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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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 carolinenis*	**↑↑**
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]

[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

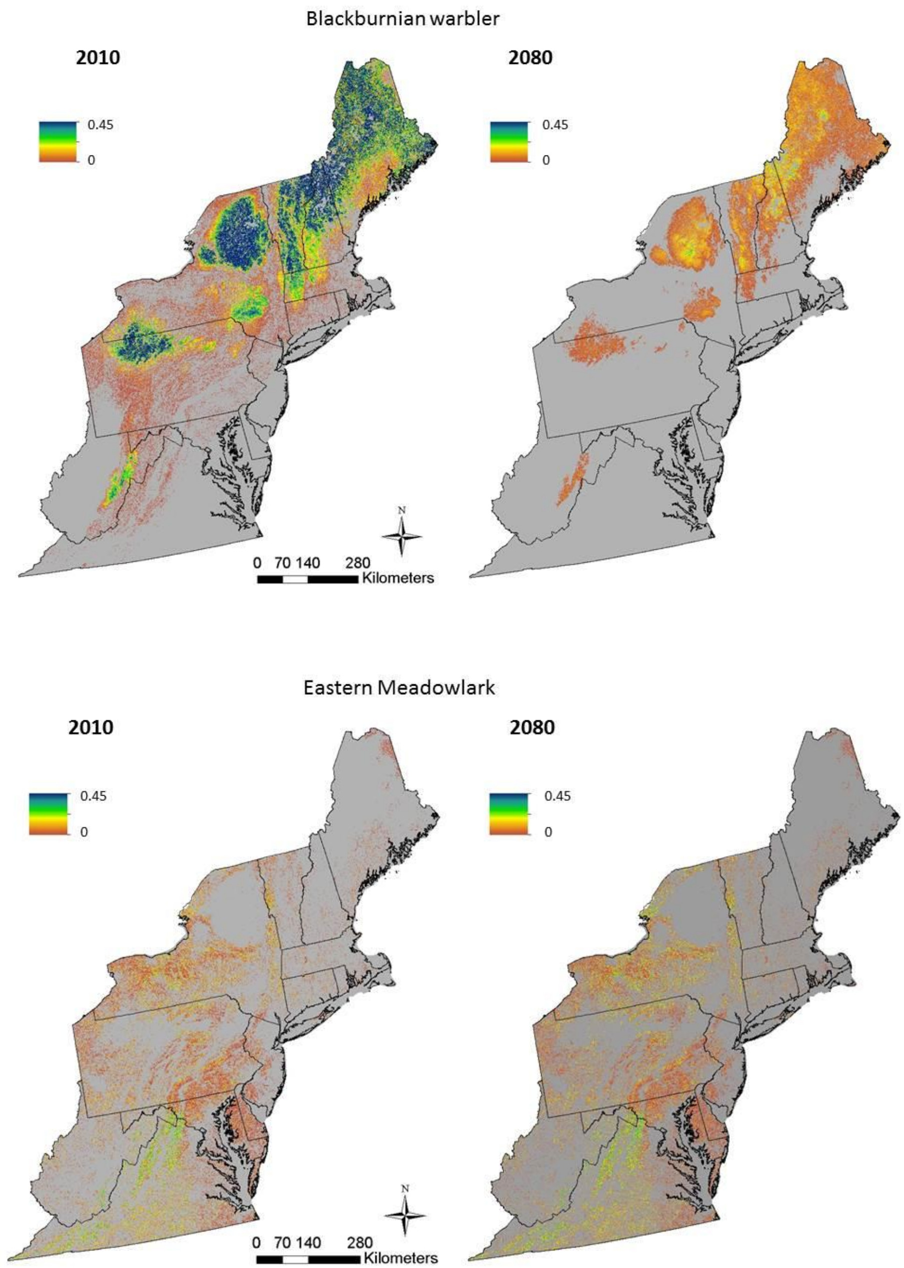

Figure 1: Change in Landscape Capability (LC) from 2010 to 2080 for the Blackburnian warbler and the eastern meadowlark. The Blackburnian warbler is predicted to have a 71% reduction in LC in the Northeast by 2080. In contrast, the eastern meadowlark is expected to maintain throughout most of its Northeastern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