	*Baeolophus bicolor*	**↑↑**
Black-capped Chickadee	*Poecile atricapillus*	**↓↓**
Blue-gray Gnatcatcher	*Polioptila caerulea*	**↑↑**
Wood Thrush	*Hylocichla mustelina*	**↓↓**
Veery	*Catharus fuscescens*	**↓↓**
Swainsons Thrush	*Catharus ustulatus*	**↓↓**
Hermit Thrush	*Catharus guttatus*	**↓↓**
American Robin	*Turdus migratorius*	**↓↓**

Key
Bold indicates agreement among the majority of the 8 model/scenarios considered (3 GCM models [Hadley, PCM & GFDL] with low (SRES A1FI) and high (SRES A2) emission scenarios).
↑↑ Large expected increase of species-specific habitat abundance in the region.
↑ Moderate expected increase of species-specific habitat abundance in the region.
↓ Moderate expected decrease of species-specific habitat abundance in the region.
↓↓ Large expected decrease of species-specific habitat abundance in the region.

field sparrow (*S. pusilla*), vesper sparrow (*Pooecetes gramineus*), Lark sparrow (*Chondestes grammacus*), and Brewer's Blackbird (*Euphagus cyanocephalus*), and brown-headed cowbird (*Molothrus ater*) (George et al. 1992). On the other hand, forest clearing may cause grasshopper sparrows to increase across the eastern United States (Naujokaitis-Lewis et al. 2013). Similarly, northern bobwhite (*Colinus virginianus*) will likely increase in the Midwest and parts of the Northeast as pine woodland and savanna replace some hardwood forests (Rodenhouse et al. 2008; Matthews et al. 2007).

Forest Birds

Perhaps best studied is the effect of climate change on forest-dwelling Passerine birds. The effects of changing temperature and precipitation regimes will be felt in a variety of ways. First, in a taxon known for its seasonal migrations, one of the biggest concerns is phenological mismatch, with food and habitat available at different times than the species is cued to. Studies have shown that birds are arriving earlier to their breeding grounds across the northern U.S. (Butler 2003; Marra et al. 2008; Wilson 2013). American woodcock (*Scolopax minor*) distribution has expanded in recent decades, possibly in response to climate change (Thogmartin et al. 2007), and this short-distance disperser has begun arriving to its breeding grounds earlier in the spring in the Northeast (Butler 2003). Wood thrush (*Hylocichla mustelina*) and Louisiana waterthrush (*Parkesia motacilla*) have also advanced their arrival times in the Northeast over the last century (Butler 2003). The scarlet tanager (*Piranga olivacea*) has been shown to be vulnerable to shifting seasons and spring mistiming (Zumeta & Holmes 1978). Black-throated blue warblers (*Setophaga caerulescens*) studied in New Hampshire initiated breeding earlier in warmer springs, with early breeders more likely to have a second brood, leading to higher reproductive rates (Townsend et al. 2013). Climate variability could exacerbate problems with timing. For instance, late spring storms and extreme weather events have been shown to kill migrating birds (Dionne et al. 2008; Zumeta & Holmes 1978).

On the other end of the breeding season, a study in Rhode Island showed that some birds are departing later in the autumn, including the black-and-white warbler (*Mniotilta varia*), blackpoll warbler (*Dendroica striata*), red-eyed vireo (*Vireo olivaceus*), eastern towhee (*Pipilo *erythrophthalmus*), hermit thrush (*Catharus guttatus*), song sparrow (*Melospiza melodia*), yellow-rumped warbler (*Dendroica coronate*), gray catbird (*Dumetella carolinensis*), veery (*Catharus fuscescens*), white-throated sparrow (*Zonotrichia albicollis*), and the ruby-crowned kinglet (*Regulus calendula*) (Smith & Paton 2011).

Birds may be affected by climate change through shifts in habitat. The Canada warbler (*Cardellina canadensis*), for example, is projected to shift its distribution northward as boreal and northern hardwood forest that it inhabits shift northward, with the most severe model projections showing complete extirpation from the Northeastern U.S. (Rodenhouse et al. 2008; Table 1). Likewise, the Bicknell's thrush is expected to contract its U.S. range by more than half as temperatures increase and its habitat subsequently shifts northward. Similar negative trends are expected for other birds that inhabit the montane spruce-fir forest of the Midwest and Northeast at the southern edge of their range, including ruby-crowned kinglet, blackpoll warbler, spruce grouse (*Alcipennis canadensis*), three-toed woodpecker (*Picoides tridactylus*), black-backed woodpecker (*P. arcticus*), yellow-bellied flycatcher (*Empidonax flaviventris*), gray jay (*Perisoreus canadensis*), boreal chickadee (*Poecile hudsonica*), and white-winged crossbill (*Loxia leucoptera*) (Rodenhouse et al. 2008). The blue-headed vireo (*Vireo solitarius*) is predicted to decline 6 to 8% across its range within the next 50 years due to shifts in its conifer habitat (Rodenhouse et al. 2009).

Additionally, the Designing Sustainable Landscapes Project at the University of Massachusetts Amherst and Northeast Climate Science Center has developed models to predict future landscape capability for a suite of species (DeLuca & McGarigal 2014). The Landscape Capability index (LC) represents the capability of the landscape to provide suitable and accessible conditions for a species to survive and/or reproduce. The LC is the product of three separate modeling efforts for each species: habitat capability (HC), climate suitability (CS), and prevalence. For example, LC for the blackpoll warbler is predicted to decrease by 66% and the LC for the Blackburnian warbler (*Setophaga fusca*) is predicted to decrease by 71% of their 2010 Northeastern range by 2080 (DeLuca & McGarigal 2014; **Table 2**; **Figure 1**).[1]

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[1] For further details on the GCMs and emissions scenarios used, see http://jamba.provost.ads.umass.edu/web/lcc/DSL_documentation_climate.pdf

Table 2: Relative change (%) in Landscape Capability between 2010 and 2080 for 14 representative species. DeLuca & McGarigal (2014) first calculated Landscape Capability (LC) for each species in 2010. LC is an index that represents the capability of the landscape to provide suitable and accessible conditions for a species' to survive and/or reproduce. LC is the product of three separate modeling efforts for each species: habitat capability (HC), climate suitability (CS), and prevalence. DeLuca & McGarigal (2014) derived LC-climate in 2080 for each species by multiplying 2010 HC by 2080 CS, thus keeping the effect of habitat constant and focusing the potential change in LC solely on the changing climate. This metric can be interpreted as: 1) For any species whose % change in LC in 2080 is near 0%, suitable climate conditions are predicted to prevail in the Northeast for these species; 2) For any species with substantial positive % change values, the amount of area in the Northeast that has suitable climate conditions is predicted to increase; and, 3) For any species with substantial negative % change values, the amount of area in the Northeast that has suitable climate conditions is predicted to decrease.

Species	Change in LC by 2080
American woodcock	-9%
Blackburnian warbler	-71%
Blackpoll warbler	-66%
Eastern meadowlark	+17%
Wood turtle	-2%
Louisiana waterthrush	+14%
Marsh wren	+40%
Moose	-3%
Northern waterthrush	-70%
Prairie warbler	-18%
Ruffed grouse	-54%
Saltmarsh sparrow	-59%
Wood duck	+37%
Wood thrush	-1%

On the other hand, species like the black-throated green warbler (*Setophaga virens*) may remain stable due to more flexible habitat use and large population size, despite potential negative impacts from habitat change driven by increasing temperatures and pests like hemlock woolly adelgid as well as mismatched phenology (Cullen et al. 2013). Some species may see positive impacts of climate change (e.g., Louisiana waterthrush, eastern meadowlark (*Sturnella magna*), and marsh wren (*Cistothorus palustris*), **Table 2**); the eastern wood-peewee (*Contopus virens*) has been arriving earlier in the spring and is expected to increase in abundance in response to precipitation and other climate changes (Rodenhouse et al. 2008). Similarly, the hooded warbler (*Setophaga citrina*) may increase in abundance in the Northeast and Midwest, its northern range edge. Likewise, species that depend on early successional habitat may see increases due to climate-change-induced increases in disturbance (Cullen et al. 2013).

Populations of ruffed grouse (*Bonasa umbellus*) have been declining in much of the eastern U.S. as early successional habitats have given way to mid-aged and mature forest (Blomberg et al. 2009). The distribution of ruffed grouse is closely associated with the distribution of quaking aspen (Kubisiak 1985), and population densities are typically high in this forest type (Dessecker et al. 2007). Declines in quaking aspen due to climate change, reduced logging, and forest succession could lead to declines in grouse populations compared to recent centuries (Iverson et al. 2008; Worrall et al. 2013). Moreover, snow cover can be important for overwinter survival in grouse, as they will burrow into deep soft snow during cold winter periods (Whitaker & Stauffer 2003). Warming temperatures will likely change snow quantity and characteristics (e.g., crusting conditions; See **Chapter 1**), making snow roosting more difficult. Models predict that, over the long term, climate change will greatly reduce the proportion of the Northeast that is capable of supporting ruffed grouse (DeLuca & McGarigal 2014; Matthews et al. 2007; **Tables 1 and 2**). Studies of grouse also highlight a cascading effect of climate change: plants may become more heavily defended and less nutritious with warming temperatures, posing an increasing threat to the birds that consume them (Buskirk 2012).

Complex interspecific interactions must also be considered. Black-billed cuckoos (*Coccyzus erythropthalmus*), for example, feed primarily on gypsy moth caterpillars, which are expected to increase in abundance with climate change (Cullen et al. 2013). Cuckoo nest

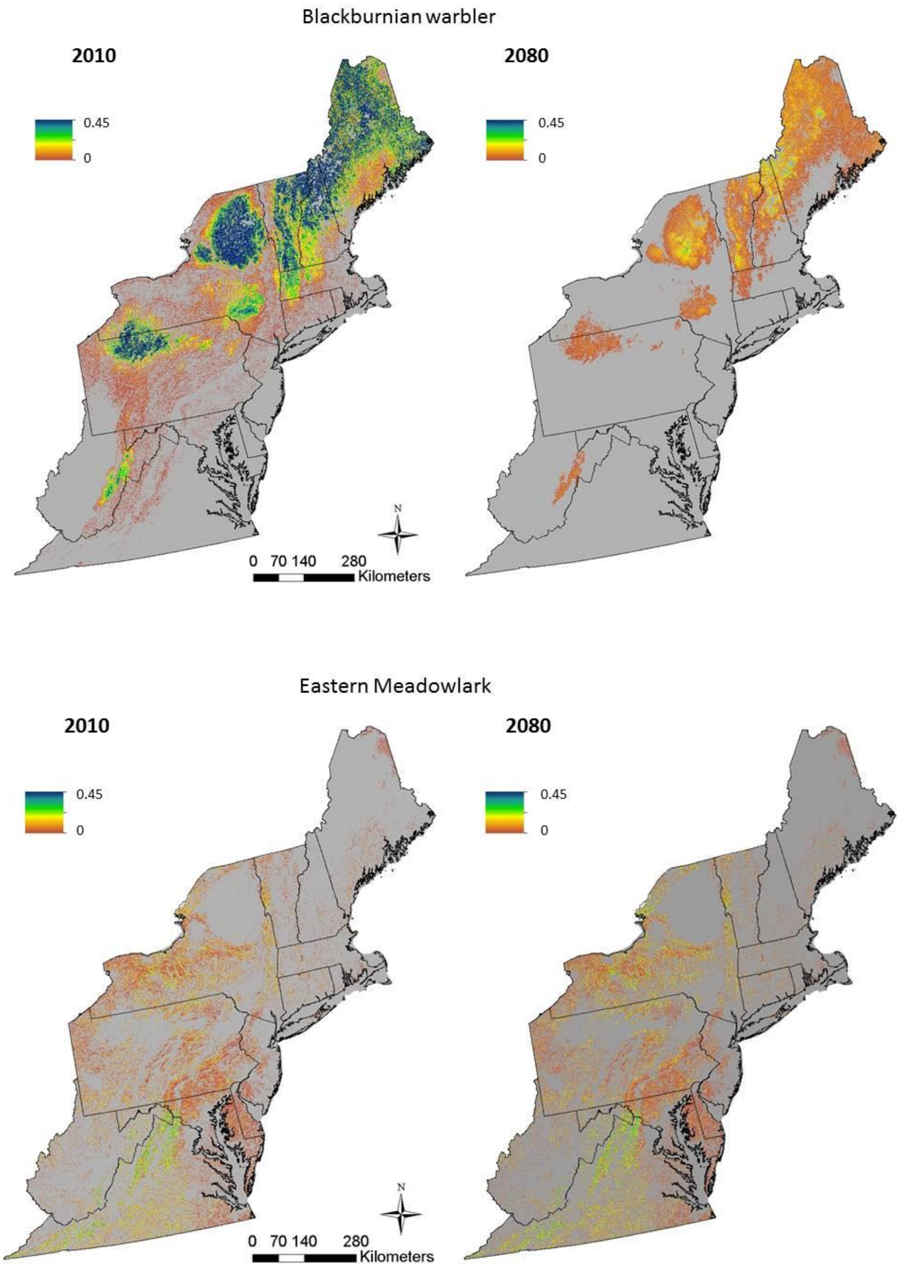

Figure 1: Change in Landscape Capability (LC) from 2010 to 2080 for the Blackburnian warbler and the eastern meadowlark. The Blackburnian warbler is predicted to have a 71% reduction in LC in the Northeast by 2080. In contrast, the eastern meadowlark is expected to maintain throughout most of its Northeastern U.S. extent by 2080. See **Table 2** caption for methods.

parasitism of other species could increase as a result. Likewise, competitive interactions could exacerbate or even drive species shifts. For instance, if climate change causes Carolina chickadees (*Poecile carolinensis*) to expand northward, black-capped chickadees (*Poecile atricapillus*) may see a significant range reduction due to competitive exclusion (Wilson 2012). A study by Cox and colleagues (2012) highlighted the complex effects of climate change; they found an interaction effect of temperature and forest cover on the productivity of the Acadian flycatcher (*Empidonax virescens*) and the Indigo bunting (*Passerina cyanea*). Higher temperatures were correlated with lower productivity due to increased nest predation by snakes, but only in areas with higher forest cover, which otherwise had higher productivity. Greater forest cover resulted in greater productivity because of reduced brood parasitism and increased nest survival, whereas greater temperatures reduced productivity in highly forested landscapes because of increased nest predation but had no effect in less forested landscapes. Climate change can also reduce access to prey through phenological mismatch. For instance, aerial insectivores like flycatchers may see food shortages due to climate change (Nebel et al. 2010).

Land use change is an important consideration for projecting changes of populations into the future. Dramatic geographic shifts upslope and northward are projected for the hooded warbler (Sohl 2014), which seems to already be shifting its breeding distribution north in response to climate change (Melles et al. 2011). Land use change models predict diverse local-scale changes in habitat suitability; for example, development around the Great Lakes is a limiting factor for range expansion for hooded warblers (Naujokaitis-Lewis et al. 2013).

