ATTACHMENT 4

Massachusetts Vulnerability Assessment 2016
Species of Greatest Conservation Need
Animal Species Profiles

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Preface

These species profiles were produced for the 2016 Massachusetts Rapid Assessment Protocol of their Species of Greatest Conservation Need (SGCN). Each profile summarizes what is known about specific SGCN species responses to climate change to date and anticipated under future scenarios and highlights 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”, “drought”, “flood”, or “precipitation”. A substantial amount of information was available from the Massachusetts Climate Action Tool, a project produced by Scott Jackson, Michelle Staudinger, Steve DeStefano, Toni Lyn Morelli, and others. In addition, Staudinger et al.’s 2015 Integrating Climate Change into Northeast and Midwest State Wildlife Action Plans was an important resource for these reports, including work by Colton Ellison and Stephen Jane. Funding for these reports was provided by Massachusetts Department of Fish and Wildlife and the Department of Interior Northeast Climate Science Center.
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AMPHIBIANS

Blue-spotted salamander

Scientific Name: Ambystoma laterale

Species Stressors: Changes in hydrology, Development and habitat loss, Pests and diseases, Precipitation changes, Temperature change, Terrestrial connectivity loss

Background: The blue-spotted salamander is primarily found from Quebec, Newfoundland, and the Maritime provinces to northern New Jersey, and west to Iowa, and Manitoba. This species is often considered in conjunction with the Jefferson salamander as a “complex” that is composed of each of the species in a diploid, bisexual form, and two all-female triploid species (A. platineum and A. tremblayi) that are thought to have arisen through ancient hybridization between Jefferson and blue-spotted salamanders (Phillips et al. 1997). Diploid blue-spotted salamanders are one of the rarest amphibians in the northeastern US, and are only known to occur at the eastern tip of Long Island, in Hockomock Swamp in Massachusetts, and the Quinebaug River watershed in eastern Connecticut (Ryan and Calhoun 2014). The blue-spotted salamander breeds in the early spring, typically in pools that are free of fishes (Ryan and Calhoun 2014), but are deep enough to maintain water levels throughout their breeding period (Donner et al. 2015). The eggs typically take 3-4 weeks to hatch, and juveniles spend 2-3 months in the breeding pools feeding on aquatic insects, and zooplankton (Natural Heritage and Endangered Species Program 2015a). After depositing their eggs, adults disperse up to a few hundred meters (Ryan and Calhoun 2014) into the upland habitat surrounding their breeding ponds, where they typically spend up to 11 months each year (Homan et al. 2007). Thick leaf litter, abundant coarse woody debris, closed canopy cover, rodent tunnels, and loose soils are important in upland habitats (Natural Heritage and Endangered Species Program 2015a). Adults show high site fidelity to breeding areas (Ryan and Calhoun 2014), and may live up to 10 years (Natural Heritage and Endangered Species Program 2015a).

The blue-spotted salamander is listed as a species of special concern in Massachusetts. The primary threats to this species are habitat loss, infectious disease, road mortality and degradation of habitats through contaminants, fragmentation, and commercial silviculture (Natural Heritage and Endangered Species Program 2015a).

Climate Impacts: Climate change is likely to affect the quantity and quality of habitat available for this species. Climate projections for the Northeast suggest that higher temperatures and a longer growing season will lead to increases in evapotranspiration (evaporation and transpiration from plants) (Huntington et al. 2009). These changes are expected to increase the frequency of short-term drought conditions, which is likely to reduce the amount of time vernal pools hold water (hydroperiod). Shortened hydroperiod can lead to significant loss of habitats, changes in community composition of pools, and significant changes in prey abundance, composition, and diversity (Brooks 2009). Loss of breeding pools is also likely to reduce connectivity due to larger distances between pools (Brooks 2009). For many amphibians, inadequate precipitation can also result in reduced activity and mobility in adults, difficulty in evading predators, reduced food supplies, and lethal desiccation (Carey and Alexander 2003, Yiming et al. 2013). This could be important for Jefferson salamanders that require rainfall for dispersal movements. Maintaining connectivity between individual breeding populations is thought to be important for the conservation of blue-spotted salamanders (Ryan and Calhoun 2014).
Climate change may also influence the timing of life history events for this species. The timing of movement to the breeding ponds is determined by precipitation and temperature factors for blue-spotted salamanders; this species has exhibited shifts in breeding phenology in response to changes in air and water temperature, with peak abundance occurring on average 11.7 days earlier in the 2000s compared to the 1990s (Donner et al. 2015).

Changes in water and ambient temperatures associated with climate change might also affect blue-spotted salamanders. For instance, higher water temperature is thought to increase fertilization rates between the triploid species to produce tetraploids, and between the tetraploids to produce pentaploids (Phillips et al. 1997). An increase in the polyploid mixture in the population can in turn influence population dynamics for this species through skewed sex ratios, and lower fecundity and survivorship for polyploid individuals (Homan et al. 2007). However, it is also expected that overall warming trends will accelerate larval development, and thereby reduce exposure to contaminants for many amphibians (Yiming et al. 2013).

Finally, there is also some evidence that decreases in precipitation related to climate change might make amphibians more susceptible to infectious diseases. For instance, a number of studies have proposed that drought and/or changes in temperature regimes can exacerbate outbreaks of chytridiomycosis an infectious disease that is threatening amphibians globally (Yiming et al. 2013).
Eastern spadefoot

Scientific Name: Scaphiopus holbrookii

Species Stressors: Changes in hydrology, Development and habitat loss, Pests and diseases, Precipitation changes, Temperature change, Terrestrial connectivity loss

Background: The eastern spadefoot toad can be found along the Atlantic coastal plain from Massachusetts to southern Florida, and westward into southeastern Missouri. New England populations typically inhabit river valleys, pitch pine barrens, or coastal areas with sandy, well drained soils, and prefer areas with sparse shrub growth or open forest (DeGraaf and Rudis 1986, Timm et al. 2014, Ryan et al. 2015). Spadefoot toads breed in isolated, ephemeral ponds and exhibit explosive breeding in previously dried ponds immediately after heavy rainfall (Greenberg and Tanner 2004). They are opportunistic and sporadic breeders from late March until August in New England, but can forgo breeding for many consecutive years (Ryan et al. 2015). The larvae are adapted for very rapid development, given their highly ephemeral breeding pools (Greenberg and Tanner 2004). After breeding, toads move considerable distances away from wetlands (3-449m) (Timm et al. 2014). Adults spend the majority of their time in upland areas surrounding their ephemeral breeding ponds, in underground burrows that they dig, and emerge only occasionally on wet nights to feed (Ryan et al. 2015). The larvae are planktonic in early life then become carnivorous or cannibalistic; adults consume a wide variety of small invertebrates, as well as some other small amphibians (Natural Heritage and Endangered Species Program 2015b).

The spadefoot toad is one of the rarest amphibians in the northeastern US (Ryan et al. 2015), and are listed as threatened in Massachusetts. Historic records suggest that they used to be widespread and abundant in the state (Natural Heritage and Endangered Species Program 2015b); however they have exhibited precipitous population declines, largely due to habitat loss (Timm et al. 2014). Other threats to this species include significant road mortality, and vulnerability to pesticides (Natural Heritage and Endangered Species Program 2015b).

Climate Impacts: Climate change is likely to affect the quantity and quality of habitat available for the eastern spadefoot toad. Climate projections for the Northeast suggest that higher temperatures and a longer growing season will lead to increases in evapotranspiration (evaporation and transpiration from plants) (Huntington et al. 2009). These changes are expected to increase the frequency of short-term drought conditions, and reduce the amount of time vernal pools hold water (hydroperiod). Shortened hydroperiod can lead to significant loss of habitats, changes in community composition of pools, and significant changes in prey abundance, composition, and diversity (Brooks 2009). The eastern spadefoot toad is adapted to specifically occupy ephemeral breeding pools, and can forgo breeding for many years; however, spadefoot toads can exhibit almost complete reproductive failure in years when individual wetlands dry before the larvae are able to finish developing completely (Timm et al. 2014). Yet, larval growth rate of spadefoot toads increases with greater water temperatures (up to 29°C) (Greenberg & Tanner 2004), so increases in water temperature may also help larvae to develop more rapidly during particularly warm periods before pools dry. Loss of breeding pools is also likely to reduce connectivity due to larger distances between pools (Brooks 2009); maintaining connectivity between individual breeding populations is likely to be important for the conservation of this species (Timm et al. 2014). For many amphibians, inadequate precipitation can also result in reduced activity and mobility in adults, difficulty in evading predators, reduced food supplies, and lethal desiccation (Carey and Alexander 2003,

There is also some evidence that decreases in precipitation related to climate change might make amphibians more susceptible to infectious diseases. For instance, mass mortality of western toad (Bufo boreas) embryos is believed to be caused in part by low precipitation in the Pacific Northwest that resulted in shallower breeding pools and amplified exposure to ultraviolet B radiation, which in turn increased susceptibility to infection with the Saprolegnia ferax fungus (Carey and Alexander 2003). For instance, a number of studies have proposed that drought and/or changes in temperature regimes can exacerbate outbreaks of chytridiomycosis an infectious disease that is threatening amphibians globally (Yiming et al. 2013).
Jefferson’s salamander

**Scientific Name:** Ambystoma jeffersonianum

**Species Stressors:** Changes in hydrology, Development and habitat loss, Invasive plants and animals, Pests and diseases, Precipitation changes, Temperature change, Terrestrial connectivity loss

**Background:** The Jefferson salamander can be found from southern Ontario through western New England and New York, south to West Virginia, and as far west as eastern Illinois. The Jefferson salamander is often considered in conjunction with the blue-spotted salamander as a “complex” that is composed of each of the species in a diploid, bisexual form, and two all-female “unisex” triploid species (*A. platineum* and *A. tremblayi*) that are thought to have arisen through hybridization between Jefferson and Blue-spotted salamanders (Phillips et al. 1997). In Massachusetts, this species is primarily found in the western portion of the state, and polyploid individuals are believed to be present in most Massachusetts populations (Natural Heritage and Endangered Species Program 2015c). They breed in ponds with no fish and high surrounding canopy cover (Peterman et al. 2013), and in Massachusetts appear to prefer isolated vernal pools and shrubby sites located in mature deciduous or mixed forests at higher-elevation sites that are nestled between ridges (Natural Heritage and Endangered Species Program 2015c). They also prefer large deep pools that are at least 0.2 acres, and 3 feet deep (Natural Heritage and Endangered Species Program 2015c). Eggs are deposited from February to April, often beneath ice; eggs take 13-45 days to hatch, and the larval period is 56 to 125 days (DeGraaf et al. 1998). The larvae consume mosquito larvae and zooplankton (Natural Heritage and Endangered Species Program 2015c). After metamorphosis, Jefferson salamanders can disperse large distances (up to 1600 m) a from breeding areas, where they typically remain underground (Peterman et al. 2013).

Major threats to the Jefferson salamander include emerging infectious disease, road mortality, introduction of fishes to breeding ponds, habitat loss, hydrological changes in wetland habitats, and habitat fragmentation and degradation (Jefferson Salamander Recovery Team 2010, Natural Heritage and Endangered Species Program 2015c).

**Climate Impacts:** Climate change is likely to affect the quantity and quality of habitat available for this species, and impact reproduction. Climate projections for the Northeast suggest that higher temperatures and a longer growing season will lead to increases in evapotranspiration (evaporation and transpiration from plants) (Huntington et al. 2009). These changes are expected to increase the frequency of short-term drought conditions, and reduce the amount of time vernal pools hold water (hydroperiod). Jefferson salamanders exhibit significant mortality when ponds dry completely during breeding or before larvae finish metamorphosis (Jefferson Salamander Recovery Team 2010). Shortened hydroperiod can also lead to significant loss of habitats, changes in community composition of pools, and alteration in prey abundance, composition, and diversity (Brooks 2009). Loss of breeding pools is also likely to reduce connectivity due to larger distances between pools (Brooks 2009). Jefferson salamanders can also exhibit significant mortality when ponds freeze during breeding, or before larvae finish metamorphosis (Jefferson Salamander Recovery Team 2010), so overall increases in temperatures may benefit this species in this regard.

Climate change is also expected to influence the timing of life history events, and reproductive success of the Jefferson salamander (Jefferson Salamander Recovery Team 2010). For one, their dispersal occurs in a narrow range of temperatures, during precipitation (Natural Heritage and Endangered Species Program 2015c). Moreover, the similar blue-spotted salamander, and the hybrid forms of these species have
exhibited shifts in breeding phenology in response to changes in air and water temperature, with peak abundance occurring on average 11.7 days earlier in the 2000s compared to the 1990s (Donner et al. 2015).

Changes in water and ambient temperatures associated with climate change might also affect Jefferson salamanders. Fertilization rates between the triploid species to produce tetraploids, and between the tetraploids to produce pentaploids increase with water temperature (Phillips et al. 1997). An increase in the polyploid mixture in the population can in turn influence population dynamics for this species through skewed sex ratios, and lower fecundity and survivorship for polyploid individuals (Homan et al. 2007). However, it is also expected that overall warming trends will accelerate larval development, and thereby reduce exposure to contaminants for many amphibians (Yiming et al. 2013). For many amphibians, inadequate precipitation can also result in reduced activity and mobility in adults, difficulty in evading predators, reduced food supplies, and lethal desiccation (Carey and Alexander 2003, Yiming et al. 2013). This could be important for Jefferson salamanders that require periods of rainfall for their long dispersal movements.

Finally, there is also some evidence that decreases in precipitation related to climate change might make amphibians more susceptible to infectious diseases. For instance, a number of studies have proposed that drought and/or changes in temperature regimes can exacerbate outbreaks of chytridiomycosis an infectious disease that is threatening amphibians globally (Yiming et al. 2013).
**Marbled Salamander**

**Scientific name:** Ambystoma opacum

**Species stressors:** Temperature changes, Precipitation changes, Changes in hydrology, Changes in winter, Storms and floods, Change in timing of seasons, Development and habitat loss, Terrestrial connectivity loss

**Background:** Marbled salamanders are distributed across the eastern US from New Hampshire south to northern Florida, and west to the Lake Michigan region in the north and Texas in the south (Hammerson 2004). The species generally inhabits deciduous forest and prairie and is absent from much of the Appalachian Mountains (Hammerson 2004, Fairman et al. 2013). In Massachusetts, it is state-listed as Threatened, present at relatively low abundances at least partially due to being at the extreme northern limit of the range (Charney et al. 2015). Marbled salamanders breed in temporary, fishless ponds, commonly referred to as vernal pools (Fairman et al. 2013). They breed in the fall, depositing eggs while ponds are still dry (Herstoff and Urban 2014). Eggs will hatch if ponds subsequently fill with water and larvae overwinter under ice cover (Gamble et al. 2009, Herstoff and Urban 2014). Adults are terrestrial and retreat to higher ground surrounding breeding ponds for most of the year (Charney et al. 2015). Marbled salamanders exhibit a high degree of philopatry, meaning they return to their natal ponds to breed (Gamble et al. 2009). However, a small percentage will disperse to different ponds, creating connections between different pond populations. Dispersal appears to be more frequent in contiguous forest habitats, and increasing development leads to isolation of populations (Greenwald et al. 2009).

**Climate Impacts:** The species is at the northern terminus of its range in Massachusetts and it is likely that a warming climate will result in expansion of the range northward (Herstoff and Urban 2014). High winter pond temperatures significantly increase overwinter survival of larvae in southern New Hampshire. In addition, larvae are absent from ponds that freeze solid, suggesting that warmer temperatures could enhance available winter habitat as well as overwinter survival (Herstoff and Urban 2014). However, climate projections for the Northeast suggest that higher temperatures and a longer growing season will lead to increases in evaporation and evapotranspiration (Fan et al. 2014). These changes are expected to increase the frequency of short-term drought conditions, which is likely to lead to reduced vernal pool hydroperiod. Marbled salamander breeding success is associated with vernal pools that become dry in mid-summer (McGarigal 2008). Breeding success is reduced in pools that dry up too early in the spring or stay filled with water into the late summer. As such, higher temperatures have the potential to reduce reproductive success, and thus the population size and distribution of marbled salamanders in Massachusetts.
Northern leopard frog

Scientific Name: Lithobates pipiens

Species Stressors: Changes in hydrology, Changes in winter, Development and habitat loss, Invasive plants and animals, Pests and diseases, Precipitation changes, Storms and floods, Temperature change, Terrestrial connectivity loss

Background: The northern leopard frog is found across much of southern and central Canada and the Northern US, and historically was one of the most abundant wetland frogs (Johnson et al. 2011). They are currently found in at least 8 counties in Massachusetts, where they are near the southern edge of their range in New England (Natural Heritage and Endangered Species Program 2015d). Northern leopard frogs breed in early to mid-April in semi-permanent or permanent shallow waters that are characterized by a significant amount of emergent vegetation and no fish, such as still backwaters of streams, beaver ponds, springs, shrub swamps, and marshes (Species at Risk Committee 2013, Natural Heritage and Endangered Species Program 2015d). They are associated with larger wetlands (Johnson et al. 2011). Eggs take 13 to 20 days to hatch, and the tadpole stage lasts 9 to 12 weeks (DeGraaf and Rudis 1986). Northern leopard frogs overwinter in deeper permanent water bodies that do not freeze (Species at Risk Committee 2013). They use upland fields, grasslands, wet meadows, shrub swamps and marshes throughout the summer (Natural Heritage and Endangered Species Program 2015d), and consume a wide variety of prey including spiders, most insects, small crayfish, and snails (DeGraaf and Rudis 1986). Northern leopard frogs can disperse up to 8km into upland habitats, but require corridors of riparian habitat in order to migrate between breeding and upland habitats and only move on nights with warm temperatures and precipitation (Species at Risk Committee 2013, Natural Heritage and Endangered Species Program 2015d).

Threats to northern leopard frogs include habitat loss through urbanization, habitat fragmentation, increased predation by introduced bullfrogs and fishes, infectious disease, road mortality, contaminants, and exposure to ultraviolet radiation (Johnson et al. 2011, Species at Risk Committee 2013, Natural Heritage and Endangered Species Program 2015d).

Climate Impacts: Climate change is likely to affect the quantity and quality of habitat available for the northern leopard frog. Climate projections for the Northeast suggest that higher temperatures and a longer growing season will lead to increases in evapotranspiration (evaporation and transpiration from plants) (Huntington et al. 2009) that will reduce the amount of time vernal pools hold water (hydroperiod). Climate change is expected to reduce habitats that the northern leopard frog uses for breeding, foraging and overwintering, and result in population declines (Friggens et al. 2013). Shortened hydroperiod can also lead to changes in community composition of pools, and significant changes in prey abundance, composition, and diversity (Brooks 2009). Finally, decrease in summer precipitation and increased drought conditions are expected to reduce the persistence of smaller breeding wetlands and decrease connectivity (Species at Risk Committee 2013). Habitat fragmentation is likely a serious threat to this species, given its large dispersal distances (Species at Risk Committee 2013, Natural Heritage and Endangered Species Program 2015d).

Changes in temperature and precipitation regimes associated with climate change may also impact physiology and breeding of northern leopard frogs. Northern leopard frogs can experience reproductive failure during drought or late spring freezing (Species at Risk Committee 2013). Given their short lifespan
of 4-5 years in the wild (Natural Heritage and Endangered Species Program 2015d), most individuals would not likely outlive long term drought conditions. The northern leopard frog also exhibited a drastic reduction in occupancy following a historic flood in the Missouri floodplain, and relatively low subsequent re-colonization rates (Grant et al. 2015). For many amphibians, inadequate precipitation can also result in reduced activity and mobility in adults, difficulty in evading predators, reduced food supplies, and lethal desiccation (Carey and Alexander 2003, Yiming et al. 2013). Indeed, declines in northern leopard frog have been linked to increases in variability of precipitation and temperature (Johnson et al. 2011). However, some changes in climate could also benefit this species. Northern leopard frogs are not freeze-tolerant and do not hibernate in the winter (Species at Risk Committee 2013), so warmer overall winter temperatures could benefit them. Moreover, climate change may benefit northern leopard frogs through earlier ice melt and breeding initiation, and possibly even range expansion for northern populations (Species at Risk Committee 2013).

Finally, there is also some evidence that climate change might make amphibians more susceptible to infectious diseases. For instance, mass mortality of western toad (Bufo boreas) embryos is believed to be caused in part by low precipitation in the Pacific Northwest that resulted in shallower breeding pools and amplified exposure to ultraviolet B radiation, which in turn increased susceptibility to infection with the Saprolegnia ferax fungus (Carey and Alexander 2003). Chytridiomycosis is widespread in northern leopard frogs and increased exposure to UV radiation could be particularly problematic for them because they lay their eggs near the water surface (Species at Risk Committee 2013). Moreover, a number of studies have proposed that drought and/or changes in temperature regimes can exacerbate outbreaks of chytridiomycosis (Yiming et al. 2013).
References


Natural Heritage and Endangered Species Program. 2015a. Blue-spotted Salamander Ambystoma laterale.

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American bittern

Scientific Name: Botaurus lentiginosus

Species Stressors: Aquatic connectivity loss, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Sea level rise, Storms and floods, Temperature change

Background: The American bittern breeds from Newfoundland to British Columbia, and as far south as Virginia and central California. They winter in the east from coastal Maryland through the southeastern US and Gulf coast, and in the west from coastal areas of the Pacific Northwest through California, Mexico and Central America. They are very secretive and solitary animals, so their life history and ecology are poorly understood (Lowther et al. 2009). American bitterns primarily inhabit freshwater marshes, bogs and fens, and wet meadows with sluggish streams characterized by emergent grasses, sedges, bulrushes and cattails, but can occasionally be found in brackish wetlands (DeGraaf and Rudis 1986, Natural Heritage and Endangered Species Program 2015a). American bitterns are area sensitive, so primarily occupy larger wetlands and tend to avoid areas with exotic invasive species like reed canarygrass (Glisson et al. 2015a). They forage in emergent vegetation, water, and shallow bottoms for frogs, reptiles, shellfish and crustaceans, small fishes and mammals, insects, and spiders (DeGraaf and Rudis 1986). They nest on the ground or on a platform over water in dense vegetation (Lowther et al. 2009). Migratory behavior is poorly understood for American bittern, and some southern populations may remain sedentary (Lowther et al. 2009).

The American bittern has undergone significant population declines at the continental level (Lowther et al. 2009), and they are listed as endangered in Massachusetts (Natural Heritage and Endangered Species Program 2015a). Primary threats to this species appear to be habitat degradation and decline in prey species (particularly amphibians) from acid deposition, eutrophication, siltation, chemical contamination of wetlands, and human disturbance (Lowther et al. 2009).

Climate Impacts: Climate change may result in habitat loss and range shifts for the American bittern. The freshwater habitats that this species inhabits are very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydroperiod, depth and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014). American bittern are expected to lose up to 42% of their current habitat in the Prairie Pothole region by 2040 under climate change projections (Steen and Powell 2014). This impact of habitat loss and fragmentation may be heightened for this species, as small remaining patches of habitat may not be viable for breeding (Glisson et al. 2015a). The coastal habitats that this species occasionally occupies are also very vulnerable to climate change (Kundzewicz et al. 2007). For instance, climate change and sea level rise are likely to reduce habitat quality in brackish marshes by increasing salinity and shifting these habitats toward salt-tolerant vegetation (Woodrey et al. 2012). Some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with future rates of sea level rise (Galbraith et al. 2002). Finally, climate-mediated shifts in regional abundance could alter both the structure of wetland communities, and prey populations (Kelly and Condeso 2014). Projections under the most severe climate change scenarios also suggest that this species could experience an eastward range shift (Steen and Powell 2012).
American black duck

Scientific Name: Anas rubripes

Species Stressors: Change in timing of seasons, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Pests and diseases, Precipitation changes, Sea level rise, Storms and floods, Temperature change

Background: The American black duck summers in the eastern half of North America as far south as the Great Lakes and coastal North Carolina, winters in eastern North America as far north as the Great Lakes and the Maritime provinces of Canada, and is found year round in the Great Lakes region, New England, and the eastern Seaboard from the Canadian Maritimes to North Carolina. This species uses a variety of habitats in Massachusetts, including forested wetlands, rivers, and coastal salt marshes. American black ducks are considered partial-short distance migrants (Longcore et al. 2010), with migration behavior likely being influenced by weather, food abundance, and hunter disturbance (Devers and Collins 2011). In recent decades, black duck populations have declined around 1.5% per year, likely as a result of hunting, habitat loss, and interactions with other waterfowl species (Grandy, 1983; Barnes, 1989). Nesting activity in Massachusetts has decreased in recent years; however, salt marshes, mud flats and bays remain important feeding grounds during the winter (Morton et al. 1989, Heusmann et al. 2000) as these habitats support high densities of invertebrate and vertebrate food items.

Wetland and forested habitats throughout the US have experienced significant declines (Foster & Forest 2003) which has likely contributed to the decline of black ducks and other wetland-dependent waterfowl. Mallard populations have expanded as black ducks have decreased, and mallards occupy more black duck habitat than they have historically (Merendino et al. 1993). Black ducks are known to hybridize with mallards (Johnsgard 1967, Barnes 1989), with percent of hybrids ranging from 2-10% of the total black duck and mallard populations. Some evidence suggests that mallards may be competing with black ducks for habitat and resources, although this is still somewhat uncertain (Massachusetts Division of Fisheries and Wildlife 2015a). Other threats to American black duck populations include loss or degradation of habitat, especially salt marshes and wetlands, due to development, pollution, agricultural and recreational activities.

Climate Impacts: Climate change impacts many aspects of bird populations, including feeding patterns, migration timing and behavior, and breeding (Crick 2004, Carey 2009). There is evidence that some of these impacts may be affecting American black duck populations as their habitat distribution has shifted northward (Link et al. 2006; Brook et al. 2007). Increased temperatures are expected to worsen the existing threats to American black ducks, including the incidence of parasites and disease (Devers and Collins 2011). Rising sea level is expected to negatively impact coastal habitats, including salt marshes and mud flats, which would alter feeding and overwintering habitat of black ducks (Adaptation Subcommittee to the Governor’s Steering Committee on Climate Change 2010). Although American black ducks have already lost much of their optimal existing habitat, warming conditions are likely to shift their winter range northward, potentially increasing the size of suitable cold-season habitat by 25% by the year 2080 (National Audubon Society 2006).
American Oystercatcher

**Scientific Name:** Haematopus palliatus

**Species Stressors:** Change in timing of seasons, Changes in hydrology, Development and habitat loss, Sea level rise, Storms and floods

**Background:** On the east coast American oystercatchers breed as far north as Cape Cod, Massachusetts and as far south as Florida, Mexico, and even the Caribbean (Nol and Humphrey 1994). This species formerly occurred in the northeast as far north as Canada, but by the early 1900s their northern range became restricted to Virginia (Davis et al. 2001), likely due to hunting pressure and habitat loss. However, in recent decades, American oystercatchers have expanded throughout the northeast and have reestablished former habitat, with breeding pairs observed in Maine and Nova (Mawhinney et al. 1999, Brown et al. 2005). American oystercatchers are listed as “Species of High Concern” in the U.S. Shorebird Conservation Plan (Brown et al. 2001).

In Massachusetts, American oystercatchers are found along salt marshes and sandy beaches on small coastal islands, and feed around intertidal areas and mud flats (Mass Audubon n.d.). They use their long, powerful, blade-like bills to feed on mussels and other bivalves (Bull and Ferrand 1995), and can pry open bivalves and other hard-bodies invertebrates such as barnacles, snails, and various worms. American oystercatchers are among the first migrant birds to appear on the beaches in Massachusetts in the spring, usually arriving around mid-March. Oystercatchers nest in shallow depressions on sand or dry marsh grass, and clutch sizes are usually 2-5 eggs (Mass Audubon n.d.). They have low survival and productivity, and are extremely vulnerable to predation, as well as nest overwash from storm surge and severe weather (Davis et al. 2001).

**Climate Impacts:** Climate change will likely have negative impacts on American oystercatcher populations. Extreme high tides are a prominent threat to nest success (Davis et al. 2001, Denmon et al. 2013), and as sea levels rise and storm surge increases, overwash will continue to be a major factor influencing early life stages (The National Wildlife Federation and Manomet Center for Conservation Sciences 2014). Loss of breeding, wintering, and migration habitats are recognized as threats to oystercatcher populations, as well as their high degree of habitat specialization (Galbraith et al. 2014). Tidal marsh and mud flat habitats will likely experience declines and further fragmentation under future climate change (Whitman et al. 2013). There is evidence that oystercatchers are increasingly using inland river habitat for nesting, which may be an adaptive response to changing climatic conditions (Mcgowan et al. 2005).
American woodcock

**Scientific Name:** Scolopax minor

**Species Stressors:** Temperature changes, Precipitation changes, Storms and floods, Change in timing of seasons, Development and habitat loss

**Background:** The American woodcock is a migratory species that winters along the Atlantic and Gulf coastal plains from the Carolinas to Texas and uses temperate forest habitat for breeding in Massachusetts and elsewhere in the region (Galbraith et al. 2014). Within temperate regions, it is dependent on shrub-dominated and early successional habitats, where the younger forest's dense vegetation protects them from predators and allows them to reach higher population densities than in more mature forest (Mass Audubon 2015a). The replacement of this habitat type with mid-aged to mature forest over the past several decades has resulted in population declines of woodcock in the eastern US (Dessecker and McAuley 2001, Masse et al. 2014). Although woodcock consume a variety of invertebrates, earthworms compose 30-100% of their diet and woodcock distributions have been found to be associated with the availability of earthworms across the landscape (Cade 1985, Masse et al. 2014). Because earthworms are most available when soil moisture is between 15 to 80%, woodcock are also associated with moist, rich soil conditions (Cade 1985, Kelley et al. 2008, Williamson 2010).

**Climate Impacts:** Studies have observed phenological (seasonal timing) changes in some aspects of American woodcock life history. Changes include earlier date of spring arrival in Massachusetts and New York (Butler 2003), earlier date of first arrival in Maine (Wilson et al. 2000), and earlier date of their breeding call in Wisconsin (Bradley et al. 1999). Some of these authors have attributed these changes to the effects of climate change. Butler (2003) noted that, taken to the extreme, such changes could result in some birds remaining at breeding locations year-round.

One modeling study determined that although habitat is an important predictor of woodcock population numbers, the date of the start of the growing season is the strongest predictor, with a later date corresponding to lower numbers of American woodcock (Thogmartin et al. 2007). The authors speculated that this is likely related to the impact that growing season has on the availability of earthworms, a primary food source for woodcock. Based on this variable alone, an earlier growing season as a result of climate change could potentially favor higher woodcock abundance in Massachusetts, but this would have to be accompanied by changes in forest habitat from mid- to older age to early or younger forest. However, warmer temperatures, lengthened growing season, and increased evapotranspiration are all anticipated to result in increased short-term drought frequency in the Northeast (Fan et al. 2014). Such droughts are defined by soil moisture content below 10% by volume. Such conditions may make earthworms less available to woodcock, which could potentially negatively impact populations. Modeling conducted by the University of Massachusetts suggests that future climate scenarios should have a negative, though relatively small, impact on woodcock populations in the Northeast (DeLuca and McGarigal 2014).
**Black-crowned night-heron**

**Scientific Name:** Nycticorax nycticorax

**Species Stressors:** Changes in hydrology, Development and habitat loss, Precipitation changes, Sea level rise, Storms and floods, Temperature change

**Background:** Black-crowned night herons breed from Quebec and westward into Oregon, and in the eastern US from New Brunswick to the Gulf coast, though not in the Appalachians. They are highly varied in their breeding and wintering habitat use, and can be found in freshwater, brackish and salt water marshes, tidal flats, ponds and creeks (DeGraaf and Rudis 1986, Natural Heritage and Endangered Species Program 2015b). Black-crowned night-herons historically occurred throughout Massachusetts, but after severe population losses from pesticide poisoning, are currently only common near the coast (Natural Heritage and Endangered Species Program 2015b). They forage at dusk, dawn, and nocturnally in shallow water, mud flats and even in upland areas and consume insects, fishes, crustaceans, mollusks, reptiles and amphibians, and occasionally young mammals and birds (DeGraaf and Rudis 1986). Black-crowned night-herons nest colonially in trees and shrubs, typically in woody vegetation, but can also construct floating nests (Natural Heritage and Endangered Species Program 2015b). This species winters along the Atlantic coast from Massachusetts to Texas, along the Mississippi River, and in portions of Mexico, California and the southwestern US in habitats similar to those in which they breed. They are highly varied in migratory pattern, ranging from sedentary to long-distance migrants (Hothem et al. 2010).

Population trends for black-crowned night herons are highly variable across their range; at a continental level they are increasing, however, they have been in decline in Massachusetts since the late 19th century (Hothem et al. 2010, Natural Heritage and Endangered Species Program 2015b). They are threatened by habitat loss, and in the past, contaminants have reduced reproductive success (Hothem et al. 2010).

**Climate Impacts:** Climate change may result in habitat loss for black-crowned night herons. Sea level rise and altered hydrology will adversely impact coastal marsh and wetland habitats, and impair nesting and foraging activities for many wetland birds (Adaptation Subcommittee to the Governor’s Steering Committee on Climate Change 2010, Manomet Center for Conservation Science and Massachusetts Division of Fisheries and Wildlife 2010). Some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with future rates of sea level rise (Galbraith et al. 2002). The freshwater habitats that this species occupies are also very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydroperiod, depth and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014). Finally, climate-mediated shifts in regional abundance could alter both the structure of wetland communities, and prey populations (Kelly and Condeso 2014). However, the tidal flats that these species also use are likely to greatly increase in extent (The National Wildlife Federation and Manomet Center for Conservation Sciences 2014).

Climate-change induced changes in precipitation and storm intensity may make both breeding and wintering habitats less suitable for black-crowned night-herons (Hothem et al. 2010). For instance, periods with greater than average winter rainfall and spring rainfall were both correlated with reduced abundance of black-crowned night-herons in central California (Kelly and Condeso 2014). In addition, spring storms are a significant cause of chick and egg mortality for black-crowned night-herons in the northeast (Hothem et al. 2010), so the increased severity and frequency of large storm events expected
under climate change (The National Wildlife Federation and Manomet Center for Conservation Sciences 2014) could adversely affect this species’ reproductive success.
**Blackpoll warbler**

**Scientific Name:** Setophaga striata

**Species Stressors:** Precipitation changes, Change in the timing of seasons, Temperature change

**Background:** Blackpoll warblers breed in the boreal forests of North America and winter in South America (Ralston and Kirchman 2013). Each fall, blackpolls from throughout the North American range migrate eastward to congregate at staging areas along the northeast, including Massachusetts (Ralston and Kirchman 2013, Boal 2014). These birds will then fly directly from these locations as far as 3,500 km over the open ocean to wintering grounds in South America, making stops in the Caribbean islands to rest and feed (Boal 2014, DeLuca et al. 2015). In total, some individuals will migrate 8,000 km, making this the longest migration of any North American warbler (Boal 2014). Though these birds are common migrants in Massachusetts, they are at the extreme southern limit of their breeding range in the state (Massachusetts Audubon 2015a). Currently, blackpoll warblers breed only in the montane spruce-fir forest surrounding the summit of Mount Greylock in the west of the state (Massachusetts Audubon 2015a).

**Climate Impacts:** Because they are dependent upon limited montane spruce-fir forest habitat for breeding, climate change is likely to greatly impact breeding populations within Massachusetts. This forest type is expected to shift upwards in elevation (Beckage et al. 2008, Rodenhouse et al. 2008). Some modeling studies have projected breeding populations of blackpoll warblers will be greatly reduced or extirpated from New York, Vermont, and New Hampshire by 2080, depending on the climate scenario used (Ralston and Kirchman 2013). This implies complete loss from the state of Massachusetts.

Although northward shifts in distribution are anticipated (Ralston and Kirchman 2013), it is unclear how this would impact migration routes. The species does migrate through locations as far south as Cape Hatteras, North Carolina (Mcnair et al. 2015), so it seems likely that Massachusetts will remain within the migration corridor. Though changes in the timing of migration have been observed for many short- and medium-distance migrants (Butler 2003, Miller-Rushing et al. 2008), long-distance migrants such as blackpoll warblers do not appear to be changing migration timing (Miller-Rushing et al. 2008). This raises concerns that as phenological (seasonal timing) changes occur for plant and insect species, blackpoll warblers may be exposed to significantly different environments along migration routes than they have in the past (Miller-Rushing et al. 2008).
Blue-winged teal

Scientific Name: Anas discors

Species Stressors: Temperature changes, Precipitation changes, Changes in hydrology, Change in timing of seasons

Background: Massachusetts is at the eastern edge of the blue-winged teal's distribution. The historical status of blue-winged teal in Massachusetts is unclear, but the current breeding population is relatively small and dispersed (Mass Audubon 2015b). The species is, however, common during spring and fall migrations between wintering and breeding ground (DeGraaf and Yamasaki 2001). Although blue-winged teal breed from coast to coast, the distributional center is located in the Prairie Pothole Region of the Northern Great Plains. This is an area characterized by a high density of shallow wetlands that produces 50-80% of the continent’s ducks (Sorenson et al. 1998). The blue-winged teal appears to have a greater sensitivity to cold than most duck species and winters from the Gulf coast south through Mexico, Central America, and South America (Johnsgard 1975a).

Climate Impacts: Because the Prairie Pothole Region produces a large proportion of the continent’s ducks, events in this region can greatly impact entire populations. 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). Climate models project increased drought conditions for the region, resulting in northward shifts in the breeding distribution, with the potential for dramatic reductions in overall duck populations (Sorenson et al. 1998). In addition, loss of pothole wetlands through drying can concentrate predators, which would have a greater impact on nesting ducks in the remaining potholes. Dramatically reduced duck populations could potentially reduce the number of blue-winged teal that migrate through the state of Massachusetts.

Though the local breeding population of blue-winged teal is small, climate change has the potential to impact this population in many ways. Climate models generally predict increased short term drought conditions, reduced summer stream flows, and increased duration of low summer flows in the northeastern US (Fan et al. 2014). Typical responses to drought conditions in ducks include increased frequency of non-breeding, decreased clutch sizes, shortened breeding season, decreased frequency of renesting, and other responses that depress production (Davies and Cooke 1983, Krapu et al. 1983, Cowardin et al. 1985, Sorenson et al. 1998). Changes in migration timing are likely, and have already been documented for blue-winged teal in Massachusetts and New York (Butler 2003). Modeling by the US Forest Service predicts the loss of breeding populations from the state of Massachusetts, along with a range-wide decrease in both distribution and abundance (Matthews et al. 2004).
Canada warbler

Scientific Name: Wilsonia canadensis

Species Stressors: Temperature changes, Change in timing of seasons, Development and habitat loss

Background: The Canada warbler breeds from the southern boreal forests of Canada south into the Great Lakes region and the northeast US, extending farther south along the Appalachian Mountains (Becker et al. 2012). The Canada warbler is a long-distance migrant that winters in South America (Marra et al. 2005, Hallworth et al. 2008a). Several studies associate Canada warblers with young, regenerating forest 6-20 years post-harvest, with disturbances (such as tree falls, insect outbreaks), and with forested wetlands; they appear to be dependent upon well-developed understory shrub layers typically found in these forest types (Hallworth et al. 2008b, Becker et al. 2012). Highest natural densities are found in swamps and riparian forests.

In Massachusetts, they appear to be strongly associated with wetlands having a dense understory mixed with significant coniferous growth (Mass Audubon 2015c). As a result, though found throughout the state, they are most common in the western part of Massachusetts. Canada warbler populations in Massachusetts have been steadily declining for the past several decades (Becker et al. 2012, Mass Audubon 2015c) in Massachusetts and the rest of its range. Causes of declines are unknown, but possibilities include the loss of forested wetland, maturation of forests, increased urban development, and reduced understory vegetation as a result of deer herbivory.

Climate Impacts: As temperatures increase, spring migration timings for many species of birds have shifted earlier (Butler 2003). Among 25 species of short-distance migrants (those wintering in the southern US), arrival dates averaged 13 days earlier in the period from 1951-1993 than in the period from 1903-1950. However, many long-distance migrants such as Canada warblers have not changed their migration timings (Butler 2003, Miller-Rushing et al. 2008) even though many spring events on breeding grounds, such as flowering, leaf out, and insect emergence, are occurring earlier. This raises concerns that timing of migrations may become mismatched to historical environmental conditions that Canada warblers have adapted to.

Modeling conducted by the US Forest Service predicts a northward range shift for this species, with suitable habitat restricted to the Berkshires over the next century (Matthews et al. 2007).
**Common Gallinule**

**Scientific Name:** Gallinula galeata

**Species Stressors:** Changes in hydrology, Changes in winter, Development and habitat loss, Invasive plants and animals, Precipitation changes, Sea level rise, Storms and floods, Temperature change

**Background:** The common gallinule breeds throughout much of the eastern US and in dispersed locations throughout the West and Midwest. Most breeding activity in New England is close to the coast. This species winters in the southeastern US, Mexico, Central America, and the Caribbean. In the northeast, the common gallinule breeds mainly in permanent deep, non-tidal marshes or in freshwater or slightly brackish tidal marshes that are characterized by tall emergent vegetation interspersed with pools and channels, or mudflats (Bannor and Kiviat 2002). They are associated with deeper water (1-3 ft) and patchy emergent vegetation, and are most active in open water, along the edge of emergent vegetation (DeGraaf and Rudis 1986, Monfils et al. 2014). The common gallinule will also occupy urban or artificial habitats such as storm-water retention ponds, mining settlement ponds, sewage lagoons, and diked impoundments, and use of these habitats has expanded its range (Bannor and Kiviat 2002, Monfils et al. 2014). They typically nest within a meter of the water on beds of floating emergent vegetation, or on floating logs (Bannor and Kiviat 2002, Audubon Minnesota 2014). They have 1-2 clutches a year (DeGraaf and Rudis 1986). The common gallinule appears to exhibit strong site fidelity to breeding and wintering locations (Bannor and Kiviat 2002), and takes several years to colonize sites that are newly created by flooding or re-flooding (Monfils et al. 2014). This species consumes vegetation primarily including the seeds of grasses and sedges, leaves and stems of underwater vegetation, and berries, but can also consume snails, insects and worms (DeGraaf and Rudis 1986).

Threats to the common gallinule include mortality from collisions, reduced health from contaminant exposure, loss of wetlands, reduced wetland water depth, and replacement of native food sources and nesting substrate by exotic invasive plants (Bannor and Kiviat 2002, Audubon Minnesota 2014, Maine Dept. of Inland Fisheries and Wildlife 2015).