Wetland Birds

Precipitation and percentage of wetland area, which are affected by climate change, are good predictors of abundance for many bird species, including the black tern (*Childonias niger*) and the marsh wren in the Prairie Pothole region of the northern Great Plains (Forcey et al. 2014). The black tern, American bittern (*Botaurus lentiginosus*), American coot (*Fulica americana*), pied-billed grebe (*Podilymbus podiceps*), and sora (*Porzana carolina*), five waterbird species common to the region, were projected to lose significant parts of their range; in some cases, such as for sora and black tern, this loss could be up to 100% (Steen & Powell

2012). The Prairie Pothole region of the Midwest and Great Plains is an area characterized by a high density of shallow wetlands that produces 50-80% of the continent's ducks (Sorenson et al. 1998). Climate models project increased drought conditions for this region, resulting in northward shifts in breeding distributions, with the potential for dramatic reductions in overall waterfowl populations (Sorenson et al. 1998). In addition, loss of pothole wetlands through drying can concentrate predators, which would have a greater impact on birds nesting in the remaining potholes. Duck production has been shown to vary greatly from year to year due to changes in the area of wetlands in this region linked to variable weather patterns (Klett et al. 1988).

Typical responses to drought conditions in waterfowl include decreased frequency of breeding and renesting, decreased clutch sizes, shortened breeding season, and other responses that depress production (Cowardin et al. 1985; Davies & Cooke 1983; Krapu et al. 1983; Sorenson et al. 1998). Dramatically reduced duck populations could potentially reduce the number of birds that migrate throughout the rest of the country. For example, although the blue-winged teal (*Anas discors*) breeds from coast to coast, its distributional center is located in the Prairie Pothole Region of the Northern Great Plains. Changes in migration timing are also likely and have already been documented for blue-winged teal in Massachusetts and New York (Butler 2003).

Climate variability is expected to increase in the Northeast and Midwest, with more precipitation coming in fewer events (See **Chapter 1**). Rainfall has been shown to have a negative effect on nest abundance in herons and egrets, especially in particularly wet or particularly dry years, at least in San Francisco (Kelly & Condeso 2014).

The rusty blackbird has retracted its continental range northward by over 100 km since the 1960s, with its presence correlated with cyclical climate patterns indicating climate change is having a strong negative effect on this once common species (Mcclure et al. 2012).

Coastal Birds

Many bird species, such as wading birds, are dependent upon coastal habitats that may be reduced as sea level rises and interacts with nearshore development (National Wildlife

Federation and Manomet Center for Conservation Sciences 2014). In addition to direct habitat loss from sea level rise, changes in precipitation and increased temperatures could lead to salt accumulation in soils and less productive habitat, ultimately resulting in reductions in suitable bird habitat (Woodrey et al. 2012). However, the areal extent of some tidal flats are projected to increase, which may benefit some shorebirds and waterfowl.

Piping plovers (*Charadrius melodus*) have been well-studied in the context of climate change impacts on coastal environments. They appear to have low adaptive capacity (Saunders & Cuthbert 2014). Projections indicate that piping plover populations will lose critical nesting habitat due to the dual pressures of sea level rise and urban development (National Wildlife Federation and Manomet Center for Conservation Sciences 2014; Seavey et al. 2011). Sea level rise and urban development together could result in loss of habitat for the Acadian flycatcher and other salt marsh wildlife as well (Thorne et al. 2012). These effects are exacerbated by the nutrient enrichment that often accompanies development, which can eventually cause community shifts (Woodrey et al. 2012). In response to increasing salinity, marsh wrens and least bitterns (*Ixobrychus exilis*) may become less common, although clapper rails (*Rallus longirostris*) and seaside sparrows (*Ammodramus maritimus*) could benefit (Rush et al. 2009).

The saltmarsh sparrow (*Ammodramus caudacutus*) is another species that has been investigated extensively for its response to climate change. DeLuca & McGarigal (2014) predict that landscape capability in the Northeast, based on climate change, will have a 59% reduction for saltmarsh sparrows by 2080 (**Table 2**). This species seems particularly sensitive to sea level rise and storm events, with nest success strongly linked to flooding (Bayard & Elphick 2011). Similarly, common loon (*Gavia immer*) occurrence is predicted to decrease significantly with climate change as sea level rise reduces the availability of the black spruce habitat it prefers (Rodenhouse et al. 2008, 2009).

Extreme events, specifically severe winter storms, could cause increased mortality for the great blue heron, little blue heron, snowy egret, tricolored heron, and green-backed heron (DuBowy 1996). Drastic fluctuations in annual precipitation have been shown to influence the mechanism by which watershed development impacts coastal waterbirds (Studds et al. 2012). In addition, increasing frequency and intensity of coastal storms and surges could negatively impact shorebirds, but they could also create new habitat (Cohen et al. 2009). The more intense hurricanes expected due to climate change could disturb foraging and nesting habitat for shore and marsh birds, which can have both negative and positive effects (Woodrey et al. 2012).

In addition to affecting habitat availability, climate change can shift the timing of prey availability through direct effects of climate change on prey species abundance and distribution. For example, a climate-change driven decrease in horseshoe crabs is causing a decrease in ruddy turnstones (*Arenaria interpres*), with interacting effects related to the avian influenza virus (Brown & Rohani 2012).

Raptors

Raptors are showing responses to climate change as well. Precipitation and percentage of wetland area are the best predictors of the abundance of the northern harrier (*Circus cyaneus*). A study of six raptor species (northern harrier, American kestrel (*Falco sparverius*), golden eagle (*Aquila chrysaetos*), prairie falcon (*Falco mexicanus*), red-tailed hawk (*Buteo jamaicensis*), and rough-legged hawk (*Buteo lagopus*)) showed significant poleward shifts in their wintering distributions since 1975 (Paprocki et al. 2014). Raptors appear to be arriving earlier in the spring to and leaving later in the autumn from their breeding grounds as well (Buskirk 2012).

Some raptors may be positively affected by climate change. A study in the western U.S. showed that kestrel migration distance decreased significantly over the last half century and that earlier nesting, and thus higher reproductive success, appeared to be driven by warmer winters (Heath et al. 2012). In addition, the northern goshawk (*Accipiter gentilis*) has also been shown to have high tolerance to windstorm damage (Penteriani et al. 2002), which may become more common with more intense storms in the Northeast and Midwest.

C. REPTILES

Freshwater Turtles

Freshwater turtles will be affected by climate change in a variety of ways, mostly acting through effects on water temperature and flow. For example, climate change and land conversion can act synergistically to decrease habitat for bog turtles (*Glyptemys muhlenbergii*) (Feaga 2010). Similarly, studies of the Blanding's turtle (*E. blandingii*) showed that increasing temperatures are correlated with decreases in habitat suitability, which can potentially be offset (or exacerbated) by human land-use decisions (Millar & Blouin-Demers 2012). A study of wood turtles (*Glyptemys insculpta*) in Massachusetts showed that floods displaced nearly half of the subpopulation annually, elevated mortality rates, and decreased breeding success. Floods are expected to intensify and become more common; impervious surfaces and hardening of upstream riverbanks may be amplifying these effects (Jones & Sievert 2009). In contrast, map turtle (*Graptemys geographica*) hatchlings emerge later in the season with increasing temperatures and rain events, resulting in higher survival (Nagle et al. 2004).

Population sex ratio determination is an important consideration in turtles, as it is driven by temperature. Thus, there is concern that populations will begin to be artificially skewed toward more females or more males, depending on the life history of the particular species and location of the population. Experimental manipulation has shown a lack of adaptive capacity to compensate for sex ratio bias due to warming nest temperatures, at least in some species (Refsnider et al. 2013). However, other studies have pointed out that the amount of atmospheric warming required to raise nest temperatures enough to affect sex ratio is not expected until late in the century, at least for eastern box turtles (*Terrapene carolina carolina*; Savva et al. 2010).

Sea Turtles

Sex ratio bias is also a concern for sea turtles. For example, the sex ratio of some sea turtle populations (e.g., green sea turtles, *Chelonia mydas*), is increasingly female-biased correlated with increasing temperatures (King et al. 2013).

Sea turtles have shown other responses to climate change. Experiments have demonstrated that loggerhead sea turtle (*Caretta caretta*) hatchling survivorship and locomotor ability are reduced when incubated at higher temperatures designed to mimic future higher sand temperatures (Fisher et al. 2014). In addition, the loggerhead sea turtle is advancing the timing of nesting as temperatures increase (Lamont & Fujisaki 2014). However, some turtles, such as leatherback turtles (*Dermochelys coriacea*), are showing the opposite pattern (Neeman et al. 2015).

Snakes

A few studies indicate that climate change could negatively affect snakes in the Northeast and Midwest. Extreme precipitation events might result in negative effects on snakes. For example, after a year with exceptionally high summer rainfall, a skin infection caused significant mortality in New Hampshire's timber rattlesnake (*Crotalus horridus*) population (Clark et al. 2011). Likewise, extreme fluctuations of the water table, especially near hibernacula, caused demographic stress in populations of Eastern Massasauga rattlesnakes *(Sistrurus catenatus catenatus*), trends that will likely be exacerbated in the future (Pomara et al. 2014). On the other hand, higher temperatures can increase the activity patterns, and perhaps the survival rates, of ectotherms such as snakes (Cox et al. 2012; Sperry et al. 2010).

D. AMPHIBIANS

Amphibians are often considered indicators of ecosystem health due to their sensitivity to their surroundings as well as their use of both terrestrial and aquatic environments. They have also been a taxon in global decline over the last decades (Adams et al. 2013). One study in North Carolina showed that the mole salamander (*Ambystoma talpoideum*), tiger salamander (*A. tigrinum*), ornate chorus frog (*Pseudacris ornate*), and southern leopard frog (*Rana sphenocephala*) declined with a thirty-year drying trend, raising concerns for certain areas of the Midwest and for the rest of the region by the end of the century. On the other hand, the marbled salamander (*Ambystoma opacum*) increased in abundance during this time (Daszak et al. 2005).

Stream salamanders have been particularly well studied, primarily focusing on habitat fragmentation and issues other than climate change. A study at a wetland site in South Carolina showed that two autumn-breeding species, the dwarf salamander (*Eurycea quadridigitata*) and the marbled salamander, arrived at a wetland significantly later in recent years whereas two winter-breeding species, the tiger salamander and the ornate chorus frog, arrived significantly earlier (Todd et al. 2010).

Direct effects of changes in precipitation have been studied in salamanders. One study found that precipitation influences fecundity in a population of western slimy salamanders (*Plethodon albagula*, Milanovich et al. 2006). Spring salamander (*Gyrinophilus porphyriticus*) abundance at a site in New Hampshire was negatively correlated with annual precipitation; increasing precipitation appears to be causing a decline in adult recruitment, possibly through mortality of metamorphosing individuals during spring and fall floods, which have increased in volume and frequency with the increase in precipitation (Lowe 2012). Likewise, a study on the blackbelly salamander (*Desmognathus quadramaculatus*), Ocoee salamander (*D. ocoee*), and Blue Ridge two-lined salamander (*Eurycea wilderae*) in the southern Appalachian Mountains showed that reduced body condition, productivity, and abundance were correlated with increased drought (Hamed 2014), which is expected to increase in that area as well as some areas of the Northeast and Midwest with climate change.

Studies of microhabitat and seasonal habitat use can indicate the effects of climate change. For example, both spotted salamanders (*Eurycea lucifuga*) and western slimy salamanders (*Plethodon albagula*) were more likely to be found in climate refugia such as caves with cooler temperature in summer, higher relative humidity in autumn, and near permanent streams (Briggler & Prather 2006).

Despite all of these changes, salamanders are expected to have some capacity to adapt to climate change. One study found that, although drought negatively affected larvae, high survivorship of adult northern dusky salamanders during drought likely buffers this effect. Moreover, movement around the landscape in response to drought conditions allows adult salamanders to be resilient to these climate change effects (Price et al. 2012). Furthermore, adaptive capacity to respond to variability in climate has been shown in salamanders; for example, the immune system of the hellbender (*Cryptobranchus alleganiensis*) seems to show compensatory effects at stressfully high temperatures (Terrell et al. 2013).

E. FISH

There is a better understanding of how ambient temperatures affect the survival and reproduction of fishes than any other taxonomic group, and thus in some ways the effects of climate change are better understood with fish than with other species.

Freshwater Fish

Warming water temperatures could influence activity levels, consumptive demands, growth rates, interspecific interactions, and the amount of suitable habitat available for freshwater fish. Adaptability to changing water temperature is expected to vary among species. One of the most studied species of freshwater fish in the Northeast is the brook trout (*Salvelinus fontinalis*), a riverine fish adapted to cold temperatures (Shuter et al. 2012). Although there is concern that climate change will cause rivers to increase to temperatures beyond the thermal tolerance of brook trout, some studies show that the story is more complicated. For example, brook trout populations have different temperature tolerances, and refugia resulting from groundwater inputs and riparian cover that can locally buffer the effects of increasing temperatures (Argent & Kimmel 2013), potentially allowing for adaptive capacity in the species (Stitt et al. 2014). Moreover, the temperature sensitivity of brook trout, for example, is compounded by competition with introduced and native species. One study indicated that competition for prey and thermal refugia constrains book trout growth (Petty et al. 2014).

Shifting the timing of important life history events (e.g., morphological development required for exogenous feeding) may disrupt temporal overlap between predators and prey (Winder & Schindler 2004). In recent years, larval yellow perch (*Perca flavescens*) in Oneida Lake, New York, attained a length of 18 mm earlier, correlated with above average May water temperatures (Irwin et al. 2009). Beyond intrinsic physiological thermal limitations, habitat fragmentation and land conversion are negatively impacting some fish populations (Argent & Kimmel 2013; National Wildlife Federation and Manomet Center for Conservation Sciences 2014).

An even more cold-adapted species, the burbot (*Lota lota*), has been shown to be adapted to low temperatures and low levels of oxygen and food in the winter (Shuter et al.

2012). Burbot hatchling and larval success decreases significantly with increasing temperatures (Lahnsteiner et al. 2012). For example, the burbot population in Lake Oneida, New York, has declined significantly over the last fifty years in conjunction with rising summer temperatures, apparently from reduced access to prey. This situation appears to be exacerbated by the lack of climate refugia at this site and is expected to continue, with possible extirpation of burbot from the lake (Jackson et al. 2008).

Climate change is expected to decrease the number of lakes suitable for cold-water adapted species (Herb et al. 2014). The cold-adapted lake trout may begin to disappear both from the direct effects of climate change (e.g., increasing temperatures) and the indirect effects of competition from smallmouth bass (*Micropterus dolomieu*) moving northward in response to warming temperatures (Sharma et al. 2009). The lake whitefish (*Coregonus clupeaformis*) is another species adapted to cool temperatures and lower levels of oxygen in the winter (Shuter et al. 2012). A study showed they closely track temperature in their lake habitats in May, indicating that the species' distribution may be affected by climate change (Gorsky et al. 2012). Warming water temperatures advance hatching in lake whitefish, indicating that climate change might cause a timing mismatch between the larvae and the availability of prey, thus increasing mortality (Patrick et al. 2013). Moreover, lake whitefish condition and growth are affected by factors in addition to climate change, including invasive mussel presence (Rennie et al. 2009). On the other hand, American brook lamprey (*Lethenteron appendix*) may have some ability to adapt to warming temperatures. The species was found to spawn a month earlier than the historical norm during a warm year in southeastern Minnesota (Cochran et al. 2012), although with unknown effects on the food web.