**Climate Impacts:** Climate change will likely result in habitat loss for the common gallinule, and may impact population growth. The freshwater marshes that this species occupies are very vulnerable to climate change (Kundzewicz et al. 2007) since changes in temperature and precipitation can influence wetland hydroperiod, depth, and size, and drought and storms can adversely affect water quality (Steen and Powell 2014). Sea level rise and altered hydrology are expected to adversely impact the coastal marsh and wetland habitats in which they also breed (Adaptation Subcommittee to the Governor’s Steering Committee on Climate Change 2010, Manomet Center for Conservation Science and Massachusetts Division of Fisheries and Wildlife 2010). Some coastal marshes may entirely disappear because accretion may not be able to keep pace with sea level rise (Galbraith et al. 2002). Climate change and sea level rise could also reduce habitat quality for species that occupies brackish marshes in coastal areas by increasing salinity, and shifting these habitats toward salt-tolerant vegetation (Woodrey et al. 2012). In addition, climate-mediated shifts in regional abundance could alter both the structure of wetland communities and prey populations (Kelly and Condeso 2014). The ability of the common gallinule to occupy manmade wetlands (Bannor and Kiviat 2002, Monfils et al. 2014) suggests some degree of adaptability to loss of natural habitats; there has been little study of reproductive success or health in manmade habitats however. Finally, changes in precipitation and storm intensity related to climate change may also affect population growth for common gallinules, as flash flooding and torrential rains cause nest failure (Maine Dept. of Inland Fisheries and Wildlife 2015).
Common tern

Scientific Name: Sterna hirundo

Species Stressors: Changes in the timing of seasons, Changes in hydrology, Changes in winter, Development and habitat loss, Precipitation changes, Sea level rise, Storms and floods, Temperature change

Background: In North America common terns breed throughout Canada as far west as the Northwest Territories, in isolated pockets of northern New England and the Maritimes, and along the Atlantic coast from South Carolina to Labrador. They are long distance migrants and winter along portions of the Gulf Coast in the US, much of the Pacific Coast of Mexico and Central America and as far south as coastal Argentina. Common terns nest in salt marshes, on barrier beaches, on marine islands, and occasionally in freshwater marshes; in the continental interior they typically breed on barren islands in lakes (Nisbet 2002). They arrive in Massachusetts in April and May and depart in July and August (Natural Heritage and Endangered Species Program 2015c). They make shallow plunge dives for food, and consume small fishes like American sand lance, Atlantic herring, sticklebacks and Pollock, as well as crustaceans, shrimp, amphipods, and insects (Nisbet 2002). Common terns nest in large colonies, and lay 1-4 eggs in small scrapes on the ground that incubate for 3 weeks; the chicks are semi-precocial but remain with the adults during the staging period (Natural Heritage and Endangered Species Program 2015c). They do not typically breed until they are 2-4 years of age, and survival to 4 years of age in Massachusetts is estimated at only 10% (Natural Heritage and Endangered Species Program 2015c). Common terns have highly variable productivity that is greatly affected by weather, floods, predators, energetic condition of birds upon arrival at the breeding grounds (Nisbet 2002).

Common terns are listed as a species of special concern in Massachusetts. Populations were severely reduced by the millinery trade and collection of eggs in the 1800s, and after some recovery, populations were again reduced in Massachusetts when herring and great black-back gulls displaced them from their breeding habitats (Natural Heritage and Endangered Species Program 2015c). Severe nest predation remains a large concern on the breeding grounds, as does hunting and trapping by humans on the wintering grounds (Nisbet 2002). In addition, common terns are one of the species most sensitive to toxic effects of DDE and PCB contamination, and these contaminants have impaired reproduction in many areas (Nisbet 2002).

Climate Impacts: Sea level rise and the more frequent and severe storms associated with climate change are already impacting common terns. Sea level rise and severe storms can reduce available nesting habitat, and increase flooding of nests, which in turn can cause drops in productive output, colony abandonment, and lower recruitment (Palestis and Hines 2015). Severe storms can also cause significant mortality of adults and long-lasting demographic consequences (Nisbet et al. 2010). Periods of heavy precipitation are also linked to chick mortality and reduced foraging ability in common terns (Nisbet 2002, Szostek and Becker 2015).

Increases in sea surface temperature associated with climate change can also affect common terns. Climate change can alter patterns of sea surface temperature and upwellings, which can affect composition and availability of small fishes (Fleming, Alyson et al. 2016). Data from provisioning studies in the Gulf of Maine also indicate that common terns have indeed been unable to find adequate forage fish to feed their chicks, and productivity rates have declined by 50-70% in recent years for both species (USFWS 2012). Poleward shifts of terns are expected due to changes in the distribution and abundance of
prey species (Brommer and Møller 2010). The fact that common terns are faring more poorly in the southern portion of their range suggests that this may already be occurring (Palestis and Hines 2015).

Global climate patterns such as the North Atlantic Oscillation Index (NAOI) are being altered by climate change (Visbeck et al. 2001). The NAOI can have significant effects on primary productivity and prey abundance in the habitats that common terns occupy during the wintering and migratory period (Szostek and Becker 2015). In turn, low primary productivity on the wintering grounds is associated with reduced survival and recruitment in common terns (Szostek and Becker 2015). Terns are also exhibiting earlier arrival dates at some colonies, presumably in response to changing environmental conditions (Ezard et al. 2007).
**Eastern meadowlark**

**Scientific Name:** Sturnella magna

**Species Stressors:** Changes in winter, Development and habitat loss, Precipitation changes, Temperature change, Terrestrial connectivity loss

**Background:** The eastern meadowlark breeds from New Brunswick and central Ontario to Florida and northern Mexico, and winters within this range as far north as southern New England and central New York. They breed primarily in native grasslands, pastures, and savannas with adequate grass and litter cover, and secondarily in human-made grasslands such as hay and alfalfa fields, orchards, golf courses, reclaimed strip mines, and airports, shrubby overgrown fields (Wiens and Rotenberry 1981, Jaster et al. 2012). They winter in similar habitats, and also in marshes, and are limited in wintering range by temperatures (Jaster et al. 2012). The eastern meadowlark is sedentary across most of range, but northern breeders make short distance migrations, and some individuals have been detected migrating upwards of 1000km (Jaster et al. 2012).

The eastern meadowlark has exhibited a range-wide decline of 72% in the last four decades (With et al. 2008). Although this decline has occurred throughout its entire range Breeding Bird Survey data indicates that the highest rates of decline occurred in urbanized northeastern states, including Massachusetts (Sauer et al. 2011). Population declines are linked to loss of grassland habitat due to urbanization and agriculture, (Jaster et al. 2012), disturbance and mortality from livestock and mowing, and pesticide use in the agricultural landscapes that they frequent (With et al. 2008). The eastern meadowlark has shown evidence of area sensitivity in some studies (Herkert 1994), so habitat fragmentation could also be of concern.

**Climate Impacts:** Changing precipitation and winter temperature 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). Moreover, 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 (George et al. 1992). Winter mortality from sudden and sever cold snaps have also been reported (Jaster et al. 2012) so changes in winter temperatures, and in severity of storms may also influence this species.

Eastern meadowlarks may however see some positive impacts of climate change. 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, William V and 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, and is the product of three separate modeling efforts for each species: habitat capability (HC), climate suitability (CS), and prevalence. Under these models, LC for the eastern meadowlark is predicted to increase by 17% of their 2010 Northeastern range by 2080 (DeLuca, William V and McGarigal 2014).
**Glossy ibis**

**Scientific Name:** Plegadis falcinellus

**Species Stressors:** Changes in hydrology, Changes in winter, Development and habitat loss, Precipitation changes, Sea level rise, Storms and floods, Temperature change

**Background:** The glossy ibis breeds along the Atlantic coastline from central Maine to South Carolina. It underwent a severe population decline in the 20th century, but has since shown signs of recovery, and has expanded its range into Massachusetts recently (Natural Heritage and Endangered Species Program 2015d). This colonial nesting bird is often found with herons and egrets in freshwater marshes, river-edge marshes, costal islands, and sometimes in brackish or saltwater marshes and mudflats (Davis and Kricher 2000). The glossy ibis nests over the water in low trees and shrubs, and on the ground in tall emergent vegetation (Natural Heritage and Endangered Species Program 2015d), and have only a single clutch per season (Davis and Kricher 2000). They feed away from the breeding site in the soft mud or shallow water of freshwater marshes, flooded agricultural fields, shallow lakes, rivers, or even sewage ponds, and eat crustaceans, grasshoppers, leaches, small snakes, and grubs (DeGraaf and Rudis 1986, Davis and Kricher 2000). The glossy ibis is highly nomadic, and disperses widely after the breeding season; northern populations are migratory, and winter in coastal Louisiana, Florida, the Caribbean, and a small area of Central America (Davis and Kricher 2000). This species is long lived, and individuals up to 19 years old have been recorded (Davis and Kricher 2000).

Threats include storms and droughts, road mortality, pesticide contamination and human alteration of habitats through mosquito ditching, wetlands draining, and lowering of water levels (Davis and Kricher 2000, Natural Heritage and Endangered Species Program 2015d).

**Climate Impacts:** Climate change may result in habitat loss for the glossy ibis, both in its nesting and foraging habitats. The freshwater habitats that this species uses for foraging are very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydroperiod, depth, and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014). Sea level rise and altered hydrology are expected to adversely impact the coastal marsh and wetland habitats in which they breed (Adaptation Subcommittee to the Governor’s Steering Committee on Climate Change 2010, Manomet Center for Conservation Science and Massachusetts Division of Fisheries and Wildlife 2010). Some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with sea level rise (Galbraith et al. 2002). Finally, climate-mediated shifts in regional abundance could alter both the structure of wetland communities, and prey populations (Kelly and Condeso 2014). However, the tidal flats that these species also use on occasion are likely to greatly increase in extent (The National Wildlife Federation and Manomet Center for Conservation Sciences 2014). Changes in precipitation and temperature regimes related to climate change may also affect glossy ibis population growth. Periods of high rain and low temperatures are known to cause chick mortality for this species (Davis and Kricher 2000), and conditions of reduced rainfall and drought both reduce population numbers (Ramo et al. 2013, Santoro et al. 2013). In addition, the extreme storm events that are likely to become more prevalent and severe under climate change (The National Wildlife Federation and Manomet Center for Conservation Sciences 2014) may also impact the glossy ibis because storms can significantly lower reproductive success through nestling mortality, and alteration of nesting habitat (Davis and Kricher 2000). However, the extreme dispersive ability of this species, and its known tendency to disperse specifically in response to severe climatic
events such as droughts and storms (Santoro et al. 2013) suggests that it may be able to colonize new locations quite easily, and colonize alternate wetland habitats more easily than other wetland obligates.
Great egret

Scientific Name: Ardea alba

Species Stressors: Changes in hydrology, Development and habitat loss, Precipitation changes, Sea level rise, Storms and floods, Temperature change

Background: Except for some isolated locations in Maine and Ontario, Massachusetts is the northern edge of this species breeding range, and this species is found mainly in the eastern fringes of the state. Great egrets winter in the southeastern US, Mexico and the Caribbean. The great egret breeds in freshwater, marine, and estuarine wetlands that have forested areas necessary for their nests, and near lakes (Massachusetts Division of Fisheries and Wildlife 2015b). They feed mainly on a variety of small fishes, but will also consume small amphibians, reptiles, mammals and birds opportunistically (McCrimmon et al. 2011). They typically make long-distance migrations, but some are known to remain on breeding grounds during mild winters (McCrimmon et al. 2011). Habitat loss and contamination with pesticides, lead, and mercury are the primary threats to great egrets (McCrimmon et al. 2011, Massachusetts Division of Fisheries and Wildlife 2015b).

Climate Impacts: Climate change may result in habitat loss for great egrets. Sea level rise and altered hydrology will adversely impact coastal marsh and wetland habitats, and impair nesting and foraging activities for many wetland birds (Adaptation Subcommittee to the Governor’s Steering Committee on Climate Change 2010, Manomet Center for Conservation Science and Massachusetts Division of Fisheries and Wildlife 2010). Some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with future rates of sea level rise (Galbraith et al. 2002). The freshwater habitats that this species occupies are also very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydroperiod, depth and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014). Finally, climate-mediated shifts in regional abundance could alter both the structure of wetland communities, and prey populations (Kelly and Condeso 2014).

Changes in precipitation and temperature regimes related to climate change may also affect great egret population growth. Precipitation levels above and below average resulted in declines in nest abundance and growth rate for great egrets in California in subsequent years, and severe temperatures in the winter reduced juvenile survival (Kelly and Condeso 2014). The extreme storm events that are likely to become more prevalent and severe under climate change (National Wildlife Federation and Manomet Center for Conservation Sciences 2014) may also impact egrets, because the volume and intensity of rainfall can influence their foraging rates and reproductive success (Kelly and Condeso 2014).
King rail

Scientific Name: Rallus elegans

Species Stressors: Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Sea level rise, Storms and floods, Temperature change

Background: The king rail breeds from southern New Hampshire and Vermont to the Gulf coast, and as far west as Minnesota, and winters along the Atlantic coastline form the Mid-Atlantic states to southern Mexico. It is a rare breeder in Massachusetts, and is listed as threatened in the state (Natural Heritage and Endangered Species Program 2015e). King rails breed in tidal rivers, and permanent freshwater marshes that are characterized by dense and tall emergent vegetation like bulrushes, cattails and sedges (DeGraaf and Rudis 1986). Coastal saltwater and brackish wetlands and estuarine intertidal wetlands also appear to be important for this species (Glisson et al. 2015b). King Rails favor marshes with interspersion of dense vegetation and small shallow areas of open water (Pickens and Meanley 2015). They typically forage in or near dense vegetation and on the edge of open water, and tend to use shallow water sources (Pickens and King 2014). King rails consume amphibians, crustaceans, a variety of insects, and seeds of marsh plants (DeGraaf and Rudis 1986). They breed in June in the northeast, likely with only one clutch per season, and place nests over water among in thick vegetation (Natural Heritage and Endangered Species Program 2015e, Pickens and Meanley 2015). Inland and northern populations are migratory, and coastal and southern populations sedentary, though little is known about migratory timing or routes (Pickens and Meanley 2015).

Both migrant and resident populations of king rail have declined significantly throughout the US over the last 40 years (Glisson et al. 2015b). The main threats to this species appear to be the loss and degradation of wetland habitats, exotic invasive vegetation, hunting and trapping mortality, collisions with structures during migration, and lead poisoning (Natural Heritage and Endangered Species Program 2015e, Pickens and Meanley 2015).

Climate Impacts: The freshwater habitats that the king rail relies upon are very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydroperiod, depth and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014). Because the king rail relies specifically on habitats with shallow water, changes in hydrology can especially impact habitat value for this species, with heavy rains or intentional flooding for management purposes and drought/drawdowns both reducing the habitat quality of shallow water systems, and short-term reductions in rainfall/drawdowns improving habitat quality in areas where there is typically deeper water (Pickens and King 2014).

Climate change is also expected to greatly reduce the coastal wetland habitats that are used by king rail (Glisson et al. 2015b). Coastal wetlands are especially vulnerable to changes in temperature and precipitation patterns, variation in the frequency and intensity of tropical storms, and sea level rise (Woodrey et al. 2012). Shifts in plant community composition and structure due to sea level rise and increased salinity are likely to reduce habitat quality for the king rail (Woodrey et al. 2012). Increased salinity may also cause king rails to be displaced by the more salt-tolerant clapper rail, , and may even result in increased hybridization between the two species (Glisson et al. 2015b). Some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with future rates of sea level rise (Galbraith et al. 2002).
Finally, some short and medium distance migrants are arriving earlier to their breeding grounds across the northern U.S. in response to climate change (Marra et al. 2005, Wilson 2013), which can lead to mass mortality of migrants under extreme and late spring storms (Zumeta and Holmes 1978, Dionne et al. 2008). However, the king rail does not appear to be advancing the timing of its spring arrival (Fournier et al. 2015).
Least bittern

Scientific Name: Ixobrychus exilis

Species Stressors: Changes in hydrology, Development and habitat loss, Precipitation changes, Sea level rise, Storms and floods, Temperature change

Background: The least bittern breeds in eastern North America from New Brunswick to the Florida panhandle, and throughout the Midwest in the US, and winters in southern Florida, the Caribbean and Central America. The least bittern is a small heron that inhabits both brackish and fresh water marshes that have tall, dense vegetation over deep water (Parsons and Master 2000). They feed on a wide variety of prey, including frogs and salamanders, small fishes, insects, and occasionally small mammals (DeGraaf and Rudis 1986). They depart on migration late August or early September, and return mid to late May (Parsons and Master 2000).

The least bittern is threatened by loss of wetland habitat through draining and invasion by purple loosestrife (Lythrum salicaria) and phragmites (Phragmites australis), collisions with cars and human structures, and pesticides (Parsons and Master 2000). Population trends are unknown for this very secretive species, but it is listed as endangered in Massachusetts (Natural Heritage and Endangered Species Program 2015f).

Climate Impacts: Climate change may result in habitat loss for least bittern. Sea level rise and altered hydrology will adversely impact coastal marsh and wetland habitats, and impair nesting and foraging activities for many wetland birds (Adaptation Subcommittee to the Governor’s Steering Committee on Climate Change 2010, Manomet Center for Conservation Science and Massachusetts Division of Fisheries and Wildlife 2010). The brackish marshes that the least bittern occupy are likely to be some of the most severely impacted wetland habitats (The National Wildlife Federation and Manomet Center for Conservation Sciences 2014). Climate change and sea level rise are also likely to reduce habitat quality for least bittern in coastal areas by increasing salinity and shifting these habitats toward salt-tolerant vegetation (Woodrey et al. 2012). Some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with future rates of sea level rise (Galbraith et al. 2002). The freshwater habitats that this species occupies are also very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydropериod, depth and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014). Finally, climate-mediated shifts in regional abundance could alter both the structure of wetland communities, and prey populations (Kelly and Condeso 2014).
Long-tailed Duck

Scientific name: Clangula hyemalis

Species stressors: Temperature changes, Change in timing of seasons, Development and habitat loss

Background: The long-tailed duck is a sea duck that is the most arctic-adapted of all ducks, requiring tundra habitat near lakes, ponds, coastlines, or islands for breeding. In North America, it breeds from the northern parts of Ellesmere Island to the south coast of Hudson Bay (Johnsgard 1975b). On the east coast, long-tailed ducks winter in coastal habitats from New England south to Chesapeake Bay, and less commonly, to the Carolinas (Johnsgard 1975b). Large numbers of long-tailed ducks winter off Nantucket and Chesapeake Bay. It is estimated that up to 30% of the North American breeding population may winter in the vicinity of Nantucket. These ducks spend the night on Nantucket Sound and travel roughly 65 km offshore during the daytime to the Nantucket Shoals (White et al. 2009). There are reported observations of up to several hundred thousand long-tailed ducks making this daily flight (Perry 2006, White et al. 2009).

Climate Impacts: Climate change is expected to have an inordinate impact on arctic and subarctic ecosystems (Hof et al. 2012, Boelman et al. 2015). Tundra ecosystems are expected to decrease in extent, and northward range expansions for tundra dependent species are not possible due to the lack of land further north (Hof et al. 2012). There has been an observed increase in dominance of woody deciduous shrubs in many arctic regions over the past 50 years, altering tundra habitats (Sturm et al. 2001, Tape et al. 2006). Additionally, climate change may disrupt current predator-prey dynamics in the arctic, resulting in increased predation pressure on duck eggs. Such a scenario has been suspected of decreasing breeding success of long-tailed ducks in some cases (Guillemain et al. 2013). It seems likely that these changes have the potential to negatively impact long-tailed duck populations. However, there is limited information about the ecology and population dynamics of this species (Schamber et al. 2009, Flint 2013).

While activities in Massachusetts will have little direct impact on summer breeding habitat in the arctic, Massachusetts does host a disproportionate percentage of the wintering population of long-tailed ducks (White et al. 2009). It is unclear how climate change will impact the current winter distribution of long-tailed ducks. Large shifts in the winter distributions of other species of sea ducks have been observed, although causes of these shifts are unclear (Aarvak et al. 2013). Climate change is expected to have an effect on the winter distributions of ducks in general, but for sea ducks, non-climatic factors, such as food availability, may play a greater role (Guillemain et al. 2013, Lehikoinen et al. 2013). Additionally, changes in the timing of migration between summer and winter habitats are likely, but demographic impacts are unknown (Guillemain et al. 2013).
**Louisiana waterthrush**

**Scientific Name:** Seiurus motacilla

**Species Stressors:** Temperature changes, Precipitation changes, Storms and floods, Change in timing of seasons

**Background:** The Louisiana waterthrush is the only obligate riparian passerine that breeds in the eastern United States (Master et al. 2005). Waterthrushes are strongly associated with unpolluted headwater streams and associated wetlands occurring in contiguous forest (Prosser and Brooks 2011). In these habitats, they feed preferentially on aquatic macroinvertebrates (Mulvihill et al. 2009), but will also forage in saturated soils that are rich with arthropods (Hallworth et al. 2011). Their habitat requirements mean that they are good bioindicators of stressors on forested headwater streams (Master et al. 2005). Louisiana waterthrush breed in the eastern United States from Wisconsin to central New England and south to northern Florida, overwintering throughout the Caribbean and Central America (Hallworth et al. 2011). Although the species is found across Massachusetts, they are concentrated in the western half of the state, particularly the Berkshire Transition region (Mass Audubon 2015d).

**Climate Impacts:** A significant portion of the diet of Louisiana waterthrushes comes from foraging in muddy, saturated soils that are rich with arthropods; in addition, the species is dependent upon riparian habitat (Hallworth et al. 2011). Climate projections for the Northeast indicate that higher temperatures and a longer growing season will result in increased evapotranspiration; these changes are likely to result in increased short-term drought conditions (Fan et al. 2014). Such conditions may reduce the availability of saturated soils, and have the potential to reduce the availability of suitable habitat. In addition, one study found that daily nest survival for waterthrushes was highest when rainfall was at intermediate levels (Mattsson and Cooper 2009). This study concluded that extended periods of drought would have negative consequences for reproduction.