Some smaller tributaries in Wisconsin are projected to warm above the critical thermal threshold for lake sturgeon (*Acipenser fulvescens*) by mid-century, with the identification of climate change refugia as a key recommendation for mitigating these effects (Lyons & Stewart 2014). On the other hand, lake sturgeon year-class strength was positively correlated with mean June air temperature in a study in Minnesota (Adams et al. 2006). Similarly, year-class strength in the St. Lawrence River was positively correlated with warm June conditions and fast flows (Nilo et al. 1997).

Climate change is already affecting the Great Lakes (See **Chapter 1**). Projections show that thermally suitable habitat will remain for most species there, although in different locations than it is now. It is predicted that cold-adapted species will shift north and move deeper in the water column, with warmer-adapted species filling the niches they leave behind (Lynch et al. 2010). Invasive species could be an important exacerbating factor. For example, invasion by the parasitic sea lamprey (*Petromyzon marinus*) has already contributed to major declines in many Great Lakes fish populations and will likely lead to even higher rates of mortality as warmer waters lead to larger lamprey, higher feeding rates, and eventually higher mortality of host fishes (Cline et al. 2014; Swink 1993).

Changes in community structure can also be caused by extreme events, stemming from or exacerbated by climate change (Boucek & Rehage 2014; van Vrancken & O'Connell 2010). A population of slimy sculpin (*Cottus cognatus*), a cool-adapted species with low mobility, declined significantly as a result of a mid-winter ice break-up and the associated flood and ice scour disturbance it caused (Edwards & Cunjak 2007).

Anadromous Fish

A future of warmer temperatures, higher salinity, lower dissolved oxygen, increasing ocean acidification, and changing water currents are all expected to strongly impact anadromous fish populations (Kerr et al. 2009). These factors are expected to impact negatively on food availability for eel larvae (Knights 2003). For example, glass eel declines in the Northern Hemisphere are hypothesized to be tied to a climate-driven decrease in ocean productivity and thus food availability during early life stages (Bonhommeau et al. 2008).

Changes in precipitation and streamflow are closely linked to the reproductive success of anadromous species like American shad. Atlantic coast studies have shown that water temperature and discharge affect year-class strength of American shad populations (Crecco & Savoy 1984). Temperature appears to cue the northward movement of American shad for spawning, as well as the migration of smolts; climate change is already altering migrational timing (Kerr et al. 2009).

The effect of climate change on Atlantic salmon (*Salmo salar*), a species adapted to cool temperatures (Shuter et al. 2012), is of great interest. As with other anadromous fishes, river and ocean changes will impact salmon populations (Piou & Prévost 2013). The federally listed Atlantic salmon has experienced large population declines in the last two decades, resulting in low abundance and even extirpations in some areas of New England. This decline may be related to, and will undoubtedly be exacerbated by, the effect of increased predation pressure from mackerel and other species, reduced prey availability, and increased metabolism at warmer temperatures (Friedland et al. 2003; Mills et al. 2013). The Atlantic salmon range is predicted to continue to contract poleward with increasing temperatures. Projections in Norway found that Atlantic salmon at southern sites could be negatively affected by increasing temperatures, with the opposite effect found in more northern latitudes (Hedger et al. 2013). This could result in some community turnover, with Atlantic salmon replacing the more cold-adapted Arctic char (*Salvelinus alpinus*, Penney et al. 2014; Shuter et al. 2012). However, another study found that Arctic char may benefit from climate change in some places because of the positive effects of more ice-free days (Budy & Luecke 2014). Likewise, some adaptive capacity to warming waters has been found in the cardiac plasticity of Atlantic salmon (Anttila et al. 2014).

Coastal/Marine Fish

Increasing temperatures will likely act, in conjunction with low dissolved oxygen and prey availability, to decrease growth and reproduction in some coastal and marine fish species (Kerr et al. 2009). In the Northwest Atlantic Ocean, 24 out of 36 commercially exploited fish stocks showed significant range (latitudinal and depth) shifts between 1968–2007 in response to increased sea surface and bottom temperatures (Nye et al. 2009). For instance, the winter flounder (*Pseudopleuronectes americanus*) could be negatively affected by climate change. It has poor recruitment in warm years in New Jersey, potentially related to predator response to temperature (Able et al. 2014). Likewise, winter flounder growth and survival rates were lower in sites with low dissolved oxygen levels in New Jersey and Connecticut tidal marsh creeks (Phelan et al. 2000). Phenological changes and increased predation on winter flounder have been seen in Narragansett Bay over the last century, likely in response to increased temperatures, precipitation, and sea level, and the subsequent ecological changes (Kerr et al. 2009; Smith et al. 2010).

Changes in other Atlantic coast species have been recorded as well. The growth rate of the tautog (*Tautoga onitis*) is higher at lower temperatures (Mercaldo-Allen et al. 2006). Moreover, as a reef-based fish strongly associated with structure, distributional shifts in prey species could negatively impact the tautog, which is expected to lag behind (Kerr et al. 2009). Similarly, although the Atlantic herring (*Clupea harengus*) is expected to shift its distribution northward, predators like the Atlantic cod (*Gadus morhua*) may not be able to follow at the same pace (Kerr et al. 2009). Some species life histories are disrupted by climate variability; increases and decreases in average temperature during the spring have been shown to negatively affect the probability of capturing spiny dogfish (*Squalus acanthias*) along the Atlantic coast, although the species became more abundant in northern sites in warm years (Sagarese et al. 2014).

Whether climate change will shift the distribution or abundance of a species in a particular location often depends on whether it is at the southern or northern edge of its range limit, or whether it is in the center of its distribution. For example, a study in Maryland found that abundance of northern puffers (*Sphoeroides maculatus*) increased in association with high winter temperatures and low flows, whereas the opposite was true for the Atlantic silverside (*Menidia menidia*, Wingate & Secor 2008).

Invasive species will interact with the effects of climate change in complex ways. Zebra mussels (*Dreissena polymorpha*) seem to increase colonization in warmer water, thus further decreasing growth and abundance of striped bass, American shad, alewife (*Alosa pseudoharengus*), and blueback herring (*Alosa aestivalis*) (Kerr et al. 2009).

Disease may be increasingly important in marine ecosystems. Increasing temperatures, ocean acidification, and shifting precipitation regimes may be increasing susceptibility to outbreaks and the dynamics of pathogens. For example, mortality in the longhorn sculpin (*Myoxocephalus octodecemspinoszu*) from a protozoan gill parasite increases with increasing water temperatures (Brazik & Bullis 1995). Oysters too are seeing new disease outbreaks with warmer temperatures (Burge et al. 2014).

III. INVERTEBRATES

A. FRESHWATER MUSSELS

Freshwater mussels (*Unionidae*) are one of the most imperiled wildlife groups in the Northeast and Midwest. Their habitat is already under threat from development, urbanization, and pollution. Hydropower development can have a large negative impact on freshwater mussels; many are non-migratory with limited vertical movement and rely on flood events to make large distribution shifts (Furedi 2013). Dams could prevent migration to thermally appropriate habitat northward and upstream in the face of climate change. Moreover, the increased flooding events predicted by climate change will decrease water quality as well as displace individuals from suitable habitat. Increasing temperatures may have additional direct detrimental effects. Drought during summer could slow or eliminate critical flows (Santos et al. 2015). Additionally, mussels use fish as hosts for larval development and dispersal, often having a limited number of fish species they can parasitize. Fish hosts may themselves be negatively affected by environmental changes and will likely shift distributions at different rates than mussels. Finally, the increasing spread of zebra mussels and other invasive species will continue to negatively affect freshwater mussels (Archambault et al. 2014; Furedi 2013).

The <u>dwarf wedgemussel</u>, *Alasmidonta heterodon*, and the <u>triangle floater</u>, *Alasmidonta undulata*, are considered extremely vulnerable to climate change. Habitat for these species is threatened by future hydropower development (Furedi 2013). The dwarf wedgemussel populations are highly localized in areas within a narrow band of precipitation. Thus, these populations could be disrupted by climate change and especially increased flooding in the Northeast. Dams located upstream of some triangle floater populations could prevent movement in response to climate change. The intense precipitation predicted for the region threatens both species (Furedi 2013). Increasing stream temperatures and droughts may increase mortality, reduce burrowing capacity, and inhibit juvenile dispersal in the <u>eastern lampmussel</u> (*Lampsilis radiate*; Archambault et al. 2014). The <u>fatmucket clam</u> (*Lampsilis siliquoidea*), <u>pink heelsplitter</u> (*Potamilus alatus*), <u>black sandshell</u> (*Ligumia recta*), <u>butterfly</u> (*Ellipsaria lineolata*), <u>white heelsplitter</u> (*Lasmigona complanata*), <u>washboard</u> (*Megalonaias *nervosa*), and eastern creekshell (*Villosa delumbis*) are expected to be negatively affected by increasing water temperatures (Pandolfo et al. 2010).

As a habitat specialist, the brook floater, *Alasmidonta varicosa*, is also considered extremely vulnerable to climate change. It has narrow thermal tolerances as juveniles and adults (Pandolfo et al. 2010) and is located mostly in upstream habitats and thus will have difficulty shifting in response to climate change. Moreover, increases in drought or decreases in flow will have a detrimental impact. There are similar concerns for the eastern pondmussel, *Ligumia nasuta*, along with additional concerns associated with competition from zebra mussels that may compound the impacts of climate change upon this species (Furedi 2013).

The yellow lampmussel (*Lampsilis cariosa*) is considered highly vulnerable to climate change due to destruction and degradation of habitat and spreading zebra mussel populations. The pocketbook (*Lampsilis ovata*) is also considered highly vulnerable to climate change, with a narrow precipitation range requirement and sensitivity common to freshwater mussel species (Furedi 2013). The widespread black sandshell (*Ligumia recta*) is already declining in certain areas and is also considered highly vulnerable from typical threats to freshwater mussels (Furedi 2013).

The green floater (*Lasmigona subviridis*) is considered extremely vulnerable and is currently in decline because the calm, clear water, upstream habitats it requires are being degraded through pollution, siltation, and the introduction of non-native species. One study that included the thermally sensitive deertoe (*Truncilla truncata*) showed that a period of high water temperatures, drought, and low discharge from reservoirs caused a turnover in the species assemblage, towards thermally-tolerant species, with important implications for water management (Galbraith et al. 2010).

The eastern pearlshell (*Margaritifera margaritifera*) is considered extremely vulnerable to climate change as it is found in cold, nutrient-poor, unpolluted streams and smaller rivers with moderate flow rates (Furedi 2013). Another study, however, found that it might have some capacity to adapt to increasing temperatures and shifting flows (Hastie et al. 2003). It may also be sensitive to sea level rise. Cascading effects could result from shifts by its host species.

The species has already been extirpated as a result of pollution from coal mining in certain areas of the Northeast, and is threatened by the presence of dams (Furedi 2013; Santos et al. 2015).

Conversely, the Northern lance (*Elliptio fisheriana*) seems to have higher capacity to adapt to low dissolved oxygen levels than some other species (Chen et al. 2001).

B. INSECTS

Relatively few insects that are considered species of conservation need have been studied in the context of climate change. Northeastern species thought to have high vulnerability to climate change include tiger spiketail (*Cordulegaster erronea*), pale barrens bluet (*Enallagma recurvatum*), Roger's clubtail (*Gomphus rogersi*), Delaware River clubtail (*Gomphus septima delawarensis*), and ringed boghaunter (*Williamsonia lintneri*) (White et al. 2014). The U.S. federally threatened Northeastern beach tiger beetle (*Cicindela dorsalis dorsalis*) is predicted to be negatively affected by climate change via sea level rise and increased storm events that will lead to coastal erosion (Fenster et al. 2006). Likewise, insects associated with prairie fens like the rare Mitchell's satyr butterfly (*Neonympha mitchellii mitchellii*) will be threatened by habitat loss due to drying of headwater streams and reduced water quality (Landis et al. 2012).

Lepidoptera might have particular issues with phenological mismatches in the coming decades. Caterpillars must sync their timing with food availability, which is changing. Host plants may be shifting northward in response to changing temperatures, with caterpillars potentially responding to different cues. Moreover, leaf quality may be decreasing, with increasing rates of secondary metabolites, requiring longer feeding times. Larvae could also be affected directly through increasing temperatures and changing moisture availability. Habitat specialists are expected to be most vulnerable (Keating et al. 2014).

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CHAPTER 4: SCALE-APPROPRIATE ADAPTATION STRATEGIES AND ACTIONS IN THE NORTHEAST AND MIDWEST UNITED STATES

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CHAPTER 4: SCALE-APPROPRIATE ADAPTATION STRATEGIES AND ACTIONS IN THE NORTHEAST AND MIDWEST UNITED STATES

Summary Points

- *Climate Change Adaptation* is a growing field within conservation and natural resource management. Actions taken toward climate change adaptation account for climate impacts and ecological responses, both current and projected into the future. These actions attempt to accomplish a number of goals, including the conservation of wildlife and ecosystems by reducing vulnerability and increasing resilience.
- Climate change adaptation strategies and approaches for natural resources can be thought of as part of a continuum of potential actions ranging from 1) options or goals to 2) strategies, 3) approaches, and 4) tactics.
- There are a range of decision support tools and processes to aid climate change adaptation. This document highlights several including the Adaptation Workbook, Climate Change Vulnerability Assessments, Structured Decision Making, Adaptive Resource Management, and Scenario Planning. It will also provide case studies on the application of these tools across the Northeast and Midwest.
- Improved, better-integrated, and increasingly coordinated monitoring systems would be helpful to detect, track, and attribute species and habitat shifts to climate change over spatiotemporal scales. We highlight regional examples of projects and programs addressing these challenges.
- Illustrative case studies of climate change adaptation efforts are presented across landscape/ecoregion, state, and local scales.
- **Appendix 4.1** provides a synthesis of over 900 general, species and habitat-specific adaptation strategies and tactics from 9 regional studies being considered or implemented across the region.

The study of climate change adaptation is a relatively new and rapidly growing field focused on preparing for and responding to the current and future impacts of climate change. The goal of this chapter is to highlight different approaches, processes, and tools currently being used across the region through illustrative case studies at varying scales. In addition, we provide a synthesis of numerous species and habitat-specific adaptation strategies and actions from existing assessment reports and management plans, which is intended to showcase a range of possibilities for natural resource management under future global change. This report does not prescribe one specific approach to taking action; instead, we outline a range of adaptation tactics, which will require thoughtful consideration of the needs of the species, habitat, and location, the stakeholders and partners involved, the scale that a decision or policy is being implemented at, and the financial and personnel resources available to managers.

I. INTRODUCTION

A) ADAPTATION CONCEPTS

i. Overview of Climate Change Adaptation

Climate change adaptation is a growing field within conservation and natural resource management focused on preparing for and responding to current and future impacts of climate change, and reducing related vulnerabilities (IPCC 2007; Parry et al. 2007; Heller & Zaveleta 2009; Glick et al. 2011). Ecological systems are subject to natural variability over short and long time scales, but climate change is increasingly pushing species and systems to surpass historical ranges of fluctuations. Therefore, managers are being encouraged to embrace a new paradigm of managing for change rather than persistence (Milly et al. 2008). This requires goals and actions that consider not only how a system or population has already changed, but also what conditions it is expected to experience as climate change continues (Stein et al. 2013). In addition, conservation and management initiatives that act broadly across the landscape to increase connectivity among refugia and protected habitats, and sustain ecological functioning and processes, are increasingly necessary (Stein et al. 2013).