However, Massachusetts is located at the northern extent of the range of the Louisiana waterthrush. Distributions are expected to move north for many bird species (Gillings et al. 2015), possibly shifting Massachusetts nearer to the center of the breeding distribution. Modeling studies conducted by the University of Massachusetts project an increase (by nearly 25%) in the capability of the landscape of the Northeast to support this species by 2080 (DeLuca and McGarigal 2014).
Marsh wren

Scientific Name: Cistothorus palustris

Species Stressors: Temperature changes, Precipitation changes, Sea level rise, Storms and floods, Change in timing of seasons, Development and habitat loss

Background: The marsh wren is an obligate wetland breeding species (Grieves and Forbes 2012), using freshwater and brackish marshes with dense, reedy vegetation (American Ornithologists Union 1983, Linz et al. 1996, Benoit and Askins 1999). Marsh wrens breed from Nova Scotia south to east-central Florida and along the Gulf coast to Texas (American Ornithologists Union 1983). They winter within portions of their breeding range and south to southern Baja California and neighboring areas of Mexico (American Ornithologists Union 1983). In Massachusetts, marsh wrens are summer breeders only, dispersed throughout the state but with highest concentrations on the coastal plains; much of this concentration is centered around large wetlands such as Great Meadows National Wildlife Refuge in Concord and the Parker River National Wildlife Refuge in Newburyport (Massachusetts Audubon 2015b).

Climate Impacts: Throughout their range, marsh wrens can be found in tidally-influenced habitats, particularly tidal marsh (Rush et al. 2009). This habitat is considered vulnerable to climate change-induced sea-level rise (Veloz et al. 2013b). However, uncertainty remains regarding the response of tidal marsh habitat to climate change. Potential exists for reduction of suitable habitat for marsh wren if sea-level rise substantially alters salt marshes, especially if urban development prevents the shifting of habitat.

A study in the Prairie Pothole Region of the northern Great Plains found that climate variables were strong predictors of wetland bird abundance, including marsh wrens (Forcey et al. 2007). Spring temperature was found to be a very important predictor of abundance and yearly precipitation was moderately important. Modeling studies considering habitat capability and climate suitability conducted by the University of Massachusetts project a substantial increase (62%) in the capability of the landscape of the Northeast to support this species by 2080 (DeLuca and McGarigal 2014).
Northern harrier

Scientific Name: Circus cyaneus

Species Stressors: Change in timing of seasons, Changes in hydrology, Changes in winter, Development and habitat loss, Precipitation changes, Sea level rise, Storms and floods, Temperature change

Background: In North America, the northern harrier breeds throughout much of Canada, and in the northern reaches of the US. They breed in wet meadows, grasslands, abandoned fields, and coastal and inland marshes (Herkert et al. 1999, Smith et al. 2011, Natural Heritage and Endangered Species Program 2015g). In Massachusetts they breed primarily along the coast, and are regularly seen in the winter in coastal marshes (Natural Heritage and Endangered Species Program 2015g). They nest alone or in loose colonies, and can exhibit polygyny on occasion (DeGraaf and Rudis 1986). Northern harriers prey primarily on small mammals, including rodents, shrews, and rabbits, but can also consume reptiles, amphibians, insects and small birds (DeGraaf and Rudis 1986). Population trends and productivity are strongly influenced by the availability of the microtine voles that the species tend to rely heavily on in the early spring (Smith et al. 2011). Northern harriers are partial migrants that can range in migration distance depending on their breeding latitude (Smith et al. 2011).

The northern harrier has experienced population declines through much of its North American range, and has been identified as a species of national management concern by the USFWS due to its dependence on rare and vulnerable habitats (Herkert et al. 1999). Threats to northern harriers include destruction of freshwater and estuarine wetlands in breeding and wintering areas, agricultural conversion of native grassland prairies, nest destruction from mechanized agriculture and livestock, declines of prey species and toxicity exposure through insecticides and rodenticides (Smith et al. 2011). In the northeast, the destruction of wetlands, reforestation, and increase in nest predators are key factors in population declines (Smith et al. 2011).

Climate Impacts: Climate change may negatively impact northern harriers in a number of ways. Precipitation and percentage of wetland area are the best predictors of the abundance of the northern harrier in the Midwest (Forcey et al. 2014), indicating that changes in precipitation and hydrology associated with climate change will likely influence the abundance and distribution of these species. Prolonged periods of rain can also destroy nests and reduce productivity for northern harriers (Natural Heritage and Endangered Species Program 2015g). Habitat loss is already a serious threat to this species, and the marsh habitat that these species rely heavily on in Massachusetts (Natural Heritage and Endangered Species Program 2015g) is considered particularly vulnerable to climate change induced sea-level rise (Veloz et al. 2013a). A number of raptor species, including northern harriers showed significant poleward shifts in their wintering distributions since 1975 in response to changing climate conditions (Paprocki et al. 2014). Many raptors, including northern harriers also appear to be arriving earlier in the spring and leaving later in the autumn from their breeding grounds as well, though it is unclear whether this trend is beneficial, detrimental, or neutral (Buskirk 2012).

Some raptors do appear to be positively affected by climate-change. For instance, in the western US the American kestrel (Falco sparverius) exhibited a significant reduction in migration distance in response to warmer winters, which equated to earlier nesting, and increased reproductive success (Heath et al. 2012).
**Olive-sided flycatcher**

**Scientific Name:** *Contopus cooperi*

**Species Stressors:** Change in timing of seasons, Changes in hydrology, Development and habitat loss, Precipitation changes, Storms and floods, Temperature change

**Background:** The Olive-sided Flycatcher breeds across much of Canada, in part of the Rockies and Sierra Nevada Mountain ranges, and in northern New England and winters in the mountains of Panama and in the Andes. Massachusetts is at the very southern end of this species’ range in the northeast US (Altman and Sallabanks 2012). Olive-sided flycatchers are typically associated with pine barrens and spruce-fir forests (Ralston et al. 2015), particularly those that have meadow, bog, or forestry cut openings with tall prominent trees or snags (Altman and Sallabanks 2012). Olive-sided flycatchers are historically dependent on openings created by fire; however, they often use silvicultural openings in which they are experiencing reduced reproductive success due to increased predation (Robertson 2012). Olive-sided flycatchers hunt for aerial arthropods from an elevated perch (Robertson 2012), and are therefore rather specialized in diet. This species has the longest migration of any flycatcher in North America, and exhibits a particularly early fall departure from breeding grounds, and late spring arrival, most likely in response to availability of aerial insects that are highly responsive and vulnerable to cold temperatures (Altman and Sallabanks 2012).

The olive-sided flycatcher is listed by the International Union for the Conservation of Nature (IUCN) as “Near Threatened” (Ralston et al. 2015). They exhibited an annual decline of 3.48% from 1966-2013 across their range, and 4.5% annually in Massachusetts (Sauer et al. 2014). This species used to be common throughout Massachusetts, but currently only breeds in isolated locations in the north central and western portion of the state, primarily in high-elevation coniferous bogs and swamps (Natural Heritage and Endangered Species Program 2015h). Causes for declines are unknown but may be linked to destruction of wintering habitat, fire suppression and the ‘ecological trap’ of silvicultural openings in which predators are more abundant (Altman and Sallabanks 2012).

**Climate Impacts:** Climate change may threaten the mountain-top boreal forests that olive-sided flycatchers occupy. Boreal forests are expected to become less common through climate change, and possibly extirpated from the Northeastern US under severe climate projections (Rodenhouse et al. 2008). In response, range contraction is expected for species that inhabit montane spruce-fir forests at the southern edge of their range (Rodenhouse et al. 2008).

Climate-induced changes in the timing of seasonal events could also have serious consequences for this long-distance migrant. Studies have shown that birds are arriving earlier to their breeding grounds across the northern U.S. (Marra et al. 2005, Wilson 2013). Climate variability could exacerbate these problems with timing, since late spring storms and extreme weather events can kill migrating birds (Zumeta and Holmes 1978, Dionne et al. 2008). However, many long-distance migrants have not shifted their spring arrival dates as much as short-distance migrants (Miller-Rushing et al. 2008). As a result, phenological mismatches between migration dates and food resources have been reported for many long-distance migrants (Faaborg et al. 2010). Indeed, numerous aerial insectivores like olive-sided flycatchers (particularly long-distance migrants) have exhibited significant declines that are very likely related to food shortages and phenological mismatches between insect abundance and timing of life history events (Nebel et al. 2010).
Pied-billed grebe

Scientific Name: Podilymbus podiceps

Species Stressors: Changes in hydrology, Development and habitat loss, Precipitation changes, Sea level rise, Storms and floods, Temperature change

Background: The pied-billed grebe is the most widespread grebe in North America and breeds throughout most of the continental US and southern Canada. They breed at a wide range of altitudes in marshes, seasonal or permanent ponds, bays and sloughs in riparian areas that have still water (Muller and Storer 1999). They appear to prefer freshwater habitats, but also use mildly brackish waters, and can even be found in sewage ponds (Muller and Storer 1999). Pied-billed grebes require heterogeneous habitats with dense emergent vegetation interspersed with open water of for foraging and gaining flight (DeGraaf and Rudis 1986, Muller and Storer 1999). This species feeds primarily in open water by diving for prey, and occupancy is positively related to water depth (Monfils et al. 2014). Pied-billed grebes consume a very wide variety of foods including amphibians, leeches, crayfish, aquatic worms, snails, small fishes, shrimp, and occasionally even aquatic vegetation (DeGraaf and Rudis 1986). They nest over shallow water in emergent vegetation, or on floating platform nests in open water, and can have multiple broods; eggs are very hardy to thermal stress (Muller and Storer 1999). Pied-billed grebes depart Massachusetts on migration in late August or September, and return in April or May (Natural Heritage and Endangered Species Program 2015i). They winter throughout Mexico, the Caribbean, and much of the US, with the exception of the Midwest, and New England in habitats that are similar to those in which they breed; southern populations are sedentary (Muller and Storer 1999).

The pied-billed grebe is not well represented in BBS routes, so population trends are unknown; however the species is considered common over much of its range (Muller and Storer 1999). It is listed as endangered in Massachusetts, due to a paucity of suitable habitat, and low population size (Natural Heritage and Endangered Species Program 2015i). Threats to this species include habitat loss, mortality from motorized boats, environmental contaminants, and collision mortality (Muller and Storer 1999).

Climate Impacts: Climate change may result in habitat loss and range shifts for the pied-billed grebe. The freshwater habitats that this species inhabits are very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydroperiod, depth and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014). The pied-billed grebe is projected to lose up to of 40% of its breeding habitat in the Prairie Pothole region (Steen and Powell 2014). The coastal habitats that this species occasionally occupies are also very vulnerable to climate change (Kundzewicz et al. 2007). For instance, climate change and sea level rise are likely to reduce habitat quality in brackish marshes by increasing salinity and shifting these habitats toward salt-tolerant vegetation (Woodrey et al. 2012). Some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with sea level rise (Galbraith et al. 2002). Finally, climate-mediated shifts in regional abundance could alter both the structure of wetland communities, and prey populations (Kelly and Condeso 2014). Projections under the most severe climate change scenarios also suggest that this species could experience an eastward range shift (Steen and Powell 2012).

Changes in precipitation, and storm frequency related to climate change could also result in reduced reproductive output for pied grebes. Severe weather, high winds and waves, and drops in water levels
resulted in 8–50% of nest and egg losses in one study (Muller and Storer 1999). Chicks are also extremely vulnerable to low temperatures and winds for first two weeks after hatching (Muller and Storer 1999).
Piping plover

Scientific Name: Charadrius melodus

Species Stressors: Sea level rise, Storms and floods, Development and habitat loss

Background: The piping plover is an iconic shorebird along Atlantic Coast beaches. Although frequently associated with these coastal beaches, among the three recognized breeding populations, two are actually interior. In addition to the Atlantic Coast population which extends from Canada to North Carolina (Roche et al. 2010), populations are found on the Great Plains population extending from Nebraska through Alberta, Canada, and along the shorelines of Lakes Michigan, Superior, and Huron, with . All of these populations are short distance migrants that winter along the Gulf or southern Atlantic Coast and in the Bahamas (Roche et al. 2010).

In Massachusetts, piping plovers arrive on breeding grounds in late March, with the majority arriving in April (Massachusetts Audubon 2015c). The birds are found on wide, barren, sandy beaches, and will nest on sparsely vegetated beaches above the high tide line. Most will leave Massachusetts beaches for wintering grounds by late August, though a few will remain into September.

Increased human populations and intense development pressure associated with coastal areas have led to a decline in piping plover populations (Seavey et al. 2011). The species was federally listed as threatened in 1986 when only 790 pairs remained (Cohen et al. 2009). Management efforts in the years since have resulted in population increases so that there were approximately 8,000 individuals globally in 2006 (Gratto-Trevor and Abbott 2011).

Climate Impacts: Climate change is expected to result in rising sea levels due to the melting of glacial ice and thermal expansion of water. Sea levels have been rising at an accelerated rate for at least the past 50 years in New England, exceeding average global rates (Warren and Niering 1993, Horton et al. 2014). In addition, there is an expected increase in the frequency of severe storms along with higher storm surges, which is likely to result in increased inundation of tidal areas during storms (Anthes et al. 2006, Thorne et al. 2012). The northeast in particular has experienced approximately one foot of sea-level rise since 1900, and is projected to experience anywhere between 1.5 to 6 feet of additional sea-level rise over the next century (Horton et al. 2014, Lentz et al. 2016).

Habitat for piping plovers has the potential to migrate as sea level rises (Seavey et al. 2011). However, the degree to which this can happen depends upon the amount of development inland of beaches (Seavey et al. 2011, Sims et al. 2013). In many cases, current development will prevent migration of habitat. In addition, actions designed to mitigate the impacts of climate change, such as building sea walls, can also prevent habitat migration (Sims et al. 2013). Concurrent with sea level rise, populations of coastal communities are anticipated to increase (Seavey et al. 2011), further increasing pressure on available habitat. Strategies to reduce conflict between development and conservation of piping plover habitat in the face of climate change have been recommended, including controversial measures such as zoning regulations and closing of public access (Gratto-Trevor and Abbott 2011, Seavey et al. 2011).

In addition to loss of habitat, increasing occurrence of severe storms has the potential to directly impact piping plovers through flooding of nests (Massachusetts Audubon 2015c). Such storms may result in increased nest abandonment and bird mortality.
Prairie warbler

Scientific name: Setophaga discolor

Species stressors: Temperature changes, Change in timing of seasons, Development and habitat loss

Background: The prairie warbler is a disturbance-dependent species that breeds in shrub-scrub habitats (Akresh et al. 2015), generally with dry soils and at relatively low elevations (Nolan 1978). Prairie warblers winter in the Caribbean and breed in the eastern US (Nolan 1978) mostly in the southeastern US, but extending north to southern Maine and west to Michigan (Matthews et al. 2007). Breeding individuals return to the same location to breed from year to year (Akresh et al. 2015). However, because the habitat they breed in is not permanent, there is some flexibility in this that allows for colonization of newly disturbed habitat (Nolan 1978).

Reduction of agricultural activity since the late 1800s (Nolan 1978), and succession of forests to more mature stages over the past several decades has resulted in a decrease in available habitat for prairie warblers (Burchell et al. 2012). As a result, this species has undergone declines in abundance. Active habitat management is often required to maintain shrubland habitats and avoid forest succession.

Climate Impacts: Though many species of short-distance migrants show evidence of earlier spring arrival in response to climate change, prairie warblers breeding in Massachusetts and New York do not appear to be shifting their migration timing (Butler 2003). Nevertheless, modeling conducted by the US Forest Service anticipates a northward range shift for prairie warblers over the next century (Matthews et al. 2007). Within Massachusetts, this includes expansion into unoccupied higher elevations in the Berkshires. Modeling studies conducted by the University of Massachusetts that look at climate predict an increase in the suitability of habitat in Massachusetts by the year 2080 (DeLuca and McGarigal 2014).
Red knot

Scientific Name: Calidris canutus

Species Stressors: Change in timing of seasons, Development and habitat loss, Sea level rise, Storms and floods, Temperature change

Background: Red knots breed in the arctic region, nesting in both northern Canada and Alaska, and winter primarily in South America and the Gulf of Mexico (Natural Heritage and Endangered Species Program 2015j). These migratory birds use Atlantic coastal areas for stopover to refuel during both fall and spring migration. Red knots have historically used both inland and coastal habitats of Massachusetts during migrations (Harrington et al. 2010). Although they have never been observed nesting in Massachusetts, Cape Cod and other coastal habitats in the state provide excellent foraging grounds where red knots feed on bivalves, crustaceans, and other marine organisms. During migration and wintering periods, red knots use sandy beaches and intertidal areas to feed. Red knots, along with other coastal birds, are highly dependent on horseshoe crab eggs for energy during their northward migration stopovers, and are capable of doubling their weight during 3 week stopovers feeding mainly on horseshoe crab eggs (Karpanty et al. 2006). Red knot populations wintering in South America and North America have different foraging habitats, food sources, and flight feather molt timing, which has implications for migration timing and flight ability (Harrington et al. 2010). These populations can also differ in their stopover durations throughout the Atlantic coast (Harrington et al. 2010).

Red knot populations have recently experienced significant declines, with the eastern subspecies of red knots declining by 75% since the 1980s (Morrison et al. 2003). In southern South America, red knots experienced a 50% decline between 2001 and 2003 alone (Morrison et al. 2003, Baker et al. 2004). Reduced horseshoe crab abundance from overexploitation for bait and biomedical uses, has led to poorer energy storage and condition of migrating red knots, thus impacting adult survival and the success of offspring (Baker et al. 2004). Red knots are further threatened by unregulated hunting in the Caribbean and northern South America (Natural Heritage and Endangered Species Program 2015j).

Climate Impacts: Climate change may directly and indirectly alter migration patterns and behavior, and disrupt important life history stages. Red knots are threatened by a mismatch between the timing of optimal environmental conditions and important life stage events, and the overall availability of resources in multiple locations across their range (Jones and Cresswell 2010, Saino et al. 2011). Climate change has the potential to impact the timing of food availability, which may be critical for determining the abundance and survival of this species. Red knots have been showing declines in bill length and body size, and these changes have been linked to reduced foraging ability in wintering habitats, and a decrease in overall fitness (van Gils et al. 2016). Red knot breeding habitat is threatened by warming temperatures and rising sea levels in northern regions, while critical refueling habitat in coastal areas of the Atlantic east coast is vulnerable to rising sea level and coastal erosion. Factors that contribute to the overall vulnerability of red knots to climate change include the vulnerability of wintering and migration habitats to climate change, potentials for mismatches in ecological timing and phenology, and vast migration distances (Whitman et al. 2013, Galbraith et al. 2014).
Ruffed grouse

Scientific name: Bonasa umbellus

Species stressors: Temperature changes, Precipitation changes, Changes in winter, Development and habitat loss

Background: The ruffed grouse is a non-migratory bird species that lives in northern forest across Canada and the US (Rusch et al. 2000). Ruffed grouse prefer habitat that includes a variety of forest cover types, but early successional habitat (young forest with densely growing young trees) is particularly important (Bump et al. 1947, Rusch et al. 2000, Dessecker and McAuley 2001). Populations of ruffed grouse have been declining in much of their eastern range, including Massachusetts and southern New England, as early successional habitats have given way to mid-aged and mature forest over the past several decades (Endrulat et al. 2005, Blomberg et al. 2009, Porter and Jarzyna 2013).

Climate Impacts: The distribution of ruffed grouse is closely associated with the distribution of quaking aspen trees (Kubisiak 1985), and population densities are typically high in this forest type (Dessecker et al. 2007). Declines in this tree species have been related to climate change, as well as reduction in forest disturbance (such as fire and logging) and natural forest successional changes. The distribution of aspen is projected to continue to decline in the future, potentially impacting grouse populations (Worrall et al. 2013). In the Northeast, quaking aspen is a relatively minor component of forest tree species composition (Giroux and et al. 1996, Endrulat et al. 2005), but decreases of other young forest species and types will also reduce grouse numbers. Adequate snow cover can also be important for overwinter survival in grouse, as they burrow into deep soft snow during cold winter periods (Whitaker and Stauffer 2003). Warming temperatures will likely change the quantity and characteristics (e.g., crusting conditions) of snow (Fan et al. 2014), making snow roosting more difficult. However, warming temperatures may also offset the need for snow roosting in some cases.

Climate change could potentially result in loss of ruffed grouse from states at the southern edge of their range, such as Massachusetts (Hoving et al. 2013). Modeling studies conducted by the Wildlife Management Institute predict a 20% decline in population size for New England. These studies were based on predicted changes to forest composition as a response to climate change over the next century (Wildlife Management Institute 2007). Modeling conducted by the University of Massachusetts also predicts that climate change will greatly reduce the proportion of the Northeast landscape that is capable of supporting ruffed grouse by 2080 (DeLuca and McGarigal 2014).
**Rusty Blackbird**

**Scientific Name:** Euphagus carolinus

**Species Stressors:** Change in timing of seasons, Changes in hydrology, Changes in winter, Development and habitat loss, Precipitation changes, Temperature change

**Background:** The rusty blackbird breeds across much of Canada, and Alaska, and the very northern reaches of New England, and winters from Massachusetts and south through much of the southeastern US and Midwest. They breed and winter in Massachusetts rarely, and are seen here more often during migration (Natural Heritage and Endangered Species Program 2015k). Rusty blackbirds breed in a variety of boreal wetland habitats including fens, alder and willow bogs, muskegs, beaver ponds, swampy lake shores, and black spruce and tamarack bogs (Avery 2013). They tend to forage on the ground, near the edge of wetlands and other water bodies (Avery 2013), and consume a broad diet of insects, seeds, grains, acorn mast, crawfish, and fruits (DeGraaf and Rudis 1986, Avery 2013). Rusty blackbirds nest near the water in trees and shrubs with dense vegetation (Avery 2013), and typically have one clutch per year, of 4-5 eggs (DeGraaf and Rudis 1986). They use flooded agricultural fields and wooded swamps during the migratory period, and in the winter they inhabit swamps, wet and swampy woodlands, the marshy borders of ponds and streams, riparian areas in hardwood bottoms, cypress lagoons, and flooded fields (Avery 2013).

Rusty blackbirds exhibited declines of 85-95% between 1970 and 2010 (Avery 2013). Threats to this species include loss of both breeding and wintering habitats, silviculture, exposure to contaminants, and incidental poisoning during the winter season from controlled eradication of other blackbird species (Greenberg et al. 2011, Natural Heritage and Endangered Species Program 2015k).

**Climate Impacts:** Climate change is likely to impact the habitats that the rusty blackbird uses. Boreal habitats are under significant pressure from logging, and agriculture, and climate change is expected to exacerbate the loss of these habitats (Greenberg et al. 2011, Ralston et al. 2015). In boreal habitats, climate change is also expected to increase the abundance of red squirrels, an important nest predator for the rusty blackbird (Luepold et al. 2015, Ralston et al. 2015). The freshwater habitats that the rusty blackbird relies upon are also very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydroperiod, depth and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014).

The rusty blackbird also appears to be exhibiting northward range expansion (Norment et al. 1999). Moreover, this species 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).

Climatic factors also appear to affect reproductive success and survival for rusty blackbirds; summers with low precipitation likely increase foraging substrate, and decrease nestling mortality, which can be high in periods of heavy rain (Savard et al. 2011). Climate change may also result in a reduction of odonates, an important food for rusty blackbirds, and is likely to shift the emergence of odonates to earlier dates and could equate to a phenological mismatch for the rusty blackbird (Mcclure et al. 2012). Finally, NAO conditions, which are more variable and severe under climate change can also produce snowier conditions in the wintering areas that reduce winter survival of rusty blackbirds (Savard et al. 2011).
Saltmarsh sparrow

**Scientific Name:** Ammodramus caudacutus

**Species Stressors:** Sea level rise, Storms and floods, Development and habitat loss

**Background:** Saltmarsh sparrows nest exclusively in salt marshes (Gjerdrum et al. 2005). The breeding range for this species is limited to a narrow band of tidal marsh that extends from Maine to Virginia, with up to half of the global population estimated to breed in southern New England (Bayard and Elphick 2011). Females nest close to the ground in an environment that is prone to flooding (Meiman et al. 2012). The reproductive cycle is synchronized to the tidal cycle, timed to occur between extreme tide events to avoid flooding of nests (Shriver et al. 2007, Gherdrum et al. 2008). Despite this adaptation, flooding is the major source of nest losses, accounting for 60% of failures (Bayard and Elphick 2011).

**Climate Impacts:** Climate change is expected to result in rising sea levels due to melting of glacial ice and thermal expansion of water (Lentz et al. 2016). Sea levels have been rising at an accelerated rate for at least the past 50 years in New England, exceeding average global rates (Warren and Niering 1993, Horton et al. 2014, Lentz et al. 2016). In addition, there is an expected increase in the frequency of severe storms along with higher storm surges, which is likely to result in increased flooding of tidal areas during storms (Anthes et al. 2006, Thorne et al. 2012). The northeast in particular has experienced approximately one foot of sea-level rise since 1900, and is projected to experience anywhere between 1.5 to 6 feet of additional sea-level rise over the next century (Lentz et al. 2016).

Because saltmarsh sparrows have developed a finely tuned reproductive strategy to cope with a flood-prone environment, there is concern that disruption of this environment could have a large impact on this species through increased nest failure (Bayard and Elphick 2011, Meiman et al. 2012). Sparrow nests appear to be extremely vulnerable to even slight increases in sea level, leading some to suggest a bleak future for this species (Bayard and Elphick 2011). In addition to the direct effects of nest flooding, changes in sea level may result in changes to the distribution and character of coastal wetlands (Warren and Niering 1993), which could have additional impacts on saltmarsh sparrows. Modeling studies conducted by the University of Massachusetts that incorporate landscape characteristics and climate change predict a 41% reduction in the capability of the northeast landscape to support saltmarsh sparrows by 2080 (DeLuca and McGarigal 2014).
Seaside sparrow

Scientific Name: Ammodramus maritimus

Species Stressors: Change in timing of seasons, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Sea level rise, Storms and floods, Temperature change

Background: The seaside sparrow breeds in small and isolated pockets along much of the Atlantic coast from New Hampshire to Texas. The seaside sparrow has a very narrow habitat niche and is a habitat specialist that occurs only in coastal salt and brackish marshes (Post and Greenlaw 2009). In Massachusetts they nest only at Parker River, and Plum Island, at Sandy Neck and Monomoy in Cape Cod, and in South Dartmouth (Natural Heritage and Endangered Species Program 2015). They nest on or near the ground, just above the high tide line in high and intertidal tidal salt marsh (Post and Greenlaw 2009), and occasionally in low marsh (Natural Heritage and Endangered Species Program 2015). They require sites that have dense vegetation for nests, and mudflat openings for foraging (Post and Greenlaw 2009), and appear to be area sensitive, requiring large salt marsh habitats (Natural Heritage and Endangered Species Program 2015). They exhibit high site fidelity, (i.e. return to the same territories to nest in subsequent years), and limited natal dispersal (Post and Greenlaw 2009). Seaside sparrows eat insects, spiders, and amphipods during the breeding season (Post and Greenlaw 2009). The northeastern breeding populations are migratory, and winter in intertidal zones along creeks and bay edges, and in sheltered areas along waterways along the Atlantic coastline from North Carolina to Texas (Post and Greenlaw 2009).

Seaside sparrows are rare and sparsely distributed but population levels appear to be stable or increasing moderately in the northeast (Post and Greenlaw 2009). Threats to this species include loss or modification to habitats from dredging, filling, ditching, and diking, invasion of exotic species, insecticides, and sea level rise (Natural Heritage and Endangered Species Program 2015). Climate Impacts: Climate change may result in habitat loss for seaside sparrows, and reduced reproductive output. Sea level rise and altered hydrology will adversely impact coastal marsh and wetland habitats, and impair nesting and foraging activities for many wetland birds (Adaptation Subcommittee to the Governor’s Steering Committee on Climate Change 2010, Manomet Center for Conservation Science and Massachusetts Division of Fisheries and Wildlife 2010). Climate change and sea level rise are likely to increase salinity in coastal wetlands, which will shift these habitats toward the salt-tolerant vegetation favored by seaside sparrows, at least in the short term (Woodrey et al. 2012). However, some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with sea level rise (Galbraith et al. 2002). Sea level rise and increased storm severity are also likely to adversely affect reproductive success of seaside sparrows; their nests are highly susceptible to flooding (Natural Heritage and Endangered Species Program 2015), with up to 89% of nests lost to flooding in Massachusetts during one year of study (Post and Greenlaw 2009). Finally, climate-mediated shifts in regional abundance could alter both the structure of wetland communities, and prey populations (Kelly and Condeso 2014). Large, severe storms also appear to reduce population levels of seaside sparrows or at least local occupancy of sites (Post and Greenlaw 2009), so the increase in storm frequency and intensity associated with climate change could impact this species.

Climate-induced changes in the timing of seasonal events could also have serious consequences for the northeastern populations that undertake relatively short seasonal migrations. Studies have shown that birds are arriving earlier to their breeding grounds across the northern U.S. (Marra et al. 2005, Wilson
Climate variability could exacerbate these problems with timing, since late spring storms and extreme weather events can kill migrating birds (Zumeta and Holmes 1978, Dionne et al. 2008).
Sedge wren

Scientific Name: Cistothorus platensis

Species Stressors: Change in timing of seasons, Changes in hydrology, Changes in winter, Development and habitat loss, Precipitation changes, Sea level rise, Storms and floods, Temperature change

Background: The sedge wren is a highly nomadic species that undertakes a first round of nesting in the upper Midwest of the US and Saskatchewan in late May and June, and a subsequent nesting episode in the southern portion of the Midwest, and in isolated locations in New England (Herkert et al. 2001). Nesting sites are seldom in the same area from year to year, as this species relies on very ephemeral habitats that are created and lost through periods of high rainfall and drought (DeGraaf and Rudis 1986, Natural Heritage and Endangered Species Program 2015m). The sedge wren breeds in wet meadows found on the borders of wetlands, freshwater ponds, and marshes, and prefers areas with a thick cover of tall grasses and sedges (Natural Heritage and Endangered Species Program 2015m). Nest sites are quickly abandoned if they become too wet or dry (Natural Heritage and Endangered Species Program 2015m). Sedge wrens glean insects and spiders from the ground and marsh vegetation (DeGraaf and Rudis 1986). This species is a short-distance migrant, with populations that breed in the US and Canada wintering along the Gulf coast in the US and in northeast Mexico (Herkert et al. 2001).

Sedge wrens are rare breeders in Massachusetts (Natural Heritage and Endangered Species Program 2015m), and are listed as endangered in the state. Threats to this species include loss of open wet meadow habitat through agricultural development, hydrological changes, and early haying in areas where they nest (Natural Heritage and Endangered Species Program 2015m). The upland wetland margins that these species rely upon are very easily drained and flooded, and are easily lost through changes in hydrology from urbanization, active draining of wetlands for agriculture, and loss of wetland habitats through changes in precipitation regimes (Herkert et al. 2001).

Climate Impacts: The freshwater habitats that the sedge wren relies upon are very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydroperiod, depth and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014). Sedge wrens are expected to lose upwards of 60-70% of their habitat in the Prairie Pothole region of the US by 2040 under climate change projections, and drought conditions are expected to be particularly detrimental (Steen and Powell 2014). The wintering habitat of sedge wrens is also likely to be adversely affected by climate change. The coastal wetlands that they inhabit during the non-breeding period are especially vulnerable to changes in temperature and precipitation patterns, variation in the frequency and intensity of tropical storms, and sea level rise (Woodrey et al. 2012). Some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with future rates of sea level rise (Galbraith et al. 2002).

Climate-induced changes in the timing of seasonal events could also have serious consequences for this species since it undertakes multiple seasonal movements. Studies have shown that some birds are arriving earlier to their breeding grounds across the northern U.S. (Marra et al. 2005, Wilson 2013). Climate variability could exacerbate these problems with timing, since late spring storms and extreme weather events can kill migrating birds (Zumeta and Holmes 1978, Dionne et al. 2008).
Snowy egret

Scientific Name: Egretta thula

Species Stressors: Aquatic connectivity loss, Change in timing of seasons, Changes in hydrology, Development and habitat loss, Pests and diseases, Sea level rise, Temperature change, Terrestrial connectivity loss

Background: Snowy egrets are partial migrants, with both overwintering and year-round resident populations occurring in southern North America and South America. During the 1800’s, New Jersey marked the most northern extent of the snowy egret’s range; however, snowy egrets have expanded north and have been observed in Massachusetts since the 1950s (Peterson 2003). This species underwent population declines from hunting; however populations have since rebounded. Snowy egrets arrive in Massachusetts in April, and breeding peaks in mid-May (Mass Audubon 2016). They nest in areas of thick vegetation, ranging from freshwater and saltwater marshes to barrier islands. They typically nest off the ground along outer branches of vines, shrubs, and trees (Parsons and Master 2000). Snowy egrets are territorial and will defend their nests by raising their crests and emitting territorial calls. They feed along lakes, wetlands, marshes, and tidal flats, consuming fish, frogs, crustaceans, and insects (Parsons and Master 2000).

Snowy egrets are vulnerable to many human impacts. They are threatened by loss of nesting and foraging habitat, which has occurred primarily through wetland drainage for human development (Parsons and Master 2000); however pollution, agriculture, and human recreation have also caused habitat decline and loss. Snowy egrets have high daily energetic requirements due to their relatively inefficient flying abilities (Maccarone et al. 2008). Egrets typically nest in large colonies that are often mixed with other water birds, such as herons. Individuals that nest closer to these colonies have been shown to consume more small prey, and generally have lower energetic demands but may be more aggressive towards other birds (Maccarone et al. 2012).

Climate Impacts: Marsh and wetland habitats are vulnerable to sea level rise and altered hydrology, which will likely impact snowy egret nesting and foraging activities (Adaptation Subcommittee to the Governor’s Steering Committee on Climate Change 2010, Manomet Center for Conservation Science and Massachusetts Division of Fisheries and Wildlife 2010). Marsh and wetland accretion may not be able to keep pace with future rates of sea level rise, and coastal migratory birds such as snowy egrets will be forced to utilize new areas (Galbraith et al. 2002). The freshwater habitats that this species inhabits are also very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydroperiod, depth and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014). Existing snowy egret habitat is already highly fragmented due to human activities in coastal areas, and further degradation is expected by climate-induced expansion of invasive species and novel pathogens (Whitman et al. 2013).

Changes in temperature and the timing of the seasons may also impact this species. Projected increases in temperature have already shifted bird distributions northward in coastal Massachusetts (Valiela and Bowen 2003), and this trend will likely continue for snowy egrets. In addition, a mismatch between optimal environmental conditions and the timing of important life stages is expected to occur for a number of migratory bird species, and may continue to impact coastal bird biology and their habitats at different rates (Jones and Cresswell 2010).
Sora

Scientific Name: Porzana carolina

Species Stressors: Changes in hydrology, Changes in winter, Development and habitat loss, Invasive plants and animals, Precipitation changes, Sea level rise, Storms and floods, Temperature change

Background: The sora breeds throughout the Maritime Provinces south to Pennsylvania, throughout the upper Midwest, and much of Canada and the western US. This is one of the more abundant and common rails, but it is a rare breeder in Massachusetts (Natural Heritage and Endangered Species Program 2015n). The sora breeds primarily in freshwater marshes, ponds, swamps, and bogs characterized by shallow or intermediate water depth, and dense emergent vegetation (DeGraaf and Rudis 1986, Steen and Powell 2014). They are associated with Typha (cattail)(Glisson et al. 2015a), and sedges (Monfils et al. 2014). Soras can occupy rather small marsh habitats (Glisson et al. 2015a), and are found in marshes as small as 0.5 ha in Massachusetts (Melvin and Gibbs 2012). They also occasionally nest in brackish or salt marshes along Atlantic Coast, and can also use these habitats during migration (Melvin and Gibbs 2012). They nest over the water on a platform of vegetation, and typically have one brood a year with 10-12 eggs (DeGraaf and Rudis 1986). Soras eat the seeds of aquatic vegetation, insects, mollusks, and crustaceans (DeGraaf and Rudis 1986). During the breeding season they forage in stands of tall emergent vegetation that are intermingled with short seed-producing and floating vegetation, but during the migratory season tend to forage more in tall emergent vegetation (Melvin and Gibbs 2012). Migrants rely heavily on seed-bearing annuals like smartweed and wild rice to fuel their flights (Haramis and Kearns 2007). Soras probably range from long to short-distance migrants, and may be resident in some areas (Melvin and Gibbs 2012). They winter in the Caribbean, Mexico, and the North American coastline from Maryland to northern California in freshwater, brackish, and salt marshes with relatively shallow waters, and occasionally in rice fields, impoundments, mangroves, wet pastures, flooded and overgrown agricultural fields and ditches, and small ponds and rivers (Melvin and Gibbs 2012).

Soras have consistently exhibited population declines in the US since the 1960s with the greatest rates of decline in the Midwest (Melvin and Gibbs 2012). Threats to this species include collision mortality, and loss and degradation of wetland habitats from draining, siltation, reductions in water table related to urbanization, and invasion of exotic vegetation (Melvin and Gibbs 2012, Natural Heritage and Endangered Species Program 2015n). Soras are hunted in 31 states and 2 Canadian provinces, and are also known to perish from ingestion of lead shot; however, the population-level effects of these stressors are unknown (Melvin and Gibbs 2012). This species does not appear to be as popular for hunting as it was historically (Haramis and Kearns 2007).

Climate Impacts: The freshwater habitats that the sora relies upon are very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydroperiod, depth and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014). Because soras rely specifically on habitats with shallow to intermediate water depths during the breeding season, changes in hydrology can especially impact habitat value for this species, since heavy rains or intentional flooding for management purposes and drought/drawdowns both reducing the habitat quality of shallow water systems, and short-term reductions in rainfall/drawdowns improving habitat quality in areas where there is typically deeper water (Pickens and King 2014). For instance, this species is projected to lose up to 98% of its breeding habitat in the Prairie Pothole region (Steen and Powell 2014), where they inhabit very seasonal and semi-permanent wetlands (Melvin and Gibbs 2012). Loss of these habitats has already led to declines in sora abundance in the Prairie Pothole...
region (Niemuth and Solberg 2003). However, this species known to quickly colonize newly restored wetlands (Glisson et al. 2015a), so may be able to adapt to climate change to some degree through dispersal.

The wetland habitats that soras rely on in the winter on the Gulf Coast and in western riparian areas are also some of the most threatened in the US (Melvin and Gibbs 2012). Coastal wetlands are especially vulnerable to changes in temperature and precipitation patterns, variation in the frequency and intensity of tropical storms, and sea level rise (Woodrey et al. 2012). Some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with future rates of sea level rise (Galbraith et al. 2002). In addition this species does not appear to be very cold tolerant (Melvin and Gibbs 2012), so extreme and sudden cold snaps in the winter could result in mortality.

Finally, some short and medium distance migrants are arriving earlier to their breeding grounds across the northern U.S. in response to climate change (Marra et al. 2005, Wilson 2013), which can lead to mass mortality of migrants under extreme and late spring storms (Zumeta and Holmes 1978, Dionne et al. 2008). However, the sora does not appear to be advancing the timing of its spring arrival (Fournier et al. 2015).
**Willet**

**Scientific Name:** Tringa semipalmata

**Species Stressors:** Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Sea level rise, Storms and floods, Temperature change, Terrestrial connectivity loss

**Background:** In the eastern portion of the US, the willet breeds in coastal regions from the Canadian Maritimes to the Caribbean, and winter in coastal areas of the southern US and northern South America. In Massachusetts willets are clustered at Monomoy, Plum Island, and Parker River NWR (Lowther et al. 2001). Given their extensive latitudinal range, willets can migrate short, medium, or long distances. Eastern willets breed in coastal salt marshes, barrier islands, barrier beaches, ocean-side short grass meadows and in shallow puddles and salt pans in which cordgrass are present (*Spartina patens* and *S. alterniflora*) (Benoit and Askins 1999, 2002, Lowther et al. 2001). In Massachusetts willets are clustered at Monomoy, Plum Island, and Parker River NWR (Lowther et al. 2001). They feed in oyster beds, mudflats, sparsely vegetated salt-marsh habitats, beaches and along tidal creeks where they consume insects, small crustaceans, mollusks, polychaetes, and even small fish on occasion (Lowther et al. 2001). They nest in smooth cordgrass, salt hay grass, or on beach detritus in the high marsh; however, the invasive *Phragmites australis* that tends to invade and replace salt marsh grasses do not provide adequate nesting habitat (Benoit and Askins 1999, Lowther et al. 2001).

Breeding Bird Survey data show an overall decrease of 1.94% annually across the eastern BBS region for the willet, but no statistically significant trends for the species in Massachusetts (Sauer et al. 2014). Threats to eastern willets include contaminants that accumulate in coastal sediments, habitat loss on breeding grounds, stopover sites and wintering areas from development, and reduction in habitat quality through draining and impounding of salt marshes and mosquito ditching (Benoit and Askins 1999, Lowther et al. 2001). They are less abundant in small habitat patches, and may therefore also be sensitive to habitat fragmentation (Benoit and Askins 2002). The willet was recently added to the USFWS conservation watch list as a species requiring management attention.

**Climate Impacts:** Climate change is likely to adversely affect willet habitats. The coastal habitats they rely on may be reduced as sea level rises and interacts with nearshore development (Thorne et al. 2012, Galbraith et al. 2014). This species could be particularly sensitive to sea level rise, as nest success is linked to flooding (Lowther et al. 2001). Moreover the coastal armoring aimed at mitigating sea level rise can also reduce willet abundance and the abundance of their macroinvertebrate prey (Dugan et al. 2008). Some tidal flats and salt marsh habitats are projected to increase with climate change, which may benefit some shorebirds (Scavia et al. 2002); however, changes in hydrology and stream flow from land use change and climate change may reduce the sediment and organic matter that some salt marshes receive so much that they cannot keep up with rates of sea level rise (Najjar et al. 2000). Changes in precipitation and increased temperatures could lead to salt accumulation in soils, and less available and productive habitat, (Woodrey et al. 2012). These effects can be exacerbated by the nutrient enrichment that often accompanies development and can eventually cause community shifts (Woodrey et al. 2012).

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). Finally, in addition to affecting habitat availability, climate change can also
shift the timing of prey availability through direct effects of climate change on prey species abundance and distribution.
**Wilson’s snipe**

**Scientific Name:** Gallinago delicata

**Species Stressors:** Aquatic connectivity loss, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Sea level rise, Storms and floods, Temperature change

**Background:** The Wilson’s snipe breeds throughout much of Canada and Alaska, and in the northern portions of the US, and winters in northern South America, the Caribbean, Central America, Mexico, and throughout much of the US. They are primarily found in Massachusetts in the winter and migratory period, though there are a few breeding records in the Berkshires and eastern MA (Natural Heritage and Endangered Species Program 2015o). This small sandpiper breeds on the marshy edges of ponds, rivers and brooks, in fens, sedge bogs, and willow and alder swamps, and in other wet meadow habitats, and avoids marshes with tall, dense vegetation (Mueller 1999). They forage in rich, moist soils that are on land, or in shallow water, and consume crustaceans, worms, larval insects, and mollusks (Mueller 1999). Most individuals are long distance migrants, though they may remain resident in some regions (Mueller 1999, Cline and Haig 2011). During the migratory and wintering period, Wilson’s snipes can occupy salt marshes, estuaries, and agricultural fields, in addition to their breeding habitat types (Natural Heritage and Endangered Species Program 2015o).