Information on what factors contribute to a species or habitat’s vulnerability to climate change is increasing, and managers are searching for ways to realistically use this information in planning and implementation to meet specific needs on-the-ground (Millar et al. 2012; Janowiak et al. 2014). However, challenges still remain in putting high-quality scientific information within reach of most natural resource professionals and making the information understandable and actionable (Vose et al. 2012; Seppälä et al. 2009).

Climate change adaptation is largely about balancing goals and trade-offs, and there are many lessons to be drawn from ecosystem-based management approaches, which have been challenged with similar complex issues (Larkin 1996). Climate change also introduces high uncertainty to the decision making process as we are unable to exactly predict future climate conditions, how species and systems will respond to climate change and other stressors that act synergistically or cumulatively, as well as human response and behavior. Therefore managers are considering actions and making informed decisions that consider a range of possible futures and associated risks. Fortunately, planning approaches have been developed to help managers account for that uncertainty (e.g., scenario planning), as presented in this chapter. Finally, managers may consider their available resources and weigh decisions and actions that have the greatest chance of success under future climate conditions.

Climate change adaptation requires thinking over multiple temporal and spatial scales to sustain fish and wildlife populations and the habitats they depend on. Over the short-term and small scale, regardless of whether further assessment and information is needed, there are things that can be done now to minimize the effects of climate change on both ecosystems and humans. Over the long-term and large scale, responses to climate change can take advantage of existing and emerging knowledge to identify areas that are more resilient, more likely to adapt, or conversely, that are at highest risk. Efficient and effective adaptation plans and actions that can engage and form collaborations and partnerships among government agencies, NGOs, planners, researchers and municipalities to achieve common goals will be helpful (New Hampshire Fish & Game Department 2013).

Many broad recommendations for adapting ecosystems to climate change have already been suggested and synthesized (e.g., Heinz Center 2008; Heller & Zaveleta 2009; Millar et al. 2007; Ogden & Innes 2008). The purpose of this chapter is to highlight goals, approaches, processes, and actions being considered and implemented across the Northeast and Midwest for fish and wildlife species and their habitats through illustrative case studies at landscape, ecoregion, state, and local scales. Various case studies highlight how different researchers and organizations are confronting complex issues related to climate change. Because of the relatively emergent nature of the adaptation field and regional programs that support adaptation, many of the initiatives we highlight are ongoing. Our intention is to increase awareness of these initiatives and facilitate connections between researchers and managers across the region who may have specific interests in the process or outcomes of these projects. These examples may provide guidance for the development of adaptation plans that incorporate existing knowledge of the effects and ecological responses to climate change, as well as associated uncertainty.

ii. Principles of Adaptation

A great deal of work has occurred to provide conceptual frameworks (e.g., Millar et al. 2007; Peterson et al. 2011), compile adaptation strategies (e.g., Heinz 2008; Heller & Zavaleta 2009; Ogden & Innes 2008), and provide tools to support natural resource management decision making (e.g., Cross et al. 2012; Morelli et al. 2012; Swanston & Janowiak 2012). The following principles can serve as a starting point for incorporating a climate change adaptation perspective into an existing management framework (Joyce et al. 2008; Millar et al. 2007; Swanston & Janowiak 2012; Wisconsin Initiative on Climate Change Impacts 2011):

- **Prioritization and triage –** It will be increasingly important to prioritize actions for adaptation based both on the vulnerability of natural resources and on the anticipated effectiveness of actions that attempt to reduce vulnerability.
- **Flexible and adaptive management –** Adaptive management provides a decision-making framework that maintains flexibility and incorporates new knowledge and experience over time.
- **“No regrets” decisions –** Actions that result in a wide variety of benefits under multiple scenarios and have little or no risk may be initial places to consider re-prioritization and look for near-term implementation.
- **Precautionary actions –** Where vulnerability is high, precautionary actions to reduce risk in the near term may be extremely important, even when long-term uncertainty is high.
- **Variability and uncertainty –** The effects of climate change go far beyond increasing temperatures; increasing climate variability will lead to equal or greater impacts that will need to be addressed as well.
- **Integrating mitigation –** Many adaptation approaches complement actions to mitigate climate change; for example, adapting forests to future conditions can help maintain and increase their ability to sequester carbon.

B) ADAPTATION ACTIONS: BROAD GOALS TO SPECIFIC TACTICS

Climate change adaptation strategies and approaches for natural resources can be thought of as part of a continuum of potential actions (**Figure 1**). At the highest level are the broad and largely conceptual *options* of resistance (forestall change in ecosystems), resilience (enhance resilience of ecosystems to change), and transition (transition ecosystems into alignment with anticipated future conditions) (Millar et al. 2007). Adaptation *strategies* and *approaches* provide intermediate "stepping stones" that enable managers to translate broad concepts into targeted and prescriptive tactics for implementing adaptation (Janowiak et al. 2010; Swanston & Janowiak 2012).

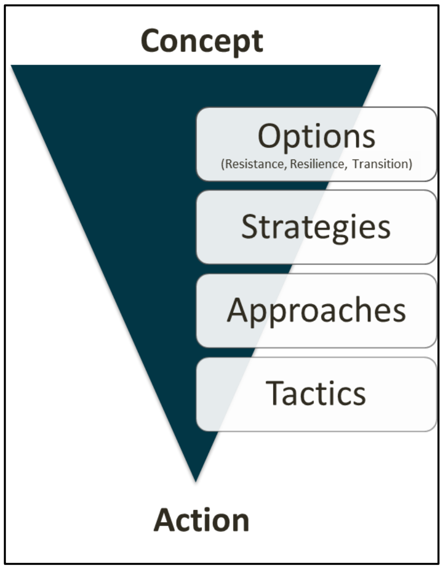

Figure 1: Actions for adaptation actions become increasingly specific along a continuum of options, strategies, approaches, and tactics.

- **Options or Goals** – The options of resistance, resilience, and transition serve as the broadest and most widely applicable level of a continuum of management responses to climate change (Janowiak et al. 2011).
- **Strategies** – Adaptation strategies begin to illustrate the ways that adaptation options could be employed, and are abundant in recent literature and reports. Strategies, however, are still very broad, and can be applied in many ways across a number of landscapes and species.
- **Approaches**– Provide greater detail in how managers may be able to respond to changing environmental conditions; differences in application among species and habitat types and management goals start to become evident.
- **Tactics –** Ultimately, tactics are the most specific adaptation response on the continuum, providing prescriptive direction in how actions can be applied on the ground.

A national perspective on climate change adaptation for natural resources is provided in the National Fish, Wildlife and Plants Climate Adaptation Strategy (NFWPCAS 2012). Information is organized under seven broad goals for adaptation, which as a whole address resistance, resilience, and transition with options at finer scales; yet NFWPCAS goals (presented below) are still broader than strategies (as outlined above).

1. **Conserve habitat** to support healthy fish, wildlife, and plant populations and **ecosystem functions** in a changing climate.
2. **Manage species and habitats** to protect **ecosystem functions** and provide sustainable cultural, subsistence, recreational, and commercial use in a changing climate.
3. **Enhance capacity** for effective management in a changing climate.
4. Support adaptive management in a changing climate through **integrated observation and monitoring** and use of **decision support tools**.
5. **Increase knowledge** and information on **impacts** and **responses** of fish, wildlife, and plants to a changing climate.
6. **Increase awareness** and motivate action to safeguard fish, wildlife, and plants in a changing climate.
7. **Reduce non-climate stressors** to help fish, wildlife, plants, and ecosystems adapt to a changing climate.

In addition, ten strategies and 39 more specific approaches were synthesized from dozens of scientific papers that discussed adaptation actions at a variety of scales and locations and are presented in Butler et al. (2012) (extracted strategies are listed in **Appendix 4.1**). Although the list was originally developed with a focus on forest ecosystems in northern Wisconsin, the strategies and approaches have proven to be broadly applicable to a variety of terrestrial ecosystem types across the Midwest and Northeast. By stating an intention to promote options of resistance, resilience, or transition and explicitly linking the strategies and approaches to on-the-ground tactics, managers are better able to specify how they will meet management goals through adaptation.

II. IMPLEMENTING ADAPTATION ACTIONS

A) PROCESSESS FOR ADAPTATION PLANNING AND IMPLEMENTATION

Several processes are available to support planning and decision-making in resource conservation. They offer frameworks and structured steps aimed at enhancing transparency and participation in planning and decision making, and directly address sources of uncertainty from climate change (e.g., possible future conditions, model projections), human response behaviors, and other sources (e.g., land use change). Some approaches, such as structured decision-making, adaptive resource management, scenario planning, and risk assessment could be applied broadly, with a climate change component incorporated into the framework. Other approaches have been developed in response to the novel challenges that climate change brings to natural resource management through specific adaptation strategies that bring together familiar elements of existing processes with new climate-relevant concepts (e.g., multi-looped learning, resistance, resilience, and transition) and tools (e.g., vulnerability assessments). These are not necessarily mutually exclusive options; many if not all can work in a complementary fashion (**Figure 2**). For example, a vulnerability assessment is an initial step in the adaptation planning process that identifies where the greatest risks and uncertainties are while scenario planning and other decision support approaches can be used as part of, and to inform, the vulnerability assessment.

Below we describe several adaptation and decision support processes. Regional Case Studies (**Section III**) provide illustrative examples of the application of many of these methods.

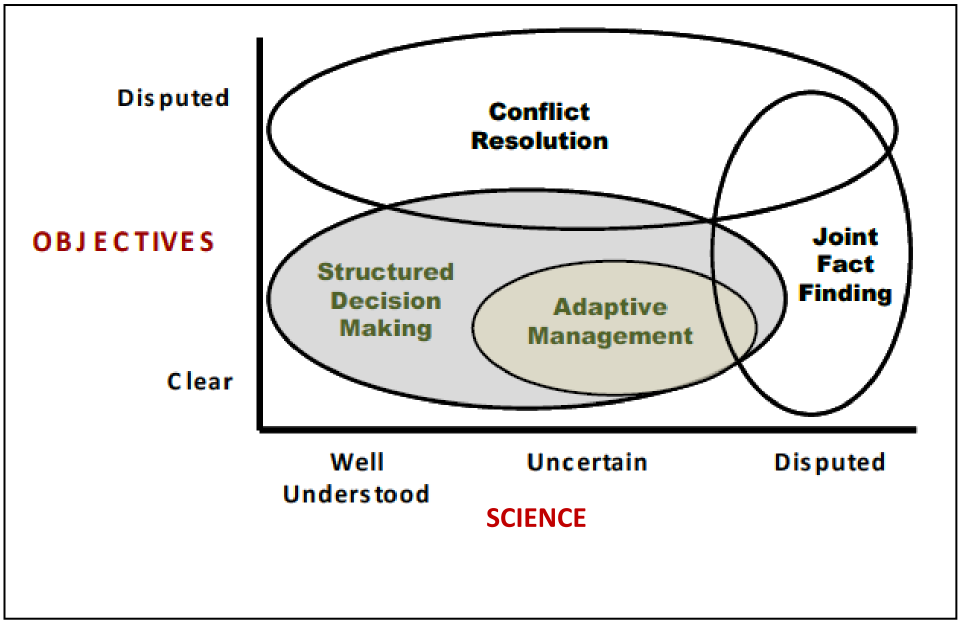

Figure 2: Structured Decision Making in the context of other decision support approaches. Extracted from USGS and U.S. Fish and Wildlife Service National Conservation Training Center course module materials, and modified from Williams & Brown (2012).

i. Adaptation Workbook

The Adaptation Workbook from *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers* (Swanson & Janowiak 2012) outlines a conceptual five-step process to assist natural resource managers in integrating climate change into natural resource management plans and actions. It provides a structured process for managers to work through and draws upon region-specific information such as Climate Change Vulnerability Assessments (CCVAs). It is designed to incorporate climate change considerations into resource management at a variety of spatial scales (parcels to large reserves) and many levels of decision-making (e.g., planning, implementation). It is not intended to provide specific solutions, but rather draws upon the expertise of natural resource professionals and complements already existing processes for developing plans and projects. It provides step-by-step instructions for managers to translate the adaptation strategies and approaches, described above, into on-the-ground management tactics that are expected to help ecosystems adapt to climate change. Finally, it helps managers to consider how a suite of forest management actions can be implemented over long time periods (often through the year 2100) to maintain desired ecosystem functions and benefits across a range of plausible future climates.

The Adaptation Workbook is a structured process to consider the potential effects of climate change on ecosystems and design management and conservation actions that can help prepare for changing conditions. The process is completely flexible to accommodate a wide variety of geographic locations, scales, habitat types, management goals, and ownership types. The Workbook consists of 5 basic steps (**Figure 3**):

1. Define goals and objectives
2. Assess climate impacts and vulnerabilities
3. Evaluate objectives considering climate impacts
4. Identify adaptation approaches and tactics for implementation
5. Monitor effectiveness of implemented actions both in the short and long-term

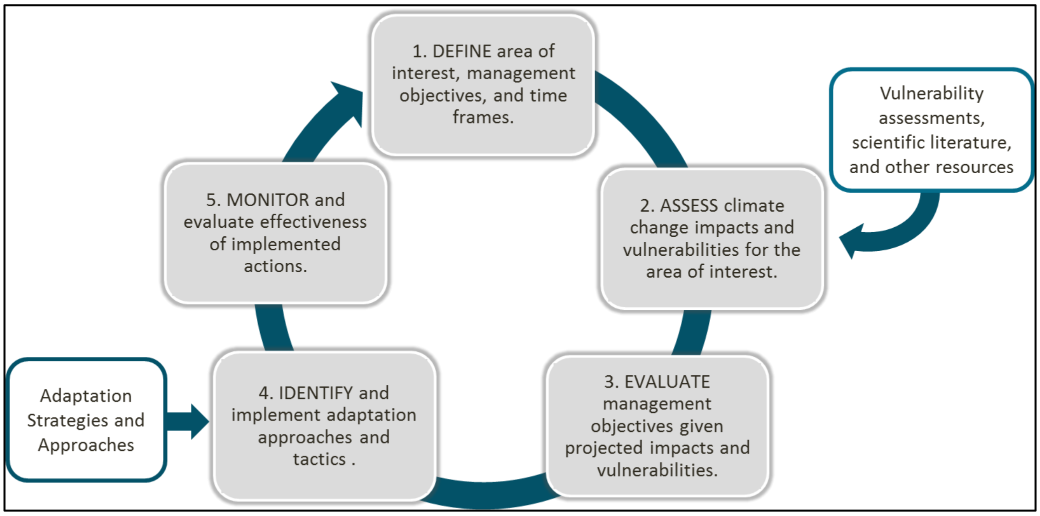

Figure 3: Five steps of the structured process outlined in The Adaptation Workbook Modified from Swanson & Janowiak 2012.

ii. Climate Change Vulnerability Assessments

Chapter 2 of this report provides an overview of Climate Change Vulnerability Assessments (CCVAs), outlines a range of CCVA frameworks being implemented regionally and nationally (e.g., NatureServe Climate Change Vulnerability Index (CCVI) and the Climate Change response Framework (CCRF)), and synthesizes information on approximately 1,000 fish and wildlife species, and 82 habitats evaluated across 21 studies in the Northeast and Midwest. Briefly, climate change vulnerability assessments determine which species are relatively more or less vulnerable to the direct and indirect impacts of climate change, and to identify the specific elements of exposure, sensitivity, and adaptive capacity that contribute to their overall vulnerability. The process of conducting a vulnerability assessment can be nested within other frameworks (e.g., Structured Decision Making), and can also include other adaptation processes and approaches (e.g., scenario planning) (Glick et al. 2011). There are a variety of qualitative and quantitative approaches to assess vulnerability (**see Chapter 2, Table 2; Chapter 3** results related to the Designing Sustainable Landscapes project (DeLuca & McGarigal 2014)). As part of the vulnerability assessment process, information about what is known and uncertain about a species or system is amassed as well as the confidence levels in the existing information. Clear reporting of uncertainties is one outcome of a CCVA that can inform and help prioritize adaptation strategies such as targeted monitoring of specific biological and ecological attributes, or coordinated monitoring of paired biological and environmental monitoring systems to better detect and attribute responses to climate drivers and ecosystem shifts. Please refer to **Chapter 2** for additional information on regional CCVAs.

iii. Structured Decision Making

Structured Decision-Making (SDM) is the application of decision theory, risk analysis, and stakeholder engagement in the analysis of natural resource management decisions. In this process, special attention is devoted to decisions made by natural resource managers and to the potential alternatives and outcomes, quality of information available, and uncertainty they encounter trying to achieve their objectives. The approach recognizes the iterative component of natural resource decision-making, and the ability to update decisions as more information becomes available about how a species or system is responding to management actions. The SDM process breaks the decision that needs to be made into components that separate science and policy issues. The SDM process is deliberate, transparent and replicable. Managers are more likely to achieve their objectives through SDM because stakeholders are involved throughout the process and all viewpoints are represented in the decision (Gregory et al. 2012).

The SDM approach has recently become very popular within natural resource and conservation communities of practice, and is currently being utilized in numerous initiatives across the Midwest and Northeast. Case studies outlined in the next section of this report (**Section III. A.**) show SDM being used at the landscape scale by the Landscape Conservation Cooperatives (LCCs) as part of their Landscape Conservation Design project development, and also provides an example of SDM use at the watershed scale (**Section III.i.**: Headwater Stream Ecosystem Conservation).

Trainings on how to apply the SDM approach using the PrOACT decision model (**Figure 4**) are offered by the U.S. Fish and Wildlife Service National Conservation Training Center.

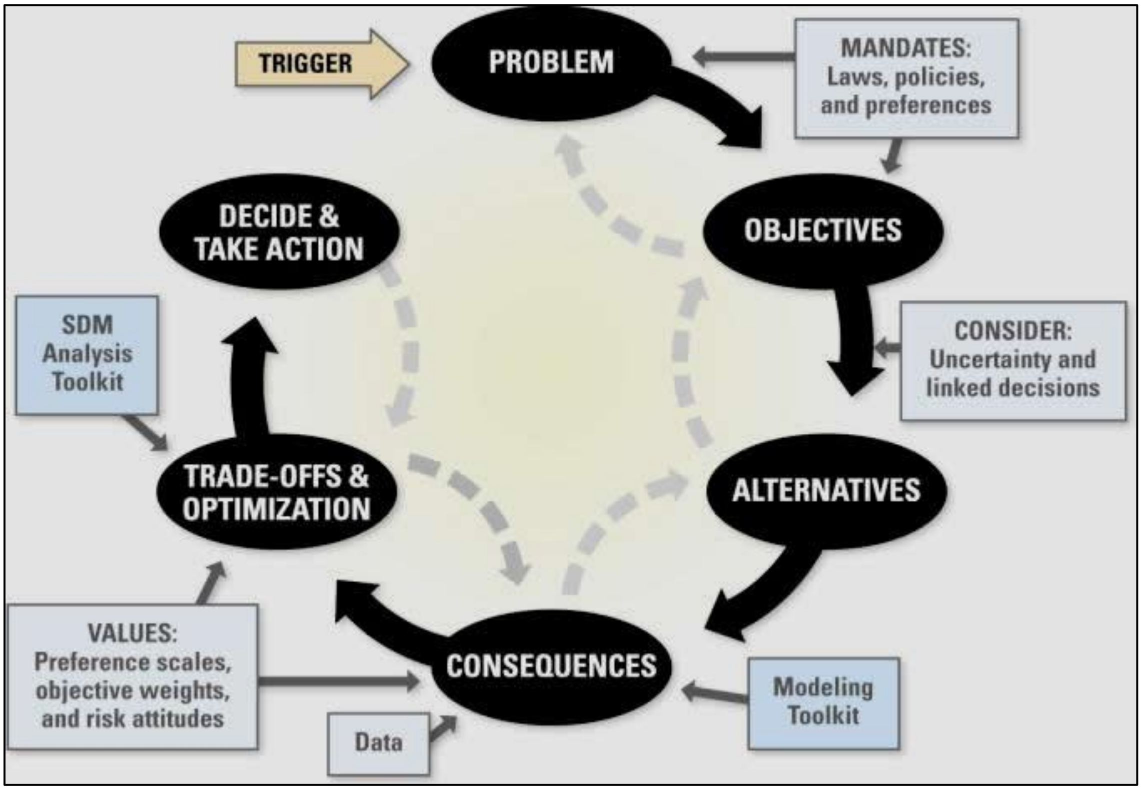

Figure 4: Diagram of the five core elements of the PrOACT decision model. Figure modified from Hammond et al. 2002.

iv. Adaptive Resource Management

Adaptive Resource Management (ARM) is another decision tool and a special case of SDM. ARM was developed for recurrent decisions regarding dynamic resources that are subject to high but potentially reducible uncertainty (Williams & Brown 2012). Through this process, management actions provide feedback to decision makers of how the system or resource is responding to actions, helps verify or disprove competing hypotheses, and informs more refined, improved decisions over time (Walters 1986). The ARM approach reduces uncertainty through a collaborative approach that involves managers and scientists. The ARM process includes five elements (adapted from Williams & Brown 2012):

1. *Stakeholder involvement* – includes the different perspectives, preferences and values related to the decision and resource being considered. Even when conflicts are present among stakeholders, this process generally increases acceptance and compliance with the decision outcome.
2. *Objectives* – development of clear goals that serve as benchmarks to compare and contrast alternative management actions and the effectiveness of their implementation.
3. *Management alternatives* – alternatives are developed from which an action is selected at each decision point, which has direct or indirect effects on the target resource.
4. *Predictive models* – describe or quantify resource dynamics, ecological and environmental relationships, and the costs and benefits of the alternative actions being considered.
5. *Monitoring protocols* – provide feedback and learning about how the resource is responding to the alternative actions being implemented. To be effective, the attributes of the resource being monitored should be as closely linked as practically possible to the management action.

A case study of this approach was recently highlighted by Nichols et al. (2015), which described the process of decision-making regarding harvest regulations for mallards (*Anas platyrhynchos*), one of most economically important waterfowl species in North America. The

U.S. Fish and Wildlife Service used the ARM approach to maximize mallard harvests over the long-term and set goals that devalued harvest when the population size was below a specified threshold set by the North American Waterfowl Management Plan. The ARM approach is currently being considered and applied to other migratory waterfowl through the US Flyways collaborations.

v. Scenario Planning

Scenario planning and other scenario-based approaches contribute to climate change adaptation as a tool for explicitly incorporating uncertainties into planning and decision-making that are difficult to address with predictive methods alone. Natural resource management takes place in the context of complex systems influenced by forces (or “drivers”) that are often beyond direct control by managers (Peterson et al. 2003; Zurek & Henrichs 2007; Walker et al. 2012). These can lead to significant uncertainties about future conditions, which have implications for the management decisions being made today (e.g., Beach & Clark 2015).

Climate change, which has direct and indirect influences on natural systems and interacts with other conservation threats and stressors, is creating increasingly unpredictable futures. Additionally, it requires consideration of longer time horizons than those typically considered in natural resource management. Scenario planning can provide insights into future trajectories, and prepare managers to respond appropriately to challenges in both the short- and long-term (e.g., Duinker & Greig 2007; Weeks et al. 2011; Price and Isaac 2012; **Box 1**). Scenario planning also has the ability to identify triggers (e.g., in environmental conditions) that can guide monitoring and management decisions and actions (e.g., targets that can help managers recognize when certain thresholds are imminent or have been past, thus prompting actions).

Box 1: Regional examples of the scenario planning approach applied to address climate, ecological, and other changes for natural resources. **Appendix 4.3** contains expanded descriptions of project goals, narratives, and partners.

1) **Isle Royale National Park** (Lake Superior, Michigan): the National Park Service (NPS) is developing qualitative scenario narratives to explore how climate change will impact future park conditions (Fisichelli et al. 2013).
2) **Northern New England** (Massachusetts, Maine, New Hampshire and Vermont): the New England Landscape Futures network is developing qualitative narratives and quantitative simulations to evaluate impacts on stakeholder identified ecosystem services (S3 Research Coordination Network; Duvenek et al. 2015).
3) **Lake Ontario Ecosystem** (New York and Ontario, Canada in the Lake Ontario watershed): New York Sea Grant is using qualitative scenarios to explore uncertain trajectories of ecosystem processes and expand the perspectives of lake stakeholder groups (Ongoing, NY Sea Grant, dbm4@cornell.edu).
4) **North Woods and moose** (Northern New England, New York, Adirondacks): The Wildlife Conservation Society, USGS, and others are testing a scenario-planning approach with State and other managers to develop future scenarios of moose in the transition zone of the Northern Hardwood and Boreal forests (Ongoing, WCS, erowland@wcs.org).

Scenario planning is a flexible yet structured process. There is no single established methodology for conducting scenario planning, and the process has been depicted in different ways in its more recent application to climate change adaption (e.g., Mahmoud et al. 2009; Wiseman et al. 2011; NPS 2013). Regardless of the specific techniques used, the process is generally characterized by three broad phases: 1) preparation and scoping, 2) developing and refining scenarios, and 3) using scenarios, each with key steps that are common between approaches and similar to other decision support methods (**Figure 5**; Rowland et al. 2014). Scenario planning efforts can assist with understanding, planning for, and implementing actions, and can be tailored to available time, capacity, and financial resources.

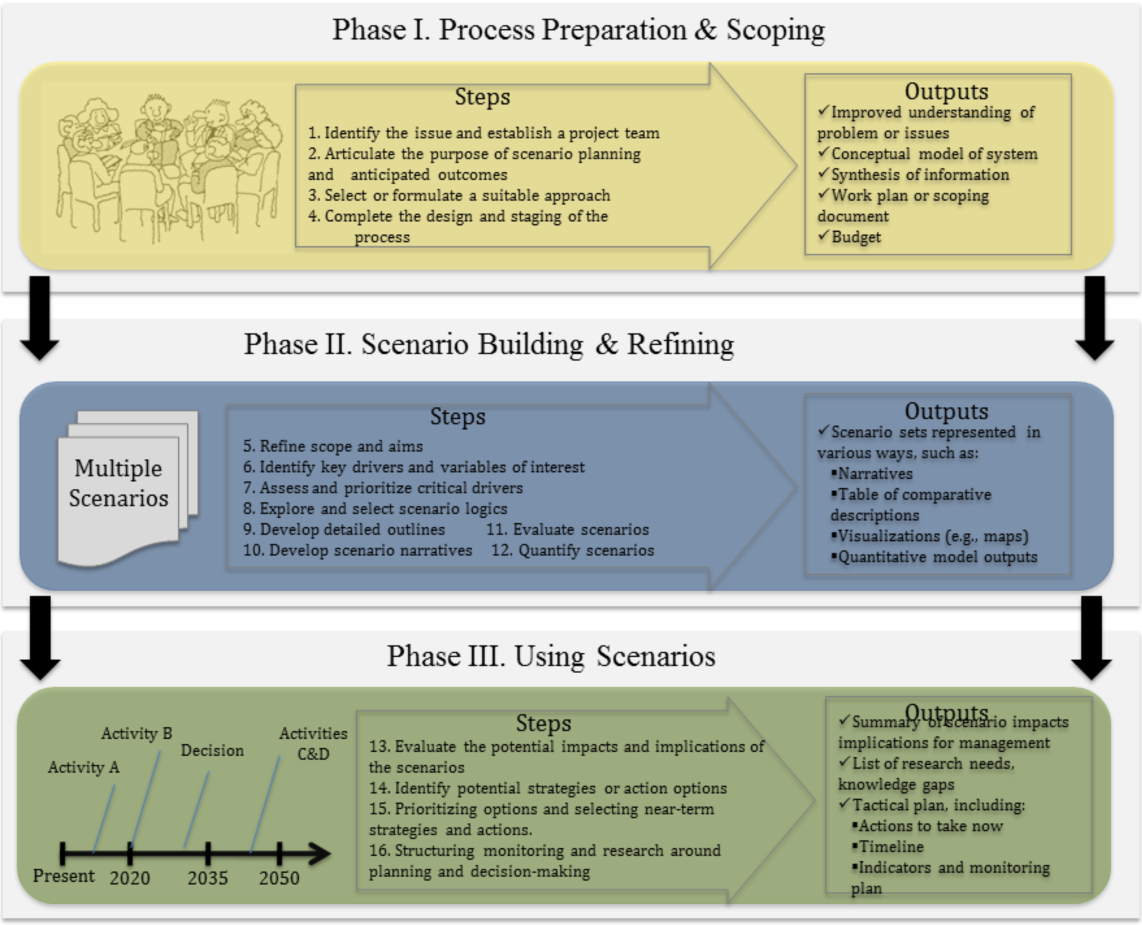

Figure 5: Three phases in the scenario planning process, including the steps and outputs for each phase (modified from Wiseman et al. 2011 and others).

While similar in many respects to other decision support methods, scenario planning is distinguished by the explicit development of scenarios built around critical uncertainties, for which the magnitude or direction of change have the potential to create diverse future conditions with different management challenges. The structured process allows practitioners to bring varying kinds of information to bear on a complex problem in a transparent way (Thompson et al. 2012; NPS 2013). Both quantitative and qualitative inputs are used to characterize ecosystem changes, and potentially economic and social changes, for a chosen time period (e.g., 2050, 2100). Scenarios describe more than just endpoints by including logically consistent, temporal pathways or sequences of events needed to arrive at those future conditions. The scenarios are often initially represented by realistic narratives or stories that capture the “who, what, where, when, and why” of the problem and portray both the positive and negative consequences of the future conditions. While the scenarios are structured around uncertain drivers of change, they should also incorporate more certain elements that different futures may have in common (NPS 2013).

Whether qualitative, quantitative, or some combination, the resulting scenarios are possible future states of the world that represent alternative plausible conditions under different assumptions. Scenario planning does not end with scenario development. The intent is to use the scenarios to explore potential effects or consequences and how to respond (Peterson et al. 2003; Mahmoud et al. 2009; Wiseman et al. 2011). Applying the scenarios becomes a "what if" exercise through which management options for the different future conditions are considered (NPS 2013). Scenario planning enables the identification of robust management strategies, if they exist, as well as those specific to the unfolding of particular conditions. It can also support the development of new strategies or the revision of existing conservation goals and objectives in cases where current actions cannot achieve the goals regardless of future conditions (e.g., Caves et al. 2013; Beach & Clark 2015). Completing the process helps recognize future decision points, as well as the development of indicators that might determine when decisions can be made (Weeks et al. 2011; Wiseman et al. 2011). Coupling scenario planning with targeted monitoring can provide information on how a particular trajectory is playing out, allowing managers to respond quickly with proactively identified actions.