The Wilson’s snipe exhibited significant range-wide declines in the US from 1980 to 2003 (Mueller 1999, Cline and Haig 2011). Habitat loss from wetland draining, spread of exotic invasive species, and successional advance is the largest threat to this species; (Natural Heritage and Endangered Species Program 2015o) however, hunting pressure, contaminants, and collisions with tall structures are also possibly important stressors (Mueller 1999).

**Climate Impacts:** The freshwater habitats that the Wilson’s snipe relies upon are very vulnerable to climate change (Kundzewicz et al. 2007), since changes in temperature and precipitation can influence wetland hydroporometry, depth and size, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014). The Wilson’s snipe is estimated to lose up to 100% of its breeding habitat in the Prairie Pothole region under climate change projections(Steen and Powell 2014). Severe droughts are known to reduce population numbers regionally (Mueller 1999). During periods of limited precipitation, Wilson’s snipe appear to disperse to and rely heavily on permanent wetlands where they can be found in concentrated numbers; as such publically managed wetlands likely represent an important climate change refugia for this species (Cline and Haig 2011). However, the Wilson’s snipe does not appear to disperse as large distances as other shorebirds, so maintaining connectivity between wetland habitats may be important for this species (Cline and Haig 2011).

The wintering and migratory habitat of Wilson’s snipe is also likely to be adversely affected by climate change. The coastal wetlands that they inhabit during the non-breeding period are especially vulnerable to changes in temperature and precipitation patterns, variation in the frequency and intensity of tropical storms, and sea level rise (Woodrey et al. 2012). Some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with future rates of sea level rise (Galbraith et al. 2002).
**Wood thrush**

**Scientific Name:** Hylocichla mustelina

**Species Stressors:** Temperature changes, Precipitation changes, Change in timing of seasons

**Background:** The wood thrush is a neotropical migrant that winters in tropical forests from southern Mexico to Panama (Brown and Roth 2002, Mass Audubon 2015e). Its breeding range extends throughout much of eastern North America, from northern Florida to southern New Brunswick (Terres 1991). In New England, wood thrush inhabit low, cool, damp deciduous forests at elevations up to roughly 600 m (Terres 1991). In Massachusetts, the species is rare along coastal areas where appropriate woodlands are lacking (Mass Audubon 2015e). The peak of the spring migration occurs in the middle of May, while the fall migration begins in late August and peaks in September (Mass Audubon 2015e).

**Climate Impacts:** Information about climate impacts on wood thrush is scarce. Because Massachusetts is near to the northern terminus of its range, climate change may not adversely affect its distribution here. Many studies suggest that climate change will eventually shift forest ecotones (transition areas between forest communities) further upslope (Beckage et al. 2008, Rodenhouse et al. 2008). It is possible that such shifts could result in this species inhabiting higher elevation habitat within Massachusetts. It is possible that such shifts could result in this species inhabiting higher elevation habitat within Massachusetts. At least one study involving a long-term dataset has detected shifts in migration timing for this species in Worcester County, MA and in Cayuga Lake Basin, New York (Butler 2003). Individuals appear to be arriving earlier to breeding grounds in the spring. Modeling studies considering habitat capability and climate suitability conducted by the University of Massachusetts projected a negligible (-0.1%) reduction in habitat across the northeast for this species by 2080 (DeLuca and McGarigal 2014). Modeling by the US Forest Service predicts slight reductions in abundance for this species in some parts of Massachusetts over the next century (Matthews et al. 2007).
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FISH

**Alewife**

**Scientific Name:** Alosa pseudoharengus

**Species Stressors:** Aquatic connectivity loss, Temperature changes, Changes in hydrology, Storms and floods, Change in timing of seasons, Invasive plants and animals, Pests and diseases

**Background:** River herring is a term referring collectively to alewife and blueback herring. The two species are commonly referenced together as they have similar life histories and are very similar in appearance (Loesch 1987). They are native to the Atlantic coast of North America and co-occur in rivers throughout much of their range (Loesch 1987). The native range of alewife extends from Labrador to South Carolina while that of blueback herring extends from the Gulf of St. Lawrence to Florida (Hasselman et al. 2014). Both species are anadromous, returning to natal freshwaters to spawn after spending 3-6 years in the ocean. Alewife use stream corridors to access ponds for spawning, although they will also use quiet reaches of rivers, whereas blueback herring prefer flowing waters in rivers and streams for spawning (Hall et al. 2011, Mather et al. 2012). Alewifes spawn at cooler temperatures than blueback herring, resulting in initiation of spawning 3-4 weeks earlier. Despite this, there is much overlap in timing of spawning between the two species (Hasselman et al. 2014). In New England, spawning may extend from late March to early June (Durbin et al. 1979). Adult river herring migrate to the ocean once spawning is completed, while juveniles migrate from nursery habitats in October to November of the same year (Post et al. 2008). River herring are iteroparous, meaning they return to freshwater to spawn multiple times (Hall et al. 2011).

River herring are an important forage resource for many species of birds and fish (Post et al. 2008). Historically, river herring supported thriving fisheries (Palkovacs et al. 2014). Although early dam construction, habitat degradation, and harvest resulted in large declines, a stable fishery existed through the 1960s (Palkovacs et al. 2014). Recent declines have been precipitous and prompted a petition to consider the two species for listing under the Endangered Species Act (ESA) (Lynch et al. 2014). Recent declines may be due to overharvest in marine fisheries and higher levels of natural mortality due to rebounding striped bass populations (Ellis and Vokoun 2009, Lynch et al. 2014).

**Climate Impacts:** Anadromous species like alewife and blueback herring utilize a wide range of habitats throughout their life cycle, making predictions about responses to climate change particularly complicated. Each life stage is likely to be impacted in a unique way (Lynch et al. 2014). However, initiation of spawning is known to be cued by temperature (Hasselman et al. 2014). Many studies have found long-term warming trends for North American rivers over the past century (Ellis and Vokoun 2009). Spring water temperatures in several New England streams have begun reaching suitable spawning temperatures about twelve days earlier than in the 1970s, implying that runs of river herring are occurring earlier (Ellis and Vokoun 2009).

Warming in the marine environment has also been observed and will likely increase (Nye et al. 2009). Such warming is expected to shift distributions of many fish species poleward. A similar shift has already been observed for alewife, and, given predictions for future warming, may continue (Nye et al. 2009).
The recent petition to list river herring under the ESA prompted a modeling study to isolate the impacts of climate change on river herring populations (Lynch et al. 2014). This study determined that, overall, climate change is likely to impact river herring populations negatively in the Northwest Atlantic Ocean from Cape Hatteras to the Gulf of Maine, with reductions in suitable habitat. However, the authors of the study were careful to note that these projections isolate the effects of ocean warming and that these effects will not occur independently of other stressors, including biotic interactions and the effects of dams.
American Brook Lamprey

**Scientific Name:** Lethenteron appendix

**Species Stressors:** Aquatic connectivity loss, Change in timing of seasons, Changes in hydrology, Development and habitat loss, Precipitation changes, Storms and floods, Temperature change

**Background:** The American brook lamprey is a primitive, eel-like fish that occupies coldwater habitats in creeks and small to medium rivers. This species spends much of its life as filter-feeding larvae in silty stream sediments (Cochran et al. 2012). After 3-5 years the American book lamprey undergoes a metamorphosis that begins in the fall or winter, and is completed by mid-April to May, when it begins spawning (Natural Heritage and Endangered Species Program 2008a). The adults spawn in coarse substrates just upstream from riffles, most commonly at temperatures of 10–15°C; however spawning activity has been reported at temperatures as low as 6.7°C and as high as 20.6°C (Cochran et al. 2012). Both adults and ammocoetes (larvae) require permanent, high-quality coldwater habitats that are clear and unpolluted, and remain between 14-22.5°C during the summer (Page and Burr 1991). The adults typically occupy river portions with sand and gravel substrates, and the ammocoetes silty pools with slower water flow (Page and Burr 1991). The spawning period is only a few days in duration, and is followed by death (Cochran et al. 2012). There are currently only 12 known populations of the American brook lamprey in Massachusetts, and it is listed as threatened in the state (Natural Heritage and Endangered Species Program 2008a).

**Climate Impacts:** The coldwater streams that this species inhabits are vulnerable to the effects of climate change, which can include changes in temperature regimes, and the timing of peak flows (Manomet Center for Conservation Sciences and National Wildlife Federation 2013). Climate change is also expected to alter riverine habitats by increasing the frequency and severity of floods and droughts (Dolloff et al. 1989, Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Lampreys are particularly vulnerable to sedimentation, and extreme changes in water levels (Natural Heritage and Endangered Species Program 2008a), both of which can accompany floods and droughts, particularly in landscapes that are already disturbed. Extreme floods can also strip streams of sediment layers (Dolloff et al. 1989) which could remove important habitats for ammocoetes.

There is also concern that some waterbodies may warm beyond the physiological tolerances of some fish species (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). In response, some species of cold-water adapted fishes are shifting poleward or to higher altitudes in response to increases in water temperature (Comte et al. 2013). Lampreys are believed to be sensitive to water temperature increases (Natural Heritage and Endangered Species Program 2008a), but 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), with unknown effects on the food web. Moreover, refugia resulting from groundwater inputs and riparian cover can locally buffer the effects of increasing temperatures (Argent and Kimmel 2013).
American eel

**Scientific name:** Anguilla rostrata

**Species Stressors:** Aquatic connectivity loss, Temperature change

**Background:** The American eel exhibits a life-cycle involving growth in freshwater, and reproduction in the ocean (Hanel et al. 2014). The coastal range of American eels extends from southern Greenland to Venezuela (Rypina et al. 2014). Eels from throughout this range spawn in the Sargasso Sea, in some cases migrating thousands of miles from coastal areas (Kuroki et al. 2014). The transparent larvae are transported by ocean currents back to coastal areas where they will either migrate up rivers or remain in estuaries (Friedland et al. 2007, Munk et al. 2010). Eels will spend from 3-30 years growing in these environments during a phase in which they are referred to as yellow eels (Rypina et al. 2014). They then develop into silver eels and migrate back to the Sargasso sea to spawn (Harrison et al. 2014). Upon spawning, American eels die (Vélez-Espino and Koops 2010).

American eels are one of three closely related northern hemisphere eel species, two of which, American and European eels, both spawn in the Sargasso sea (Harrison et al. 2014). All three of these species have undergone dramatic declines since the 1970s (Vélez-Espino and Koops 2010). European eels have declined by 99% (Casselman and Cairns 2003), and American eel recruitment to eastern Ontario waters has declined by 97% since the early 1980s (Harrison et al. 2014). Though causes of declines remain unclear, suspected reasons include climate change, over fishing, habitat loss and degradation, barriers to migration, disease, and pollution (Righton et al. 2012).

**Climate Impacts:** American eels in their coastal habitats inhabit an extremely broad latitudinal range, and are generalist in their choice of prey, suggesting they should be relatively adaptable to climate change within these environments (Knights 2003). They do exhibit some latitudinal gradients in behavior. For example, in northern latitudes where marine environments are more productive relative to freshwater environments, there is a higher probability that eels will spend their entire growth phase in saltwater (Vélez-Espino and Koops 2010). Consequently, changes related to climate may possibly influence these latitudinal gradients.

On the other hand, most life history events related to reproduction and recruitment occur in the marine environment (Friedland et al. 2007). Early development, larval migration, and marine survival are all influenced by oceanic and climatic factors. Declines throughout the range have led some to suggest that the main cause of declines must be related to this common environment, particularly events in the Sargasso sea (Bonhommeau et al. 2008). Temperatures in the Sargasso Sea have been increasing and may have caused changes to productivity. Shifts in temperature regimes detected in the 1970s were followed by shifts in recruitment for all three northern hemisphere eel species. Temperature induced oceanic changes may be impacting larval survival through reduced food availability (Friedland et al. 2007, Bonhommeau et al. 2008).
American shad

**Scientific name:** Alosa sapidissima

**Species Stressors:** Aquatic connectivity loss, Temperature changes, Precipitation changes, Changes in hydrology, Storms and floods, Change in timing of seasons, Invasive plants and animals, Pests and diseases

**Background:** American shad are an anadromous species of fish with a life history that involves extensive ocean and freshwater migrations (Leggett 1976). Historically, shad may have migrated up to 1,000 km upstream in coastal rivers to spawn (Leggett 1976). Shad range along the Atlantic coast from northern Florida to the St. Lawrence River in Canada, being most abundant between North Carolina and Connecticut (Leggett 1976). Populations of shad once occurred in nearly 140 rivers extending from the Pinware River in Labrador to the St. John’s River in Florida (Waldman et al. 2014). Current populations are greatly reduced from historical levels, resulting in the closure of some fisheries (Waldman et al. 2014).

In the Connecticut River, shad spawn in May and June (Savoy et al. 2004). Surviving adults leave the river by mid-August and migrate to summer feeding grounds in the Gulf of Maine (Savoy et al. 2004). Individuals in the Bay of Fundy will mix with shad that have migrated from throughout the range (Waldman et al. 2014). In November, when water temperatures drop below 12°C, fish migrate south to Florida until approximately February, when they begin migrating back towards the Connecticut River (Savoy et al. 2004). Juvenile shad spawned in the spring of the year migrate down river in late fall (Savoy et al. 2004).

**Climate Impacts:** Migrations of shad are cued by, and correlated with, temperature. Shad commence spawning in response to temperature cues, leave rivers in response to temperature, and make ocean migrations based on temperature (Savoy et al. 2004, Kerr et al. 2009). Fish from the Connecticut River move south to Florida by following the 12-13°C isotherm (Savoy et al. 2004). The importance of temperature cues suggests that changes to migration timing are likely with climatic change (Kerr et al. 2009). Introduced shad in the Columbia River are documented to be migrating more than five weeks earlier than they did in 1949 following a long-term warming trend caused by construction of impoundments (Kerr et al. 2009, Hinrichsen et al. 2013).

Many aspects of shad life-history follow latitudinal gradients that are likely to be linked to climatic factors. South of Cape Hatteras, shad are semelparous (they die following spawning) while north of Cape Hatteras, they are iteroparous (many individuals will survive spawning, return to the ocean, and repeat spawning in subsequent years) (O’Connor et al. 2012). In addition, the degree of iteroparity increases moving north from Cape Hatteras. Spawning occurs earlier in southern latitudes, timed to correspond with optimal temperatures for survival of eggs and larvae (Kerr et al. 2009). Additionally, the proportion of shad that are mature by age five increases from north to south, with 25% of New England fish mature at age five and 70% of South Carolina fish mature at age five (Tuckey and Olney 2010). This all implies that climate has the potential to have multiple direct effects on shad life history, complicating predictions about response to climate.
In addition to these direct effects, climate change is likely to have indirect effects related to changes in community structure. For example, higher temperatures favor colonization of new habitats by invasive zebra mussels, and their colonization of the Hudson River has been associated with slower growth and reduced abundance of American shad (Kerr et al. 2009).

American shad have been studied extensively in the Connecticut River. Studies have shown that high river flows and low temperatures during spring spawning result in high mortality of eggs and larvae; these two factors were significantly correlated with year-class strength in the period from 1966 to 1973 (Savoy et al. 2004). Based on this information, climate change might be expected to favor shad abundance in the Connecticut River. However, how temperature might interact with flow is unclear. Projections for the Northeast suggest a longer period of summer low flows (Fan et al. 2014), which could be favorable for spawning shad. However, other hydrological changes are expected, including earlier timing of peak spring flows and increased frequency of extreme storm events (Brooks 2009, Fan et al. 2014).
Atlantic salmon

Scientific Name: Salmo salar

Species Stressors: Aquatic connectivity loss, Changes in the timing of seasons, Changes in hydrology, Changes in winter, Development and habitat loss, Precipitation changes, Storms and floods, Temperature change

Background: Atlantic salmon breed in coastal drainages from Quebec to Connecticut in North America. Some populations are landlocked, while others are diadromous. Landlocked individuals occupy large, deep cold lakes and reservoirs (Natural Heritage and Endangered Species Program 2015a). Diadromous individuals spawn in freshwater streams and rivers in which temperature rise above 10° C for 2-3 months in the summer, but do not exceed 20° C for any significant duration in summer (Page and Burr 1991). Spawning occurs from June to November. Atlantic salmon prefer spawning sites with gravel substrates that are far upstream, and contain sections of interspersed and well oxygenated riffles and pools (Page and Burr 1991). Eggs hatch in the spring. Juveniles typically remain in freshwater habitats for 2-3 years in Massachusetts (Natural Heritage and Endangered Species Program 2015a). Juveniles defend territories in riffle areas in the upper reaches of rivers and streams characterized by coarse gravel substrates and strong currents where they consume mollusks, aquatic insects, crustaceans and fish (Page and Burr 1991). When Atlantic salmon reach 5-9 inches they migrate to the sea, where they spend at least 2 years before returning to their birthplace to spawn (Natural Heritage and Endangered Species Program 2015a). Females may repeat this cycle multiple times. Adults consume a wide variety of marine organisms including crustaceans, and small fishes (Jonsson et al. 2016). The Atlantic salmon has exhibited dramatic declines in Massachusetts in response to severe overfishing, and loss of much of their spawning habitat to siltation (Natural Heritage and Endangered Species Program 2015a). Their restoration has had little success due to poor survival rates at sea, low genetic quality of stocks, and dams that block migration (Natural Heritage and Endangered Species Program 2015a).

Climate Impacts: Climate change is likely to cause habitat loss for landlocked Atlantic salmon populations. The number of lakes suitable for cold-water adapted species is expected to decrease under climate change (Herb et al. 2014). For instance, a doubling of atmospheric carbon dioxide levels is projected to decrease the number of water bodies in the contiguous US with suitable cool or cold water fish habitat by 30% (Stefan et al. 2001).

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), and result in complex changes in the relationship between freshwater and marine habitats (Limburg and Waldman 2009). There is already evidence that climate change is indirectly influencing life history traits of Atlantic salmon such as body condition, size, mass, post-smolt growth, sea survival, and spawning age through dramatic shifts in pelagic food webs, and associated changes in sea surface temperature (Jonsson et al. 2016).

There is also a concern that some freshwater waterbodies may warm beyond the physiological tolerances of some fish species under future climate scenarios (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Climate change models predict overall increases in winter temperatures in the northern hemisphere, and reduction in ice cover; in turn, many cold-adapted fishes in
northern environments, including Atlantic salmon, are expected to experience increases in metabolism when ice melts, which can affect growth and survival (Enders and Boisclair 2016). In addition, in temperatures above 25°C, Atlantic salmon can experience reduced growth rates since maintenance costs increase in warmer water (Jonsson et al. 2016).

Future changes in water flow could also affect Atlantic salmon. For one, climate change is expected to exacerbate changes in the volume and timing of peak flows (Manomet Center for Conservation Sciences and National Wildlife Federation 2013), and may add more barriers to migration. The timing of peak spring migration for juvenile salmon is also controlled by flow, temperature and photoperiod; as such juvenile survival can be significantly reduced if the phenology of spring migration becomes out of synch with optimal conditions in the ocean, estuaries or rivers (Hayhoe et al. 2007). Changes in the timing of high-spring flow may also influence survival of Atlantic salmon (Hayhoe et al. 2007), and intense and chaotic changes in water flow and velocity in general can increase activity costs for Atlantic salmon (Enders and Boisclair 2016). Finally, climate change is also expected to increase the frequency and severity of floods and droughts (Dolloff et al. 1989, Manomet Center for Conservation Sciences and the National Wildlife Federation 2013), both of which can reduce reproductive success for anadromous fishes (Limburg and Waldman 2009).

Climate change is also expected to impact anadromous fishes through shifts in the phenology of spawning migrations, and complex changes in the relationship between freshwater and marine habitats (Limburg and Waldman 2009). Many studies have found long-term warming trends for North American rivers over the past century (Ellis and Vokoun 2009). In response, earlier spawning migration timing has been recorded for Atlantic salmon over the last few decades (Hayhoe et al. 2007, Otero et al. 2014).
Atlantic sturgeon

**Scientific Name:** Acipenser oxyrinchus

**Species Stressors:** Aquatic connectivity loss, Changes in hydrology, Development and habitat loss, Sea level rise, Temperature change

**Background:** The Atlantic sturgeon is an anadromous fish that spends the majority of its life in coastal or estuarine habitats, and spawns in large coastal rivers. All major rivers along the North American Atlantic slope used to support Atlantic sturgeon, but dredging, overharvesting, pollution, dams, and habitat destruction have extirpated this species in many locations and severely reduced abundance globally (Balazik et al. 2016). They are listed as endangered under both the federal and state ESA, and currently only spawn in the Merrimack and Taunton Rivers in Massachusetts (Natural Heritage and Endangered Species Program 2015b). Adult Atlantic sturgeons make long migratory movements along the coast and forage primarily in brackish waters for benthic invertebrates such as crustaceans, mollusks, aquatic insects (Kottelat and Freyhof 2007). Atlantic sturgeons move into freshwater habitats to spawn in May and June (Natural Heritage and Endangered Species Program 2015b), when water temperatures are at 13.3-17.8 °C (Borodin 1925). They require moving freshwater for spawning sites, as well as appropriate substrates to which they can adhere eggs, such as bedrock, hardpan clay, coarse sands (Breece et al. 2013). Males migrate back to the ocean after spawning, but females sometimes remain in the river until the fall (Natural Heritage and Endangered Species Program 2015b). Juveniles remain in rivers feeding until they are 2–6 years of age (Kottelat and Freyhof 2007). Females only reproduce every 2–5 years (Balazik et al. 2016), and do not reach sexual maturity until they are at least 10 years old whereas males begin spawning earlier and mate every 1–5 years (Natural Heritage and Endangered Species Program 2015b). Atlantic sturgeon can grow up to 4.5 m and can live up to 60 years (Balazik et al. 2016).