Scenario planning is one method to support planning and decision-making under uncertainty and can complement other decision frameworks, methods, and tools, including adaptive management, structured decision making, and iterative risk management (e.g., Caves et al. 2013; Miller & Morrisette 2014; **Figure 6**). Scenario planning can engage stakeholders, explore possible future trajectories for a system, assess the vulnerability of conservation resources, consider the consequences of management alternatives, and develop indicators of important future decision points. In some cases, the outputs from an initial exploratory exercise can provide inputs for subsequent existing planning and decision-focused efforts, helping to frame issues and suggest management alternatives (Biggs et al. 2007; Rowland et al. 2014).

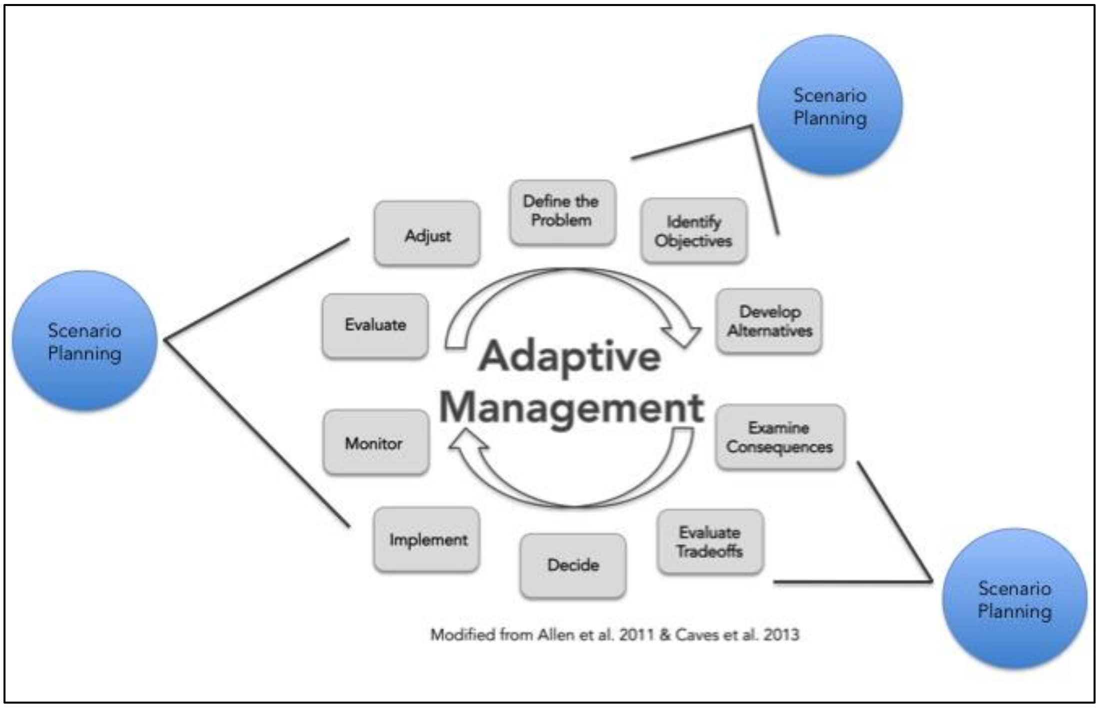

Figure 6: The parts of a decision-making process or adaptive management to which scenario planning might contribute. Modified from Allen et al. (2011) and Caves et al. (2013).

vii. Web tools

There are numerous interactive web-based climate change adaptation tools being developed and released on a daily basis. **Appendix 4.2** lists a selection of adaptation decision support tools focused on a variety of natural resources with short descriptions and website links. Many of these tools can be used to generate information to be included in the decision support approaches outlined in this section. There are many more tools available that are not listed in **Appendix 4.2**, but this list serves as a starting point to demonstrate the range of resources available for aiding in decision making and taking action.

B) MONITORING

Climate change will require novel management decisions with unknown outcomes; thus monitoring is essential to tracking successes and failures, helping refine future actions and approaches, and identifying effective adaptation strategies and management practices (West et al., 2009; Lawler et al. 2010). Monitoring also reduces uncertainty by providing baseline data as well as insight on how species and habitats are responding to climate change and other stressors. In many cases, monitoring programs were not designed with climate change impacts in mind and may need to be adjusted to accommodate new challenges and information needs (Heinz Center 2008). This includes identification of key indicators and metrics that track ecological responses, including certain demographic parameters and the seasonal timing of life history events (phenology) across components of biodiversity (species, ecosystems, and biomes). Monitoring can also provide advance warning of the direct and indirect impacts of climate change and other stressors (Heinz Center 2008; Staudinger et al. 2012).

A recent report that served as input to the National Climate Assessment (Staudinger et al. 2012) made a series of recommendations on monitoring in the context of climate change, and are summarized here:

- Improved, better-integrated, and increasingly coordinated monitoring systems are needed to detect, track, and attribute species and habitat shifts to climate change over varying spatiotemporal scales.
- Existing long-term monitoring sites provide a historical context of the underlying trajectories of fish and wildlife populations and dependent habitats, and are useful in detecting drivers of change, the places where ecological systems are adapting (or not), as well as novel shifts in range, phenology and species interactions.
- Locally based observation networks can be “nested” within a larger-scale network to deliver information to a wider range of managers and policy makers in order to better detect changes due to climate and interactions with other anthropogenic stressors.
- Inserting monitoring protocols with consistent metrics into projects will be critical to make inferences across studies and document large scale trends in impacted fish and wildlife species.
- Ecological monitoring of transition zones between ecosystems may provide early warning of potential biome shifts.

- Increased monitoring is needed to detect and subsequently eradicate invasive species before they become established in new locations or expand their range into new territories.

Here we provide examples of a regional project and national program that are addressing these recommendations for monitoring. In addition, **Appendix 4.1** provides numerous examples (searchable by Source Document Descriptor) of how monitoring can address climate change and other anthropogenic stressors through specific adaptation strategies and tactics.

i. NorEaST - A coordinated regional monitoring initiative

One example of how individual disparate monitoring locations can be linked together to inform landscape and regional scale adaptation is showcased by the NorEaST project. Climate change is expected to alter stream temperature and flow regimes over the coming decades, and in turn influence distributions of aquatic species in those freshwater ecosystems. To better anticipate these changes, there has been a need to compile both short- and long-term stream temperature data for managers to gain an understanding of baseline conditions, historic trends, and future projections. Pooled data from many sources, even if temporally and spatially inconsistent, can have great value both in the realm of stream temperature and aquatic response. Unfortunately, many agencies lack sufficient resources to compile, conduct quality assurance and control, and make accessible stream temperature data collected through routine monitoring.

The NorEaST web portal was developed to serve as a coordinated, multi-agency regional framework to map and store continuous stream temperature locations and data for New England, Mid Atlantic, and Great Lakes States. Stream temperature monitoring locations and metadata contributed by 47 different organizations can be viewed for over 10,000 monitoring locations across 22 states. Stream temperature sites can be viewed on the NorEaST mapper. Ultimately the goal of this project and portal is to make these data available to managers and the public to aid in adaptation and management planning and actions.

The NorEaST web portal was built to map stream temperature locations, store stream temperature data, and deliver stream temperature data through webservices to stakeholders, including easy access through R software. Preliminary applications of this project have allowed evaluations of seasonal associations of fish species with stream thermal conditions (e.g. range of summer and fall temperature ranges), the identification of thermally sensitive fish species, and potential differences of fish-temperature associations across regions that were previously unknown. Updates on this project can be found on the NE CSC website.

ii. National Phenology Network

The National Penology Network (NPN) provides national standardized protocols for collecting phenology observations, advice and education materials for the collection and organization of new phenology data, and supports the development of tools and approaches for natural resource decision-making. NPN developed *Nature's Notebook* as a citizen science tool to gather phenology observations on plants and animals nationally. Citizen Science is a growing way to monitor and track changes in species responses to climate change, and supplement existing scientific monitoring networks (Newman et al. 2012). Public engagement increases awareness of conservation and climate adaptation issues and can help extend limited resources for activities like monitoring. There are numerous institutions across the Northeast and Midwest using NPN's Nature's Notebook tool and contributing to a larger network of monitoring programs to inform our understanding of phenological responses to climate change.

III. REGIONAL CASE STUDIES

In this final section, we provide illustrative case studies of adaptation strategies, approaches, and tactics being implemented at the ecoregion, state, and local scales. Many of these projects are being conducted by the Northeast Climate Science Center (NE CSC) and diverse partners. At the local scale we include examples of ongoing or recently completed projects focused on aquatic systems, forests, terrestrial wetlands, coastal, and tribal lands. In addition, **Appendix 4.1** synthesizes over 900 adaptation strategies by scale (national, ecoregional, state, and local), target resource (major taxonomic group or habitat type), and climate stressor (temperature, precipitation, sea level rise) from nine regional adaptation studies. Each of the adaptation strategies listed in **Appendix 4.1** is also organized by the seven overarching goals listed in the National Fish, Wildlife and Plants Climate Adaptation Strategy (NFWPCAP 2012). Our intention in presenting these materials is to provide searchable examples ranging from large scale, broad goals to local scale, species or habitat-specific actions and implementation.

A) LANDSCAPE AND ECOREGION

i. Landscape Conservation Cooperatives and Landscape Conservation Design

The Landscape Conservation Cooperatives (LCCs; http://lccnetwork.org/) were established by the Department of the Interior as part of Secretarial Order No. 3289 to better integrate science and management of natural and cultural resources across large spatial and temporal scales as well as to address complex stressors such as climate change. There are 22 LCCs across the nation, and 7 within the Northeast and Midwest (as defined by the footprint of the NE CSC) including: North Atlantic (NA), Appalachian (APP), Upper Midwest and Great Lakes (UMGL), Eastern Tallgrass Prairie & Big Rivers (ETPBR), Gulf Coastal Plains and Ozarks (GCPO), Plains and Prairie Potholes (PPP), and South Atlantic (SA) LCCs (**Figure 7**).

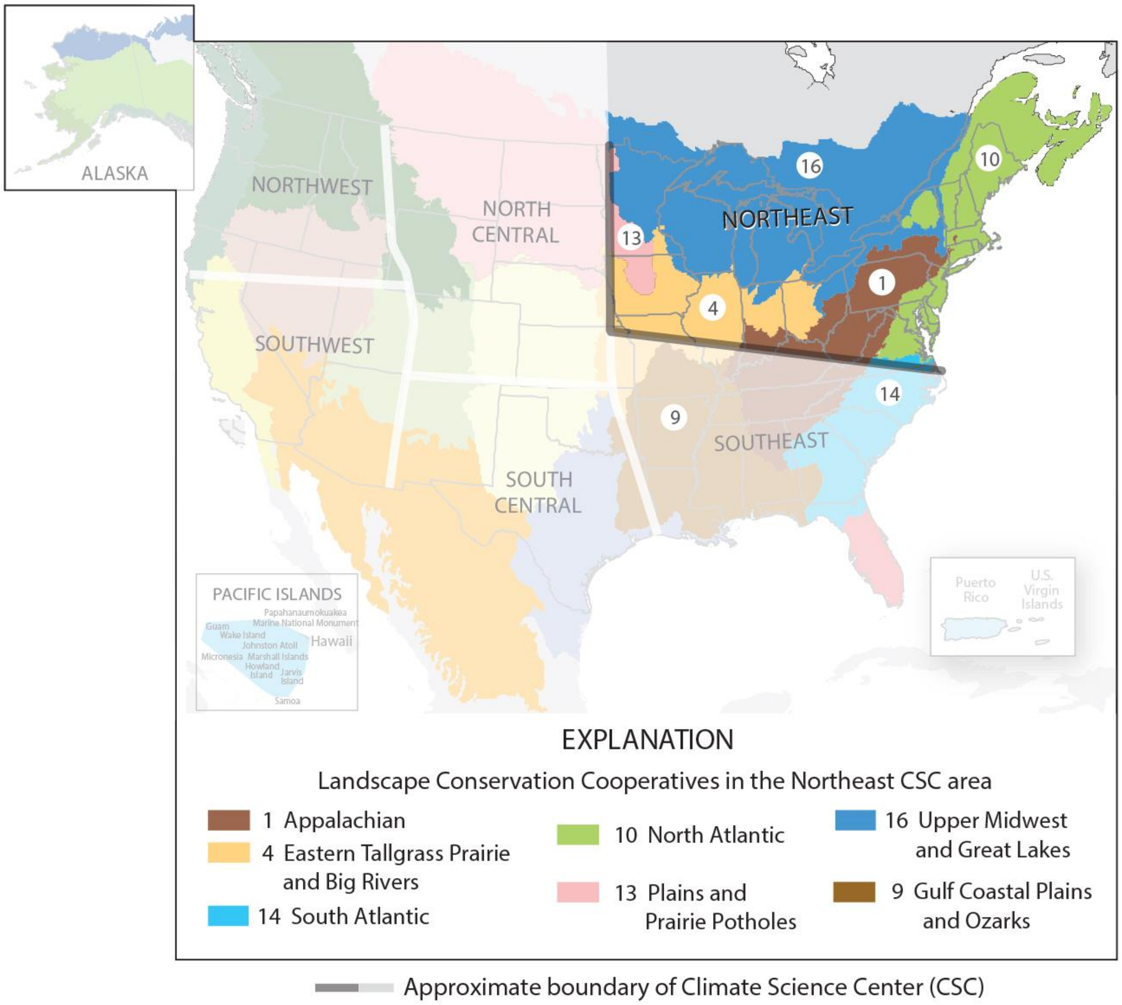

Figure 7: Map of the 7 Landscape Conservation Cooperatives contained within Northeast Climate Science Center geography. Figure modified from NE CSC 2012.

An emerging core initiative of the LCCs is to implement a Landscape Conservation Design (LCD) approach to inform refuge and conservation area planning. This collaborative and partnership-driven strategy to address large scale stressors encompasses both the process and products for designing sustainable landscapes and ecosystem services. LCDs guide landscape-scale restoration, protection, and adaptation of target resources (**Box 2**).

Box 2: Regional examples of ongoing Landscape Conservation Design initiatives being led by the Landscape Conservation Cooperatives. Expanded descriptions of each project and its partners are found in **Appendix 4.4**.

1. North Atlantic: *The Connecticut River Watershed LCD Pilot* is a collaborative effort to plan a landscape with intact, resilient, connected natural areas providing habitat for fish, wildlife and plants and many other natural benefits that support people and communities within the Connecticut River Watershed.
2. Eastern Tallgrass Prairie & Big Rivers (ETPBR): *The Mississippi River Basin / Gulf Hypoxia Initiative* is an initiative undertaking a systematic and transparent process to create an integrated framework that supports planning, design, configuration, and delivery of wildlife conservation practices within the Mississippi River watershed.
3. Gulf Coastal Plains and Ozarks (GCPO): *The Ozark Highlands Comprehensive Conservation Strategy* is a cooperative effort to take an ecoregional approach to designing landscapes capable of sustaining healthy plant and animal communities in the Ozark Highlands.
4. Upper Midwest and Great Lakes (UMGL): The primary goal of the *Great Lakes Coastal Wetland LCD* is to guide landscape scale restoration/protection of historical, existing, or potential wetlands that are, or could be hydrologically influenced by levels of Great Lakes and their connecting channels.
5. Appalachian (App): The goal of the Appalachian Conservation Modeling project is to use data and models to develop a regional conservation plan and LCD that supports natural and cultural resources in the Appalachian region.
6. Plains and Prairie Potholes (PPP): The PPP LCC is currently developing a strategic plan that will help determine how and when to undertake LCD from a partnership perspective using decision analysis techniques, land use change, and human dimensions as priorities.

ii. USDA Northern Forests Sub Hub

The Northern Forests Sub Hub tiers to and expands the work of the Midwest and Northeast USDA Regional Climate Hubs. The primary goals of the Northern Forests Sub Hub are to ascertain and meet the needs of the forest sector through 1) ongoing engagement and networking with a wide array of landowners, organizations, universities, and interests related to the sector, 2) creation and distribution of sector-relevant climate information and resources for natural resource professionals and landowners, and 3) establishment of adaptation planning and implementation, with associated promotion of peer-to-peer learning where appropriate. The Sub Hub is coordinated by the Northern Institute of Applied Climate Science (NIACS), a regional multi-institutional partnership that has focused on delivery of climate change and carbon science to the forest sector for more than 5 years. Deliverables and products identified in the Sub Hub work plan include: 1) vulnerability assessments; 2) adaptation resources, tools, and demonstrations; 3) science delivery, training, and technical assistance; and 4) outreach and communication demonstrations, materials, and tools.

iii. Northern Institute of Applied Climate Science

The Northern Institute of Applied Climate Science (NIACS) has been designed as a collaborative effort amongst the Forest Service (Northern Research Station, Eastern Region, Northeastern Area State & Private Forestry), Michigan Technological University, National Council for Air and Stream Improvement, and the Trust for Public Land. NIACS provides information on managing forests for climate change adaptation, enhanced carbon sequestration, and sustainable production of bioenergy and materials. As a regional, multi-institutional entity, NIACS builds partnerships, facilitates research, and synthesizes information to bridge the gap between carbon and climate science research and the management needs of land owners and natural resource professionals, policymakers, and members of the public. Through its work to integrate climate change considerations into natural resource management, NIACS is central to the coordination of the Forest Service's Climate Change Resource Center (CCRC) as well as the Climate Change Response Framework (CCRF).

Climate Change Resource Center (CCRC) – The US Forest Service CCRC is a web-based, national resource that connects land managers and decision makers with useable science to address climate change in planning and application. The CCRC addresses the land manager's question "What can I do about climate change?" by providing information about climate change impacts on forests and other ecosystems, and approaches to adaptation and mitigation in forests and grasslands. The website compiles and creates educational resources, climate change and carbon tools, video presentations, literature, and briefings on management-relevant topics, ranging from basic climate change information to details on specific management responses. The CCRC is a joint effort of the US Forest Service Office of the Climate Change Advisor and US Forest Service Research and Development.

Climate Change Response Framework (CCRF) – The CCRF is a highly collaborative approach to helping land managers integrate climate change considerations into forest management. Since 2009, the Framework has bridged the gap between scientific research on climate change impacts and on-the-ground natural resource management. Currently, there are six Framework projects encompassing 19 states, including 14 National Forests and millions of acres of forestland and 75+ partners (e.g., federal, state, tribal, private). Each regional project interweaves four components: science and management partnerships, vulnerability assessments (see **Chapter 2)**, adaptation resources, and demonstration projects.

iv. Southeast Conservation Adaptation Strategy

The Southeast Conservation Adaptation Strategy (SECAS) is a regional conservation and management partnership driven effort seeking to develop coordinated planning and adaptation across the southeast region of the United States. Conservation priorities and actions are being targeted at the landscape scale and informed by a range of approaches including future climate change and sea level projections, and interactions with other anthropogenic stressors, particularly urban growth. Leveraged and collective resources are being coordinated across state fish and wildlife agencies, regional LCCs and CSCs, joint ventures, and a range of other organizations invested in conservation and adaptation of natural resources.

Examples of conservation and adaptation strategies underway through SECAS efforts at the landscape-scale include:

- Increasing connectivity among fragmented habitats and populations so that fish and wildlife can shift their ranges or migrations to follow optimal environmental conditions under future climate and land-use changes.

- Developing predictions of urban growth patterns and rates across the region to identify areas where fragmentation will increase and potentially have negative impacts on ecosystem health (Terando et al. 2014).
- Conducting regional multi-species and large-scale vulnerability assessments of fish, wildlife and habitats.

v. Conservation Opportunity Areas

Conservation Opportunity Areas (COAs) are spatially delineated places where actions to support or enhance populations of Regional Species of Greatest Conservation Need (RSGCN) and/or their habitats are likely to be most effective. State fish and wildlife agencies are partnering to establish COAs across the Northeast and Midwest. This process requires the development of a methodology to document and map COAs across the region to achieve fundamental objectives (**Figure 8**). A recent workshop (March 2015) convened by the North Atlantic LCC, discussed how COAs could be developed to inform State Wildlife Action Plans, evaluate possible fundamental objectives, and identify a refined set of alternatives for consideration by the Northeast Fish and Wildlife Diversity Technical Committee (NEFWDTC). The types of information included as part of this process included indices of ecological integrity, resilience, barriers to fish and wildlife movements and migration, and spatial data layers on habitat species distributions. Workshop participants then scored different alternatives for their inclusion in the development of COA objectives.

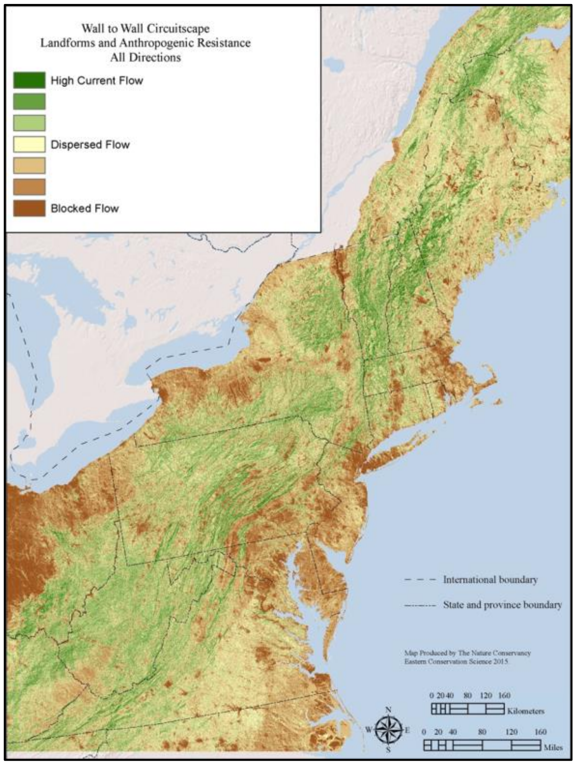

Figure 8: Map showing potential areas of high permeability for upslope range shifts under future climate change and considering anthropogenic barriers and fragmentation. Modified from Anderson et al. (2015) and used with permission from The Nature Conservancy.

One study that was unanimously scored for inclusion was a new landscape permeability study led by The Nature Conservancy (Anderson et al. 2015). Building on previous work by Anderson et al. (2012), which documented climate-resilient sites, new methods were used to evaluate patterns of regional landscape permeability most likely to facilitate fish and wildlife movements as they respond to climate change through geographical range shifts. Spatially explicit data layers highlight areas where northward and upslope movements are most likely across terrestrial landscapes, as well as riparian corridors, such as intact floodplains, that would allow moisture-dependent species to track optimal habitat conditions under future climate change (**Figure 8**; Anderson et al. 2015). The Appalachian Mountain chain was one area identified as highly important for thermal corridors of movement in the Northeast. Next steps for this work are to integrate species range and movement data with the landscape layers to gain a better understanding of actual occupied habitats and prioritize specific areas for conservation.

B) STATE

Several State Wildlife Action Plans have already been begun the process of including adaptation strategies in their planning. **Appendix 4.1** provides a synthesis of adaptation strategies and tactics recommended in five State Wildlife Action Plans including Connecticut (Adaptation Subcommittee to the Governor's Steering Committee on Climate Change 2011), Massachusetts (Climate Change Adaptation Advisory Committee, 2011), New Hampshire (New Hampshire Fish and Game Department, 2013), Vermont (TetraTech, Inc. 2013), and Rhode Island (Rhode Island SWAP Wildlife Action Plan 2015).

Table 1: Total numbers of species and habitat-specific adaptation strategies and tactics listed in **Appendix 4.1.**

Target Habitat or species	**N**
Alpine	5
Coastal, Marine	85
Forest	285
Freshwater Aquatic	202
General	277
Terrestrial Wetland	83
Urban/Developed/Agriculture	21
Total	**958**

C) LOCAL

i. Aquatic systems

Landscape Scale Decision Making for Headwater Stream Ecosystem Conservation: Researchers from the USGS Patuxent Wildlife Research Center, USGS Massachusetts Cooperative Fish and Wildlife Research Unit, and University of Massachusetts Amherst are working together to understand the impediments to landscape scale conservation of headwater stream ecosystems which are managed by multiple stakeholders in watersheds across the Northeast. The project uses decision theory and tools, specifically SDM (see **Section II.A.iii**) to evaluate how stakeholders can collaboratively create adaptive strategies that protect headwater ecosystems from various threats and stressors, including future climate and land use changes. Since headwater stream ecosystems are differentially valued by organizations for their species diversity, recreational opportunities, and/or ecosystem services (i.e., water quality and supply as well as flood control), and individuals and agencies are often working with limited resources (i.e., funding, staff), trade-offs may be inevitable, and can be explicitly incorporated into the decision framework to find an optimal solution for collaboration which best satisfies multiple stakeholder objectives. By working with federal, state and local governmental agencies and non-profit organizations from two watersheds (Deerfield and Merrimack in New England), this project will provide an example of when collaboration can improve effectiveness and efficiency of conservation actions. Using decision-theory approaches, this project is explicitly incorporating critical uncertainties (i.e., environmental variation, partial controllability, structural and parameter uncertainty), risk preferences, and scenario planning tools to generate insights into the range of potential future outcomes under alternative management strategies. Solutions to other such landscape-scale conservation problems will require a similar decision framework that incorporates diverse stakeholder objectives, scientific and management uncertainty, and risk tolerance into large-scale conservation efforts across the Northeast and beyond. Updates on this project can be found on the NE CSC website.

Assessing aquatic vulnerability through storm transposition: Risk assessment is a process used across many disciplines, agencies and institutions to evaluate the likelihood of harmful impacts that may occur or are occurring as a result of exposure or vulnerability to climate change and other stressors. Storm transposition is a modeling approach to help communities and land managers assess and prepare for the risk of extreme rainfall. Climate scientists project heavier and more frequent extreme rainstorms for the Northeast and Great Lakes regions in the future (see **Chapter 1**). Many communities plan for and design infrastructure using “synthetic” storms (e.g., the 10, 50, 100 year storms). Storm transposition makes use of high-resolution rainfall data from actual extreme rainfall events and applies them to inform flood risk assessment and stormwater management in nearby locations that have not recently experienced extreme rainfall. Researchers at the University of Wisconsin-Madison (David Liebl and Ken Potter) developed the software tool TranStorm to facilitate hydrologic modeling with transposed storms (additional information available on the U.S. Climate Resilience Toolkit site). Land managers and municipalities can use such modeling to identify potential vulnerabilities and plan for future extreme events. The use of a well known actual storm rather than a ”synthetic” storm is more likely engage the public and may well lead to increased support and resources for restoration and adaptation actions. To date this modeling approach has involved stormwater ordinances and lake management, but can be applied to other issues involving extreme precipitation risk, including sediment and nutrient pollution, ecosystem damage, and bridge and culvert vulnerability.

The software tool TranStorm enables users to transpose a storm to a watershed of interest. The model also computes time series of rainfall amounts for subwatersheds for use in watershed modeling. The software is currently being shared with users to get their feedback.

ii. Forests

Modeling effects of climate change on spruce-fir forest ecosystems and associated priority bird populations: The primary focus of this project is on forecasting both the future distribution of spruce-fir forest ecosystems in northern New England, as well as associated priority bird species. Deliverables and tools being developed from this project for informing adaptive responses to climate change impacts on these systems include fine-scale (900 m^2 resolution) maps for the entire Green and White Mountain National Forests and surrounding region (~500,000 ha landscapes) that depict the location of potential refugia for spruce-fir forests under different climate and management scenarios. Importantly, these maps include the future distribution of all forest habitat types for these areas, allowing for evaluations of ecosystem vulnerability and associated adaptive response for all forests in this region. In addition, bird distribution models are also being developed to determine the relative suitability of these vegetation refugia for priority birds, including Bicknell's thrush (*Catharus bicknelli*) (Millar et al. 2007).

The forest modeling work is informing three different adaptive strategies for sustaining forest habitats in northern New England, which are designed to achieve the broad objective of maintaining forest habitat conditions under future changes in climate and disturbance regimes for the region. These adaptive strategies are to: 1) identify and protect climate refugia for spruce-fir forest and associated birds across the region, to minimize incompatible land uses; 2) restore and encourage spruce-fir habitats through forest management practices on portions of the Green and White Mountain National Forest that contain biophysical and localized climate conditions with the potential to support future habitat refugia; and, 3) sustain forest habitat conditions broadly across the diverse forest types found in the Green and White Mountains. In many cases, spruce and fir were selectively harvested from these areas in the past. This project is helping inform where on the landscape active restoration of this species may provide long-term refugia, despite projections for the regional decline of this forest type under climate change. This work is being completed with partners from the Vermont Agency of Natural Resources, White and Green Mountain National Forest, and NIACS, to develop forest management practices that span a spectrum of adaptation objectives. Through stakeholder input, a suite of adaptation prescriptions will be designed that range from “resistance treatments” (i.e., maintain current conditions in light of climate and forest health impacts) to “transition treatments” (i.e., intentionally accommodate projected changes by increasing representation of future-adapted species). Treatments will be implemented in several locations throughout the region, but will also use the landscape models developed to identify refugia to simulate the effectiveness of active, adaptive management at sustaining forest conditions across the region under climate change.

Linking forest landscape change models and wildlife population models to assess climate change impacts on forest habitats and wildlife populations: Forest landscape models incorporate site-scale succession and landscape-scale processes to simulate forest change at landscape scales (He 2008). They have been used to examine the importance of succession, landscape-scale processes, and climate change in affecting forest change. Forest landscape models are linked to different downscaled climate scenarios to investigate the effects of climate change on forests. For example Scheller & Mladenoff (2005) and Thompson et al. (2011) used the LANDIS II forest landscape model to investigate effects of climate change and other landscape processes on changes in forest in Wisconsin and Massachusetts, respectively. Recent advances in forest landscape models have expanded their simulation capacity and the relevance of the types of model outputs available for assessing wildlife habitat. The LANDIS PRO models forest composition and structure based on species-specific tree densities, basal areas, importance values, and biomasses, and can make simulations relevant for wildlife across the region at scales of 90-270 meters (Wang et al. 2014). Forest parameters can be used as direct indicators of wildlife habitat or as inputs to wildlife habitat, abundance, or population models. Forest landscape models can be used to simulate forest change under different climate and management scenarios to investigate tree species vulnerability and indirectly ecosystem or habitat vulnerability to climate change (Butler et al. 2015).