Dams, water pollution, and the availability of high-quality spawning habitat, are all thought to be limiting factors in the recovery of Atlantic sturgeon (Breece et al. 2013, Natural Heritage and Endangered Species Program 2015b).

**Climate Impacts:** Climate change is expected to reduce habitat availability, location and quality for Atlantic sturgeon. Increased salt-water intrusion from the ocean is likely to occur under climate change and sea level rise, and will reduce or shift suitable habitat for Atlantic sturgeon, and cause siltation of existing spawning habitats (Breece et al. 2013). For instance, the salt front is expected to move upstream by at least 11 km in the Delaware River under climate change projections by 2100; moreover, this shift is likely to be exacerbated by dredging, which can interact with climate change to increase siltation which in turn causes embryonic mortality (Breece et al. 2013).

Changes in water temperatures can also impact the physiology and growth of Atlantic sturgeon. Based on historic refuse samples from the Jamestown colony, the Atlantic sturgeon population in the James River currently consists of smaller individuals, a lower proportion of older individuals and faster growth rates compared to populations from the 1600s (Balazik et al. 2016). While this could partially be a legacy of severe overexploitation, these physiological changes are also likely related to increases in sea surface temperature, as slower growth rates at higher latitudes where temperatures are lower have been exhibited for both lake sturgeon and American shad (Balazik et al. 2016). Similarly, warming in the marine environment is expected to increase further, and shift many species poleward, as has been seen already for alewife, another anadromous fish species. The critical thermal threshold for Atlantic sturgeon is however
quite high (30.8°C) indicating that changes in water temperature under climate change are not likely to be lethal for adults, though the combined effects of high carbon dioxide and temperatures and low oxygen on this species is still poorly understood and could cause a sub-lethal stress response (Spear and Kieffer 2016).

Many studies have also found long-term warming trends for North American rivers over the past century (Ellis and Vokoun 2009), and spawning of Atlantic sturgeon is thought to be prompted by temperature (Borodin 1925, Smith 1997), so spawning may be triggered earlier for Atlantic sturgeon in response to climate change.
**Blacknose dace**

**Scientific Name:** Rhinichthys atratulus

**Species Stressors:** Changes in hydrology, Changes in winter, Development and habitat loss, Precipitation changes, Storms and floods, Temperature change

**Background:** The blacknose dace is a small fish of 3–4 inches that inhabits the pools of headwaters, and rocky runs of creeks and small rivers, particularly in fast moving water (Page and Burr 1991). They are the most common stream minnow from the Hudson River drainage to the Merrimack River drainage. Although they inhabit nearly every hill stream in central and western Massachusetts, they are currently only found in a few areas of eastern Massachusetts (Natural Heritage and Endangered Species Program 2015c). The blacknose dace feeds on aquatic insects, algae, and diatoms (Page and Burr 1991), though aquatic fly larvae are favored (Natural Heritage and Endangered Species Program 2015c). They may be threatened by sediment deposition in spawning areas, and water pollution (Natural Heritage and Endangered Species Program 2015c).

**Climate Impacts:** The coldwater streams that this species inhabits are vulnerable to the effects of climate change, which can include habitat loss, changes in temperature regimes, and the timing of peak flows (Manomet Center for Conservation Sciences and National Wildlife Federation 2013). Based on maximum temperature tolerance, this species is predicted to lose 17.4% of its nationwide habitat under a doubling of atmospheric carbon dioxide (Mohseni et al. 2003). Climate change is also expected to alter riverine habitats by increasing the frequency and severity of floods and droughts (Dolloff et al. 1989, Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Dace are believed to be vulnerable to sedimentation (Natural Heritage and Endangered Species Program 2008a) which can accompany floods, especially in otherwise disturbed landscapes. However, there is also evidence that pool-adapted species like the blacknose dace may be less sensitive to floods and drought than riffle-adapted species (Danehy et al. 1998).

There is also concern that some waterbodies may warm beyond the physiological tolerances of some fish species (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013), and that some species of cold-water adapted fishes are shifting poleward or to higher altitudes in response to increases in water temperature (Comte et al. 2013). However, refugia resulting from groundwater inputs and riparian cover can locally buffer the effects of increasing temperatures (Argent and Kimmel 2013). Finally, harsh winter temperatures can also adversely affect body condition in blacknose dace (Butler et al. 2005), so increases in overall winter temperatures could benefit this species.
Blueback herring

Scientific Name: Alosa aestivalis

Species Stressors: Aquatic connectivity loss, Temperature changes, Changes in hydrology, Storms and floods, Change in timing of seasons, Invasive plants and animals, Pests and diseases

Background: River herring is a term referring collectively to alewife and blueback herring. The two species are commonly referenced together as they have similar life histories and are very similar in appearance (Loesch 1987). They are native to the Atlantic coast of North America and co-occur in rivers throughout much of their range (Loesch 1987). The native range of alewife extends from Labrador to South Carolina while that of blueback herring extends from the Gulf of St. Lawrence to Florida (Hasselman et al. 2014). Both species are anadromous, returning to natal freshwaters to spawn after spending 3-6 years in the ocean (Mather et al. 2012). Alewife use stream corridors to access ponds for spawning, although they will also use quiet reaches of rivers, whereas blueback herring prefer flowing waters in rivers and streams for spawning (Hall et al. 2011, Mather et al. 2012). Alewifes spawn at cooler temperatures than blueback herring, resulting in initiation of spawning 3-4 weeks earlier. Despite this, there is much overlap in timing of spawning between the two species (Hasselman et al. 2014). In New England, spawning may extend from late March to early June (Durbin et al. 1979). Adult river herring migrate to the ocean once spawning is completed, while juveniles migrate from nursery habitats in October to November of the same year (Post et al. 2015). River herring are iteroparous, meaning they return to freshwater to spawn multiple times (Hall et al. 2011).

River herring are an important forage resource for many species of birds and fish (Post et al. 2015). Historically, river herring supported thriving fisheries (Palkovacs et al. 2014). Although early dam construction, habitat degradation, and harvest resulted in large declines, a stable fishery existed through the 1960s (Palkovacs et al. 2014). Recent declines have been precipitous and prompted a petition to consider the two species for listing under the Endangered Species Act (ESA) (Lynch et al. 2014). Recent declines may be due to overharvest in marine fisheries and higher levels of natural mortality due to rebounding striped bass populations (Ellis and Vokoun 2009, Lynch et al. 2014).

Climate Impacts: Anadromous species like alewife and blueback herring utilize a wide range of habitats throughout their life cycle, making predictions about responses to climate change particularly complicated. Each life stage is likely to be impacted in a unique way (Lynch et al. 2014). However, initiation of spawning is known to be cued by temperature (Hasselman et al. 2014). Many studies have found long-term warming trends for North American rivers over the past century (Ellis and Vokoun 2009). Spring water temperatures in several New England streams have begun reaching suitable spawning temperatures about twelve days earlier than in the 1970s, implying that runs of river herring are occurring earlier (Ellis and Vokoun 2009).

Warming in the marine environment has also been observed and will likely increase10. Such warming is expected to shift distributions of many fish species poleward. A similar shift has already been observed for alewife, and, given predictions for future warming, may continue (Nye et al. 2009).

The recent petition to list river herring under the ESA prompted a modeling study to isolate the impacts of climate change on river herring populations (Lynch et al. 2014). This study determined that overall climate change is likely to impact river herring populations negatively in the Northwest Atlantic Ocean.
from Cape Hatteras to the Gulf of Maine, with reductions in suitable habitat. However, the authors of the study were careful to note that these projections isolate the effects of ocean warming and that these effects will not occur independently of other stressors, including biotic interactions and the effects of dams.
Bridle shiner

Scientific Name: Notropis bifrenatus

Species Stressors: Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Storms and floods, Temperature change

Background: The bridle shiner is a small fish that ranges from the St. Lawrence River basin in Canada to the Santee River basin in South Carolina. It is found in clear and slow-flowing streams, rivers, and lakes characterized by fine substrates and moderate to abundant submerged aquatic vegetation (Kilian et al. 2011). The bridle shiner spawns from May through August and in areas with submerged aquatic vegetation to which eggs can adhere (Kilian et al. 2011, Natural Heritage and Endangered Species Program 2015d). They are not strong swimmers and to avoid predation they spend time in thick vegetation as juveniles or school in open areas as adults (Natural Heritage and Endangered Species Program 2015d). They feed on invertebrates like Chironomideae, CHladocera, and Copepoda (Natural Heritage and Endangered Species Program 2015d).

Field surveys have documented decline in this species, however, little is known about is basic ecology, physiology or behavior (Gray et al. 2014). Invasive aquatic plant species (Hydrilla and Eurasian Watermilfoil) and predators such as largemouth bass, channel catfish and blue catfish are thought to be partly responsible for extirpation of this species in many locations (Kilian et al. 2011). The bridled shiner is listed as a species of special concern in Massachusetts (Natural Heritage and Endangered Species Program 2015d).

Climate Impacts: There is little published information on the expected impacts of climate change to this species; however, we can make some educated inferences. Declines more prevalent in the southern portion of its range (Kilian et al. 2011), which may indicate that increases in water temperature are influencing the distribution, reproductive success and/or physiology of this species. The coldwater streams that this species inhabits are likely vulnerable to the effects of climate change, which can include changes in temperature regimes, and the timing of peak flows (Manomet Center for Conservation Sciences and National Wildlife Federation 2013). There is also concern that may lakes and streams may warm beyond the physiological tolerances of some fish species (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013).

Climate change is also expected to alter riverine habitats by increasing the frequency and severity of floods and droughts (Dolloff et al. 1989, Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Population declines have been linked to increased sedimentation and turbidity and subsequent loss of submerged aquatic vegetation for bridle shiners (Kilian et al. 2011). Even very low levels of turbidity altered schooling behavior and swimming speed of bridle shiners, both of which can influence physiology and survival (Gray et al. 2014). Extreme flood and storms can increase turbidity and alter sedimentation, particularly in landscapes that are already disturbed.
**Brook trout**

**Scientific Name:** Salvelinus fontinalis

**Species Stressors:** Aquatic connectivity loss, Temperature changes, changes in hydrology, Storms and floods, Change in timing of seasons, Invasive plants and animals, Pests and diseases

**Background:** Brook trout are an economically important game species throughout their native range, which extends south in the Appalachians to Georgia (Hudy et al. 2008) and north to the Atlantic drainages of Newfoundland, Labrador, and Quebec (Ficke et al. 2009). Brook trout in Massachusetts are found primarily in streams that have cold, highly oxygenated water (Hartel et al. 2002). They generally do not tolerate extended periods of water temperatures in excess of 20°C (Hartel et al. 2002), and the optimal temperature for growth and activity is between 12-19°C (Waco and Taylor 2010). Because of their requirements for clean, cold water, brook trout have experienced extensive reductions in distribution and abundance resulting from degradation of habitat (Hudy et al. 2008). In Massachusetts, wild, reproducing populations of brook trout have been greatly reduced, with the majority that remain being restricted to isolated headwater streams (Eastern Brook Trout Joint Venture 2006).

**Climate Impacts:** This species’ need for cold water implies that there is great potential for climate change to impact brook trout populations. Indeed, modeling studies conducted in various parts of its range, including parts of Canada (Chu et al. 2005), and in the southern Appalachians (Flebbe et al. 2006), suggest large reductions in future distributions for brook trout. Studies commonly have found that, in streams where temperatures exceed 20°C for extended periods, brook trout are either at low abundance or are absent altogether (Wehrly et al. 2007, Stranko et al. 2008, Kratzer, J.F. 2013). Brook trout begin to experience significant mortality as water temperatures approach 25°C (McCormick et al. 1972). However, studies have observed physiological indicators of heat stress in temperatures as low as 21°C (Chadwick et al. 2015). These sublethal temperatures are accompanied by decreased feeding, growth, and reproduction (Robinson et al. 2010, Warren et al. 2012). In one Adirondack Lake with marginal temperatures for brook trout, warm temperatures in some years resulted in complete failure to reproduce (Robinson et al. 2010).

Some studies have found that different strains of brook trout have different degrees of thermal tolerance, suggesting some limited capacity to adapt to higher temperatures (Stitt et al. 2014). However, on a broad geographic scale, distribution is largely defined by temperature constraints (Meisner 1990, Baird and Krueger 2003), suggesting that adaptive capacity is limited. Nonetheless, in some cases, brook trout do persist in rivers and streams where temperatures are at or even above lethal temperatures (Baird and Krueger 2003). Under such conditions, trout seek out thermal refuges such as inflows from cold tributaries or groundwater inputs, where they will aggregate until overall temperatures are more favorable (Baird and Krueger 2003). Additionally, brook trout are able to persist in surprisingly small, isolated populations above barriers in headwater streams (Letcher et al. 2007). Due to these characteristics, there is potential that these trout could continue to persist in isolated pockets in areas where larger populations recede (Kanno et al. 2014). While brook trout will likely not disappear from Massachusetts, reductions in suitable habitat are expected.
**Burbot**

**Scientific Name:** Lota lota

**Species Stressors:** Changes in hydrology, Changes in winter, Development and habitat loss, Invasive plants and animals, Precipitation changes, Storms and floods, Temperature change

**Background:** The burbot is a cold-adapted cod species that is distributed globally, but is rarely found below a latitude of 40°N because it has a very narrow temperature range within which it can survive (Jackson et al. 2008). They are rare in Massachusetts, where they are near the southern edge of their range, and listed as a species of special concern in the state (Natural Heritage and Endangered Species Program 2015e). Adults occupy cold waters of large rivers with slow currents, deep lakes, estuaries of large lowland rivers, and small mountain streams (Cohen et al. 1990). Burbots seek out shelter in deep holes, under rocks or trees, in river bank crevices, and are typically found in deeper waters, especially in the summer (Natural Heritage and Endangered Species Program 2015e). Larvae feed on zooplankton and small invertebrates, juveniles feed on insect larvae, mollusks and crayfish, and adults on small fishes (Cohen et al. 1990). Burbots are well adapted to low temperatures and low levels of oxygen and food in the winter (Shuter et al. 2012). They spawn from November to March, under ice, at temperatures below 6°C, and may make small spawning migrations (Cohen et al. 1990, Natural Heritage and Endangered Species Program 2015e). Young appear late February to June, and undergo rapid growth for the first 4 years of life (Natural Heritage and Endangered Species Program 2015e). Burbots can move great distances, up to 125 km, with distances of 20 km common, and can live for 10-15 years (Natural Heritage and Endangered Species Program 2015e).

Burbots are still widespread globally, but some populations are facing serious declines or are already extinct (Stapanian et al. 2010). Threats to this species include pollution and habitat change from dams in riverine habitats, pollution and exotic invasive species in lake habitats, and climate-change and dam induced increases in water temperatures at the southern end of their range (Stapanian et al. 2010).

**Climate Impacts:** Climate change induced habitat loss and distributional changes are likely for this species. Climate change is expected to decrease the number of lakes suitable for cold-water adapted species (Herb et al. 2014). For instance, a doubling of atmospheric carbon dioxide levels is projected to decrease the number of water bodies in the contiguous US with suitable cool or cold water fish habitat by 30% (Stefan et al. 2001). There is also concern that some waterbodies may warm beyond the physiological tolerances of some species (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). In response, some cold-water adapted fishes will likely shift poleward or to higher altitudes (Comte et al. 2013). Cold-adapted species are also predicted to move deeper in the water column, with warmer-adapted species filling the niches they leave behind (Lynch et al. 2010). The coldwater streams and rivers that this species can also inhabit are likely to exhibit changes in in temperature regimes and the timing of peak flows in response to climate change (Manomet Center for Conservation Sciences and National Wildlife Federation 2013), as well as severe changes in habitat through increased frequency and severity of floods and droughts (Dolloff et al. 1989, Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Burbots are thought to be particularly sensitive to habitat disturbance, and changes in community structure (Stapanian et al. 2010).

Climate change may also affect the physiology and demography of some cold water fishes. Increases in surface water temperature and longer periods of thermal stratification and ice-free conditions in lakes and ponds are expected under climate change, and can impact cold water fishes because they have narrow niches at which they achieve maximum growth rates, activity levels, and swimming performance (Shuter et al. 2010).
and Meisner 1992). Temperature shifts can also lead to differences in age of maturity of adults and survival rate of juveniles (Shuter and Meisner 1992). For instance, burbots showed a significant decrease in hatchling and larval success with increasing temperatures and have declined over the last 50 years in Lake Oneida, New York in conjunction with rising summer temperatures, apparently from reduced access to prey (Lahnsteiner et al. 2012). 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). Increased summerkill (in response to high temperature and low dissolved oxygen content in the water) is also expected to have significant adverse effects on cool and cold water habitats (Stefan et al. 2001). Burbot show signs of starvation during summer months in Oneida Lake, and predictive models indicate that temperatures greater than 21°C are expected to cause significant weight loss (Jackson et al. 2008).
Common shiner

Scientific Name: Luxilus cornutus

Species Stressors: Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Storms and floods, Temperature change

Background: The common shiner is a small minnow that ranges through much of southern and central Canada, and the northern and central US. This species is found in rocky pools near fast moving riffles of cool creeks and small to medium rivers, and occasionally lakes in the northern extent of their range (Coker et al. 2001). In Massachusetts, they are found in small streams with clean, clear water, and are more common in the portion of the state (Natural Heritage and Endangered Species Program 2015f). They spawn in gravel beds, where they establish nests (Coker et al. 2001). They are a cool water adapted species, with a maximum temperature tolerance of 29°C (Mohseni et al. 2003). Common shiners are in decline, though the cause for this trend is unknown (Natural Heritage and Endangered Species Program 2015f). Minnows in general are the most threatened family of fishes, and are sensitive to a variety of anthropogenic stressors (Findlay et al. 2000). This species is believed to be adversely affected by the introduction of pike and bass that prey heavily upon them (Findlay et al. 2000).

Climate Impacts: There is little published information on the expected impacts of climate change to this species; however, we can make some educated inferences. The cool-water streams that this species inhabits are vulnerable to the effects of climate change, which can include changes in temperature regimes, and the timing of peak flows (Manomet Center for Conservation Sciences and National Wildlife Federation 2013). Based on upper thermal tolerances, the common shiner is expected to lose 29 to 77% of available habitat under limited to major warming scenarios in Wisconsin (Lyons et al. 2010), and 12% of its habitat nationwide, under a doubling of atmospheric carbon dioxide levels (Mohseni et al. 2003). Climate change is also expected to alter riverine habitats by increasing the frequency and severity of floods and droughts (Dolloff et al. 1989, Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). There is also concern that some waterbodies may warm beyond the physiological tolerances of some fish species (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013), and that some species of cold and cool-water adapted fishes are shifting poleward or to higher altitudes in response to increases in water temperature (Comte et al. 2013).
Creek chub

Scientific Name: Semotilus atromaculatus

Species Stressors: Aquatic connectivity loss, Changes in hydrology, Changes in winter, Development and habitat loss, Precipitation changes, Storms and floods, Temperature change

Background: Creek chub are one of the most common fishes in eastern North America, and are an important ecological component of many headwater streams (Walker and Adams 2016). They are a cool water adapted species (Hansen et al. 2015) that inhabits rocky and sandy pools of small rivers, creeks, and headwaters, and are particularly common in intermittent streams (Page and Burr 2011). MA creek chub are primarily found in the western portion of the state (Massachusetts Division of Fisheries and Wildlife 2015). The adults consume fishes, mollusks, aquatic insect larvae, and the young feed on small aquatic invertebrates (Page and Burr 2011). Males create little depressions for spawning, and after they attract females to these sites, they cover the eggs with gravel, and proceed again slightly downstream (Page and Burr 2011). Threats to this species include increases in water turbidity and pollution (Massachusetts Division of Fisheries and Wildlife 2015). Creek chub is commonly used as a bait fish, and has thus been introduced accidentally in some regions where it competes with native brook trout (Marcogliese 2001).

Climate Impacts: The cool water streams that this species inhabits are vulnerable to the effects of climate change, which can include changes in temperature regimes, and the timing of peak flows (Manomet Center for Conservation Sciences and National Wildlife Federation 2013). This species is predicted to lose 13 to 46% of its habitat in Wisconsin under limited to major climate warming projections (Lyons et al. 2010), and 18% of its nationwide habitat under a doubling of atmospheric carbon dioxide (Mohseni et al. 2003). Climate change will likely make the intermittent streams that this species tends to inhabit more intermittent, which can negatively influence stream fish through stress, crowding, reduced water quality, and direct mortality from desiccation (Walker and Adams 2016). Creek chub are thought to be typically sedentary and remain in stream segments < 600m in length throughout their entire life cycle (Blevins et al. 2014). However, this species does appear to be highly mobile, and were found dispersing up to 4678 m upstream in one study, indicating that they may be able to adapt to habitat changes induced through climate change behaviorally (Walker and Adams 2016). There is also concern that some waterbodies may warm beyond the physiological tolerances of some fish species (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Creek chub that are found in disturbed landscape with higher stream temperatures exhibited stress responses; however, these stress responses were tempered compared to those of creek chub in more pristine reaches, suggesting that this species may be able to persist in disturbed areas at least in the short term by limiting the costs of thermal stress (Blevins et al. 2014). Moreover, refugia resulting from groundwater inputs and riparian cover can also locally buffer the effects of increasing temperatures (Argent and Kimmel 2013).