Outputs from forest landscape models can be linked with wildlife suitability models and population models to assess the impacts of landscape change on wildlife (Larson et al. 2004). For example, Bonnot et al. (2011) developed a spatially-explicit demographic model for several migrant songbirds that structured the regional population into ecological subsections on the basis of habitat, landscape patterns, and demographic rates to assess species viability in the Midwest. Bonnot et al. (2013) then used this approach to evaluate the response of prairie warbler (*Dendroica discolor*) and wood thrush (*Hylocichla mustelina*) populations in the Central Hardwoods Bird Conservation Region to simulated conservation scenarios. The authors also assessed the relative effectiveness of habitat restoration, afforestation, as well as increased survival, differed placement, and levels of effort for implementing those approaches; however, these approaches could also be used to assess species vulnerability under different climate scenarios or to evaluate the effectiveness of adaptation plans.

iii. Terrestrial wetlands

Novel management approaches for a vernal pool breeding salamander: Mole salamanders of the northeastern United States, including spotted salamanders (*Ambystoma maculatum*) and marbled salamanders (*Ambystoma opacum*), are vernal pool breeders and important species in the upland forest habitats surrounding these vernal pools. Marbled salamanders are a Regional Species of Greatest Conservation Need (see **Chapter 3** for full list and additional information on this species) that may require novel management approaches to reduce vulnerability due to the effects of climate and land use changes. Climate change is expected to lead to reduced vernal pool hydroperiod due to temperature effects on evaporation, evapotranspiration rates, and changes in seasonal precipitation rates (Brooks 2009).

Populations of vernal pool breeding salamanders have historically been focused at the individual vernal pool level, but recommendations are broadening monitoring and management actions to the metapopulation scale. Some vernal pools act as source populations with more persistent populations (e.g. those vernal pools with optimal hydroperiod regimes), while other vernal pools have lower numbers of breeders, and can periodically go extinct, but are often recolonized by individuals dispersing from nearby source vernal pools. At the landscape scale, individual vernal pools encompass a network of vernal pools and act as stepping stones across the environment allowing for salamander gene flow which is important for maintaining genetic diversity. Unfortunately, such networks, as well as surrounding upland habitat, have been and continue to be, severely fragmented or degraded by human development (Compton et al. 2007; McGarigal 2008)

Adaptation efforts that identify and prioritize the protection of important pool networks will be important for allowing populations to track future environmental change (see Compton et al. 2007). Individual vernal pools and networks of pools could be conserved in a landscape scale network of refugia and corridors through future land acquisition and conservation areas. Marbled salamander network connectivity and population size could also be improved by restoring vernal pools that were previously filled or by creating new vernal pools on the landscape (Windmiller & Calhoun, 2007). Another potential adaptation tactic that could be implemented is to control the vernal pool hydroperiod at individual vernal pools within a network to improve breeding conditions and increase marbled salamander fecundity. This would require baseline monitoring of hydroperiod to determine which vernal pools on the landscape would be most suitable for hydroperiod alteration for marbled salamanders and how these pools might fit into a larger landscape scale network.

Assisted migration is another adaptation approach that has been proposed for species not able to track environmental change due to fragmentation or if rapid environmental change makes such environmental tracking unrealistic (Minteer & Collins, 2010). Before assisted migration could be successfully applied to marbled salamanders, vernal pools with optimal vernal hydroperiod and suitable upland habitats would need to be identified.

A long-term marbled salamander monitoring project at the University of Massachusetts is currently working on gathering the needed information to help guide adaptation strategies for marbled salamanders. Updates on this project can be found on the NE CSC website.

iv. Coastal habitats

Coastal regions in the Northeast are diverse, and face a variety of climate hazards including coastal flooding due to sea level rise and storm surge (**Chapter 1**). The combination of diversity and variety of climate hazards are fostering a diverse set of adaptation strategies along our coasts. The coastal region of the Northeast has high, and growing, vulnerability to coastal flooding (Horton et al. 2014). Whereas global sea levels have risen by about 8 inches since 1900 (IPCC 2013), much of the Northeast has experienced approximately 1 foot. By mid-century, much of the region could see between 8 inches and 2.5 feet of sea level rise (Lentz et al. 2015); at the high end, this could lead to a several fold increase in the frequency of coastal flooding even if coastal storms remain unchanged in a changing climate (Sweet & Park, 2014).

Coastal adaptation strategies include hard infrastructure investments (e.g., sea walls and storm surge barriers; some of the region's examples are more than 50 years old), green infrastructure (e.g., oyster beds, and marsh and dune restorations that minimize wave impacts and retain sediment and sand), and policy actions (e.g., changes in building codes and insurance to reflect changing risks to health and assets). Given the scope of the adaptation challenge, many regions are employing hybrid strategies (For examples see the Rebuild by Design Program).

Tools to assess coastal landscape response to sea-level rise for the Northeastern United States: Recently researchers at USGS and Columbia University developed a new method to help support coastal adaptation to the threats of sea level rise and flooding (Lentz et al. 2015). This method distinguishes coastal areas along the Atlantic coast, from approximately Virginia to Maine that will predominantly experience inundation, from those that have the capacity to respond dynamically, for example through habitat shifts (e.g., inland). The probabilistic model goes beyond the traditional "bathtub" models by combining sea level rise projections, coastal elevation, vertical land movement, and coastal land cover as inputs (**Figure 9**). Model outputs include land cover-specific forecasts of the probability of inundation or dynamic coastal change. The model also produces an adjusted land elevation with respect to forecast sea levels.

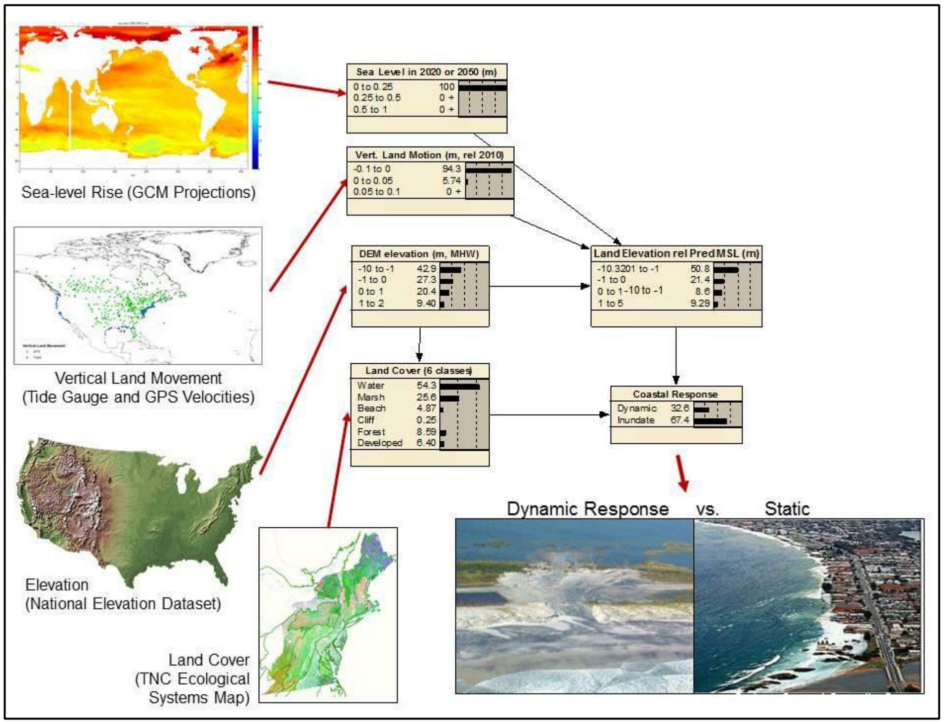

Figure 9: Diagram of the primary inputs used to predict future land elevations and coastal responses to sea level rise and storm surge. Modified from Lentz et al. 2015.

The interactive project website currently makes available for download, data layers on predicted land elevation ranges, likelihoods of observing the predicted elevation changes, and probabilities of static or dynamic change (Lentz et al. 2015). The website also anticipates providing decision support tools that allow users to explore and identify which areas may be best suited to meet their land adaptation or management requirements for a variety of planning horizons.

Coastal sandplain grassland habitats: Coastal sandplain grassland habitats are regional hotspots for biodiversity in the Northeast. These native-species rich and disturbance-influenced habitats are particularly important for regionally declining grassland birds and for habitat-restricted Lepidoptera that depend on food plants that reach their greatest abundance in these areas. Most of the highest quality grasslands occur on sandy, drought-prone glacial outwash soils that reach their greatest extent near the current coastline where they are highly vulnerable to pressures from housing development, woody regrowth caused by fire suppression, and shoreline erosion caused by sea level rise and storm surge.

One approach to sustaining these habitats in coastal landscapes is to "create" these habitats in places where proper conditions exist but that do not support these habitats today. The available lands on which to do this fall in to two general categories: (1) areas that are currently woodland, and (2) areas that are currently grassland, but dominated by non-native species that are not a high conservation priority. But creating native species-rich grassland habitats requires a different land management toolkit and presents a different set of barriers to implementation in the two categories outlined above. Use of forested areas requires forest clearing that can be controversial with the public because it brings a large structural change. It also can require collection and distribution of seeds and follow-up suppression of regrowth. Use of already-cleared non-native agricultural land requires less structural change but could generate opposition because it would remove land from active local agriculture. It may also require active management of soil properties that encourage native species growth. Developing the toolkit for successful adaptation requires experimentation to guide actions in each of these cases.

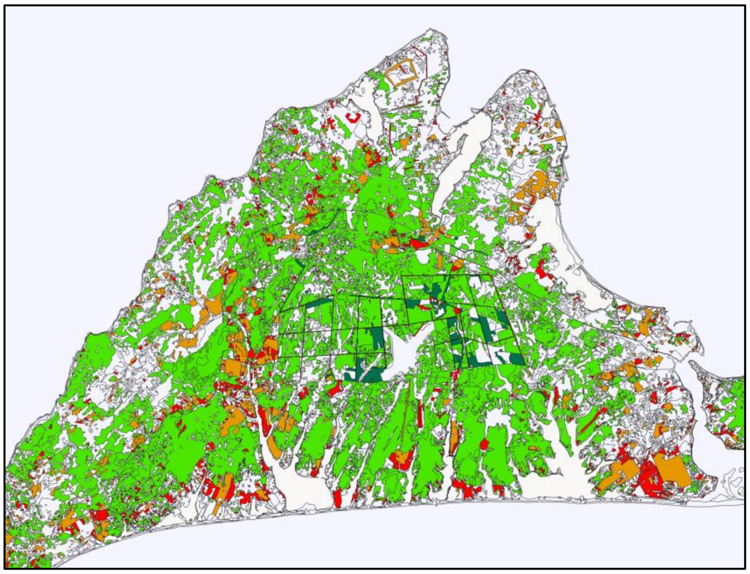

Figure 10: Restoration ahead of climate change on Martha's Vineyard Island, Massachusetts. Light green is oak woodland, red is sandplain grassland, and orange is agricultural grassland. Data from Huber 2000 and Huber & Polzen 2003.

The Marine Biological Laboratory and The Nature Conservancy conducted two large management experiments to address these cases. In the first, oak woodland habitat was surveyed for habitat characteristics and plant species composition, and then cleared and seeded with locally-collected sandplain grassland seeds (**Figure 10**). The recruitment of sandplain-associated plants was tracked for seven years in large (3+ hectare) management units in the cleared area and in uncleared control units. The experiment created increased total cover of sandplain-associated plants and increased total plant species diversity from 27 to 89 species and almost exclusively native species (Lezberg et al. 2007). However, this management approach also required mechanical clearing of regrowing trees that added significant effort and cost.

In a second experiment, an agricultural grassland was subjected to large number of manipulations to test methods of removing existing non-native species, manipulating soils (e.g., reducing pH) to benefit native species, and establishing desired sandplain grassland species. An establishment technique that combined multiple tillings in one growing season with seed addition led to the greatest increases in native species cover and richness (Wheeler et al. 2015). Lowering soil pH also increased cover of native sandplain species (Neill et al. 2015). These new native-species rich grasslands can be relatively easily maintained by mowing or burning.

At the landscape scale, there are opportunities for both of these adaptation strategies. Currently, sandplain grasslands on Martha's Vineyard, MA, cover a small total area and occur in vulnerable areas near the coast. Agricultural grasslands cover a similar area on Martha's Vineyard, and can be converted to sandplain grassland using adaptation experiments as a prescription for action. Conversely, oak woodlands cover a wider area, and present opportunities to create new sandplain grasslands.

v. Tribes and tribal lands

Tribal engagement and climate adaptation stories in the Northeast CSC Region

The 2014-2018 Northeast Climate Science Center Strategic Agenda included a set of recommendations to identify impacts and help develop culturally appropriate resources to assist Northeast and Midwest Tribes with adaptation planning. This was in response to Secretarial Order 3289, which set this as a priority within the Department of the Interior. The College of Menominee Nation's (CMN) Sustainable Development Institute has been working to address these recommendations through several related initiatives. In the fall of 2014, the CMN hosted the *Shifting Seasons: Building Tribal Capacity for Climate Change Adaptation Summit*, which brought Tribes together with federal, state, academic and non-profit groups to facilitate a better understanding of regional climate change and adaptation needs and initiatives, and support the development of a best management practices approach for tribal engagement. Part of the Summit focused on giving examples of existing climate adaptation efforts within the Northeast, including the St. Regis Mohawk Tribe and the Grand Portage Band of Lake Superior Chippewa.

The people of Akwesasne (St. Regis Mohawk Tribe) located in upstate New York created a climate change adaptation plan framed by Tribal teachings, blended with terminology and concepts specific to climate science. Through this framework, the plan identifies culturally relevant species and habitats (i.e. Mother Earth, Fish, Three Sisters, Birds, Four Winds) to provide context for the introduction of climate science information, existing or proposed adaptation strategies, and existing or proposed collaboration with federal and state agencies (St. Regis Mohawk Tribe 2013). Another important component is the education of its membership on climate change within this cultural context. The resulting plan is an adaptive effort that begins the specific work of climate change adaptation based on culturally appropriate understandings.

The Grand Portage Band of Lake Superior Chippewa in Minnesota is currently participating in a multi-agency research project (Grand Portage Indian Reservation Project) related to moose and moose habitat in Minnesota. For the Tribe, interest in this project is based on the importance moose play in cultural subsistence and how climate change may impact this way of life (Grand Portage Band of Lake Superior Chippewa 2012). This example of Tribal adaptation differs from the previous example because it focuses on a specific species and its habitat. It also differs because at this point, research is focused on the development of climate mitigation strategies with specific trigger points for management of the target species (moose).[1]

Another ongoing initiative led by the College of Menominee Nation has involved relationship-building site visits to several Tribes within the Northeast and Midwest and giving presentations to inter-tribal organizations such as the Native American Fish and Wildlife, and the United Southern and Eastern Tribes (USET). These efforts are aimed at building culturally

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[1] Dr. Seth Moore, “”Shifting Seasons Summit. October 2014. Keshena WI

appropriate relationships to better understand Tribal needs across the region, and to help Tribes communicate those needs to federal, state, academic partners working at the regional level. Results of these efforts are expected to identify climate change impacts unique to individual Tribes, and help guide solutions for adaptation and mitigation that are relevant for a number of locally-based climate scenarios targeting Tribes and Tribal lands. Anticipated products include a website providing guidelines for Tribal-Federal interactions and will be linked the NE CSC website.

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