Climate change is also expected to alter riverine habitats by increasing the frequency and severity of floods and droughts (Dolloff et al. 1989, Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Creek chub are believed to be impacted by stream turbidity (Massachusetts Division of Fisheries and Wildlife 2015), which can accompany floods, particularly in otherwise disturbed landscapes. Creek chub can be adversely affected during periods of flood or drought, particularly if these events occur during spawning, but because this species tends to occupy pools rather than riffles, it is less impacted than other small fishes (Danehy et al. 1998).
Finally, changes in winter conditions could also affect creek chub. Creek chub body condition can substantially decline in severe winter conditions (Butler et al. 2005), so overall warming in winter temperatures could benefit this species. However, reduced surface ice cover is also expected with climate change, which could impact some freshwater fishes (Hansen et al. 2015). Creek chub were not found to exhibit large differences in energy use in simulated conditions of reduced surface ice however, though other implications of reduced ice cover, such as increased predation, and changes in competitive interactions are still poorly understood (Hansen et al. 2015).
**Lake chub**

**Scientific Name:** *Couesius plumbeus*

**Species Stressors:** Aquatic connectivity loss, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Storms and floods, Temperature change

**Background:** Lake chub is a large minnow that typically inhabits cold fast moving rivers and clear, cold lakes with coarse gravel or cobble substrates, and minimal vegetation (Natural Heritage and Endangered Species Program 2015g). They tend to inhabit shallower water, but can move into deeper water bodies during hot weather (Morrow 1980). They spawn in streams in early spring, and both lake and river populations often must make long migrations, up to 10 km to spawning locations (Natural Heritage and Endangered Species Program 2015g). Lake chub consumes algae, zooplankton, aquatic and terrestrial insects, and other small fishes (Scott and Crossman 1973). They mature at 3-4 years of age, and seldom live more than 5 years (Natural Heritage and Endangered Species Program 2015g). Lake chub are listed as endangered in Massachusetts, and are only known to be found in a small portion of the Berkshires (Natural Heritage and Endangered Species Program 2015g). Threats to this species include changes in stream flow, pollution, erosion, sedimentation, introduction of non-native fishes, and increased turbidity (Stasiak 2006a, Natural Heritage and Endangered Species Program 2015g).

**Climate Impacts:** Climate change could affect lake chub through habitat loss, habitat decline, and distributional changes. Under a projected doubling of atmospheric carbon dioxide levels, the number of water bodies in the contiguous US with suitable cold water fish habitat is expected to decrease by 30%, with the largest impact on shallow lakes < 4m in depth (Stefan et al. 2001). Cold-adapted species are also predicted to shift north and move deeper in the water column, with warmer-adapted species filling the niches they leave behind (Lynch et al. 2010). Periodic drought conditions on the Great Plains have already diminished suitable habitat for lake chub (Stasiak 2006a). The coldwater streams and rivers that this species can also inhabit are vulnerable to the effects of climate change, which can include changes in temperature regimes and the timing of peak flows (Manomet Center for Conservation Sciences and National Wildlife Federation 2013). The latter may be particularly important for lake chub that rely on stream flows for dispersal and migration to spawning habitats (Stasiak 2006a). Lake chub also require very clear water because they are sight feeders, and can exhibit poor reproductive success and embryo mortality with high degree of siltation and sedimentation (Stasiak 2006a). Disturbance of terrestrial habitats through silviculture and agriculture can contribute to sedimentation and siltation in lake chub habitat (Stasiak 2006a), and the increased flooding and more frequent extreme storm events expected under climate change can exacerbate this problem.

Climate change may also affect the physiology and demography of some cold water fishes. Increases in surface water temperature and longer periods of thermal stratification and ice-free conditions in lakes and ponds are expected under climate change, and can impact cold water fishes because they have narrow niches at which they achieve maximum growth rates, activity levels, and swimming performance (Shuter and Meisner 1992). Temperature shifts can also lead to differences in age of maturity of adults and survival rate of juveniles (Shuter and Meisner 1992). For instance, burbot showed a significant decrease in hatchling and larval success with increasing temperatures and have declined over the last 50 years in Lake Oneida, New York in conjunction with rising summer temperatures, apparently from reduced access to prey (Lahnsteiner et al. 2012). Increased summerkill (in response to high temperature and low dissolved oxygen content in the water) is also expected to have significant adverse effects on cool and cold water habitats (Stefan et al. 2001). There is however some evidence that lake chub may be able to
adapt to changes in water temperatures precipitated by climate change: In addition to their typical cool water habitats lake chub can also be found in thermal hot springs in northern Canada where they exhibit a very different thermal breadth, indicating that this species has some adaptive capacity in terms of thermal range (Darveau et al. 2012).
Longnose dace

Scientific Name: Rhinichthys cataractae

Species Stressors: Aquatic connectivity loss, Changes in hydrology, Development and habitat loss, Precipitation changes, Storms and floods, Temperature change

Background: Longnose dace are small (3-6 inch) fish that occupy small to medium rivers, fast-moving creeks, and rocky lake shores throughout much of the northern reaches of North America (Scott and Crossman 1973). In Massachusetts they are most common in the western portion of the state, and can be found in very high densities in some areas (Natural Heritage and Endangered Species Program 2015h). Adults are typically found near the bottom or in rubble and gravel in areas of turbulent water, or nearby pools (Natural Heritage and Endangered Species Program 2015h), whereas the young are pelagic for the first four months of life, and tend to occupy still inshore waters (Scott and Crossman 1973). Longnose dace eat immature aquatic insects, especially larval blackflies and midges (Natural Heritage and Endangered Species Program 2015h). They spawn in gravel substrates, in riffles, often near nests of river chub, and eggs hatch at 15.6 °C (Page and Burr 1991). Adults can live up to 5 years (Natural Heritage and Endangered Species Program 2015h).

Climate Impacts: The cool water streams that this species inhabits are vulnerable to the effects of climate change, which can include changes in temperature regimes, and the timing of peak flows (Manomet Center for Conservation Sciences and National Wildlife Federation 2013). There is also concern that some waterbodies may warm beyond the physiological tolerances of some fish species (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). This species is typically associated with steep, cold waters, but can be found in lower-gradient warm-water rivers (Natural Heritage and Endangered Species Program 2015h), suggesting that it might be able to tolerate a range of temperatures. Climate change can also lead to significant loss of available habitat through temperature increases; based on maximum temperature tolerance, this species is predicted to lose 26 to 94% of its habitat in Wisconsin under limited to major climate warming projections (Lyons et al. 2010), and 22.2% nationwide under a doubling of atmospheric carbon dioxide (Mohseni et al. 2003).

Climate change is also expected to alter riverine habitats by increasing the frequency and severity of floods and droughts (Dolloff et al. 1989, Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Longnose dace were shown to be adversely affected by flood and drought conditions in a New York stream (Danehy et al. 1998). Drought in particular can cause loss of the shallow habitats upon which they rely, loss of aquatic connectivity, reduced access to refugia, decline in water quality, changes in dissolved oxygen and pH, and increased competition and predation (Avery-Gomm et al. 2014). Drought conditions caused significant declines in the abundance of the ecologically similar Nooksack dace (Rhinichthys cataractae ssp. endemic to Washington State) and reduced growth rates, indicating that use of pools for refugia did not alleviate the sub-lethal effects of drought (Avery-Gomm et al. 2014).
Northern redbelly dace

**Scientific Name:** Phoxinus eos

**Species Stressors:** Changes in hydrology, Development and habitat loss, Precipitation changes, Sea level rise, Storms and floods, Temperature change, Terrestrial connectivity loss

**Background:** The northern redbelly dace can be found throughout much of Canada, the northeastern US, and upper Midwest. In Massachusetts, this species is found in in spring-fed seepage pools and cool, clear streams (Natural Heritage and Endangered Species Program 2008b). However, throughout much of its range it is typically found in bogs, ponds, lakes, and pools of headwater creeks (Page and Burr 2011). The northern redbelly dace feeds on algae and diatoms primarily, but can also eat aquatic insect larvae and zooplankton (Natural Heritage and Endangered Species Program 2008b). They spawn in algal masses, multiple times a year, throughout the spring and summer, and can live up to 8 years (Natural Heritage and Endangered Species Program 2008b). The redbelly dace is endangered in Massachusetts; however, the factors causing its decline are poorly understood, since it occupies fairly different habitats in Massachusetts than it does in many other locales (Natural Heritage and Endangered Species Program 2008b).

**Climate Impacts:** There is not much information on the northern redbelly dace in Massachusetts. However, in Colorado, where this species also typically occupies cool clear waters, it is sensitive to increased water turbidity (Stasiak 2006b). Climate change is expected to increase the frequency and severity of floods and droughts which can alter habitats (Dolloff et al. 1989, Manomet Center for Conservation Sciences and National Wildlife Federation 2013), and increase water turbidity in areas with disturbed landscapes. The northern redbelly dace is also sensitive to changes in natural spring flow in Colorado (Stasiak 2006b), and hydrological changes, including reductions in spring flow (Manomet Center for Conservation Sciences and National Wildlife Federation 2013).

There is also concern that under climate change, some waterbodies may warm beyond the physiological tolerances of some fish species (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013), which can lead to increases in summerkill (in response to high temperature and low dissolved oxygen content in the water) (Stefan et al. 2001), differences in age of maturity of adults and survival rate of juveniles (Shuter and Meisner 1992), and significant losses of habitat. This species is predicted to lose 43 to 100% of its habitat in Wisconsin under limited to major climate warming projections (Lyons et al. 2010).
Sea lamprey

Scientific Name: Petromyzon marinus

Species Stressors: Aquatic connectivity loss, Changes in hydrology, Development and habitat loss, Precipitation changes, Storms and floods, Temperature change

Background: The sea lamprey is a primitive eel-like fish that is common in Massachusetts in the Merrimack and Connecticut Rivers, and in numerous coastal streams (Natural Heritage and Endangered Species Program 2015i). Most sea lamprey are anadromous; however some populations in other locations are permanent freshwater residents (Hardisty 1986). Adults spawn in the spring to late summer in small to medium-sized streams with coarse bottom substrates and cool water, where they subsequently perish (Natural Heritage and Endangered Species Program 2015i). Larvae drift and settle into rich and muddy habitats at the edges of rivers, lakes and streams where they live for 4-8 years feeding on detritus (Kircheis 2004). Metamorphosis occurs from summer to fall, and is followed by movement into estuaries and shallow coastal areas for roughly 2 years where the adults can grow up to 60-75 cm in length (Hardisty 1986). The adult lampreys subsequently migrate to spawning sites, and may travel up to 850 km (Hardisty 1986). Adult sea lampreys are parasitic, and consume the body fluids and flesh of large fish and cetaceans (Kircheis 2004). In some regions where this species was accidentally introduced it has decimated fish populations (Cline et al. 2014), with the help of many anthropogenic stressors. However, this species also provides vital ecosystem services in its native range, such as nutrient transport, creation of nest sites that are used by brook trout, Atlantic salmon, fallfish, and common shiners, loosening of stream beds and reduction of stream siltation, enhanced oxygenation of stream beds and in turn, improved microhabitat for aquatic insects and salmonid fry (Kircheis 2004).

The sea lamprey has declined in abundance by at least 50% in Massachusetts, and is threatened by pollution, and dams that block their migrations and degrade spawning and larval habitats (Natural Heritage and Endangered Species Program 2015i).

Climate Impacts: 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). Climate change is also expected to impact anadromous fishes through shifts in the phenology of migration, and complex changes in the relationship between freshwater and marine habitats (Limburg and Waldman 2009).

There is a concern that some waterbodies may warm beyond the physiological tolerances of some fish species under future climate scenarios (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Sea lampreys are cool water adapted, and require temperatures between 18-23 °C for spawning and nest building, 15-25°C for hatching, and 10-26.1 °C for the larval stage (Hardisty 1986). However, sea lampreys may be less vulnerable to thermal stress than other cool-water fishes, because they remain buried in silts during the larval stage. They also exhibit a wide range of spawning dates (Hardisty 1986), and high mobility, so may be able to behaviorally adapt to increases in water temperature to some degree. Climate change may even benefit permanent freshwater populations of this species, as increases in water temperature have led to increases in body size and fecundity of adults (Cline et al. 2014). However, this has also resulted in greater feeding rates and higher mortality of host fishes in the Great Lakes region (Cline et al. 2014).

Extreme storm events and changes in river flows expected under climate change may also impact the sea lamprey. Sea lamprey migration is already impacted by dams that diminish aquatic connectivity, and alter
water flows. Sea lamprey are not particularly strong swimmers, and rely heavily on increased water flow in the autumn to move out to marine habitats (Kircheis 2004). Climate change is expected to exacerbate changes in the volume and timing of peak flows (Manomet Center for Conservation Sciences and National Wildlife Federation 2013), and may add more barriers to migration. They can overwinter and delay migration until the spring during droughts, but in these cases may experience mortality, and attach to freshwater fishes (Kircheis 2004). Climate change is also expected to increase the frequency and severity of floods and droughts (Dolloff et al. 1989, Manomet Center for Conservation Sciences and the National Wildlife Federation 2013), both of which can reduce reproductive success for anadromous fishes (Limburg and Waldman 2009). Extreme floods can also strip streams of sediment layers (Dolloff et al. 1989) which could remove important habitats for sea lamprey larva.
Shortnose sturgeon

Scientific Name: Acipenser brevirostrum

Species Stressors: Aquatic connectivity loss, Changes in hydrology, Development and habitat loss, Sea level rise, Temperature change

Background: The shortnose sturgeon is amphidromous, with adults spawning and largely residing in freshwater, but occupying estuaries and coastal areas on occasion, especially during the winter (Natural Heritage and Endangered Species Program 2015j). Shortnose sturgeons can be found in large coastal rivers from the Saint John River in New Brunswick, to the St. Johns River in Florida (Jager et al. 2013), and in Massachusetts they inhabit the Merrimack and Connecticut Rivers (Natural Heritage and Endangered Species Program 2015j). Spawning occurs in turbulent, fast-flowing portions of rivers with gravel or rocky substrates and most individuals only spawn every 2-3 years (Natural Heritage and Endangered Species Program 2015j). Juveniles remain in freshwater rivers for at least 1 or 2 years before migrating to estuaries, where they tend to occupy saltwater-freshwater interface, and do not travel far into the marine environment (Jager et al. 2013). Male shortnose sturgeons do not reach sexual maturity 7-12 years of age, females 10-15 years; the maximum age is 32 and 67 years respectively for the sexes (Page and Burr 1991, Natural Heritage and Endangered Species Program 2015j). Adult shortnose sturgeons prey on benthic crustaceans, insects and mollusks while juveniles feed primarily on benthic crustaceans and insects (Murdy and Musick 2013).

The shortnose sturgeon is listed as endangered under both the federal and state ESA. Threats to the species include habitat loss, barriers that prevent movement between habitats, pollution, and mortality from collisions with water intake screens (Jager et al. 2013, Natural Heritage and Endangered Species Program 2015j).

Climate Impacts: Climate change may reduce habitat availability, location and quality for Atlantic sturgeon. For instance, increased salt-water intrusion from the ocean is likely to occur under climate change and sea level rise, and is expected to reduce or shift suitable habitat for the similar Atlantic sturgeon, and cause siltation of existing spawning habitats, because juveniles are highly intolerant of salt water (Breece et al. 2013). Juvenile shortnose sturgeon are also highly intolerant of salt water early in life (Jager et al. 2013) so a similar response may be likely in this species. Moreover, this shift in salt water intrusion is likely to be exacerbated by dredging, which can interact with climate change to increase siltation which can cause embryonic mortality in Atlantic sturgeon (Breece et al. 2013). Shortnose sturgeon also need gravel or rocky substrates for spawning, so may be similarly impacted. Indeed, larger populations of shortnose sturgeon tend to be found in larger rivers where salt water incursion does not extend well into or even near upper river portions where there are harder crystalline substrates for spawning, likely because this separates juveniles from salt water that they are intolerant of early in life (Jager et al. 2013).

It is also possible that changes in water temperatures may impact the physiology and growth of shortnose sturgeon. For instance, increases in water temperature have been linked to smaller individuals, a lower proportion of older individuals in the population, and faster growth rates for Atlantic sturgeon (Balazik et al. 2016), and increased growth rates for lake sturgeon and American shad (Balazik et al. 2016). The shortnose sturgeon is also showing the steepest declines in the southern portion of its range, where it is thought that these populations are limited by extremely low dissolved oxygen, and high water temperatures in the summer (Jager et al. 2013). Population viability analysis for the shortnose sturgeon
indicated that low dissolved oxygen and high salinity in the summer decreased persistence by 29% (Jager et al. 2013). Finally, warming in the marine environment is expected to shift many species poleward, as has been seen already for alewife.

However, there is evidence that shortnose sturgeon may be less susceptible to acute mortality from increases in temperature than some other fish species. In one study, temperature increases between 10-25°C (both rapid/acute and acclimated) produced an initial and significant increase in metabolic rate in shortnose sturgeon, but subsequently showed a plateau in metabolic rate; this indicates that this species may have physiological adaptations that make it extremely efficient at consuming oxygen over a wide range of temperatures, and possibly more resilient to small changes in water temperature induced by climate change (Kieffer and Penny 2014). Moreover, the critical thermal threshold for shortnose sturgeon is quite high (31.6°C) indicating that changes in water temperature under climate change are not likely to be lethal for adults, though the combined effects of high carbon dioxide and temperatures and low oxygen on this species still needs more study (Spear and Kieffer 2016).
**Slimy sculpin**

**Scientific Name:** Cottus cognatus

**Species Stressors:** Changes in hydrology, Development and habitat loss, Precipitation changes, Storms and floods, Temperature change

**Background:** The slimy sculpin is a small fish that is found throughout much of Canada and Alaska, and in the eastern US as far south as the Potomac drainage (Page and Burr 1991). In Massachusetts, slimy sculpin are most commonly found west of the Connecticut river, where they inhabit cold, clear, high-gradient streams that have abundant rocky substrates (Natural Heritage and Endangered Species Program 2015k). In other regions they can also be found in rocky areas of cold water lakes, in low-gradient spring-fed streams, and even in brackish water while presumably making spawning movements (Page and Burr 1991). In streams, slimy sculpin are typically found in fast flowing, well-oxygenated riffles, hidden in unembedded rock and cobble substrate (Edwards and Cunjak 2007, Natural Heritage and Endangered Species Program 2015k). They consume crustaceans, bottom dwelling aquatic insect larva and nymphs, small fishes, and plant material (Page and Burr 1991). This species is sedentary and exhibits small home ranges (Edwards and Cunjak 2007). Adult slimy sculpin are among the most acid tolerant fishes in New England; however the juveniles appear to be particularly vulnerable to acidification to such a degree that changes in reproductive success and juvenile mortality in response to acidification have led to local extirpation in some areas (Warren et al. 2008).

**Climate Impacts:** The coldwater streams that this species inhabits are vulnerable to the effects of climate change, which can include changes in temperature regimes, and the timing of peak flows (Manomet Center for Conservation Sciences and National Wildlife Federation 2013). There is also concern that some waterbodies may warm beyond the physiological tolerances of some fish species (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Some species of cold-water adapted fishes are shifting poleward or to higher altitudes in response to increases in water temperature (Comte et al. 2013); however the slimy sculpin is highly sedentary, and is therefore unlikely to be able to adapt by dispersal. Increased summerkill (in response to high temperature and low dissolved oxygen content in the water) is also expected to have significant adverse effects on cool and cold water habitats (Stefan et al. 2001). The upper lethal temperature limit for this species is 25° C; it is less abundant in streams with higher summer water temperatures (Edwards and Cunjak 2007), and shows declines in response to increases in summer water temperature (Beauchene et al. 2014).

Climate change may also affect the physiology and demography of some cold water fishes. Temperature shifts can lead to differences in age of maturity of adults and survival rate of juveniles (Shuter and Meisner 1992). Slimy sculpin have exhibited significant variation in growth rate, body condition, timing of maturity, size, and age of mortality in response to changes in water temperature and flow that were experimentally regulated at hydroelectric dams (Bond et al. 2016), indicating that this species is likely to have physiological responses to changes in water flow and temperature induced by climate change.

Climate change is also expected to alter riverine habitats by increasing the frequency and severity of floods and droughts (Doloff et al. 1989, Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Slimy sculpin appears to be adversely affected by increases in water turbidity (Natural Heritage and Endangered Species Program 2015k), which can accompany floods, especially in otherwise disturbed landscapes. Indeed, riffle-dwelling species, like slimy sculpin appear to be more heavily impacted by flood and drought than pool-adapted species (Danehy et al. 1998), and one
population of this species exhibited a significant drop in abundance in response to mid-winter ice break-up and the associated flood and ice scour disturbance it caused (Edwards and Cunjak 2007). Finally, changes in community structure can also be caused by extreme events, stemming from or exacerbated by climate change (van Vrancken and O’Connell 2010, Boucek and Rehage 2014).
**Spotfin killifish**

**Scientific Name:** Fundulus luciae

**Species Stressors:** Changes in hydrology, Development and habitat loss, Invasive plants and animals, Sea level rise

**Background:** The very small (<2 in) spotfin killifish can be found in salt and brackish marshes along the US Atlantic coast from Georgia to Massachusetts. This species is found in shallow, high intertidal areas of marshes, in shallow ditches, tidal rivulets and mud holes (Marsh and Byrne 1978) and is strongly associated with common reed and saltmarsh cordgrass (*Spartina* spp.) (Yozzo and Ottman 2003). Adults and juveniles remain on the intertidal marsh during all tidal phases, and find refuge at low time in shallow micro-depressions that retain standing water (Yozzo and Ottman 2003). The spotfin killifish spawns from mid-April to mid-August in shallow depressions between stands of cordgrass and common reed, and eats detritus, fish eggs, ostracods, dipterans, copepods, diatoms, and other small invertebrates (Marsh and Byrne 1978, Natural Heritage and Endangered Species Program 2015).

Relatively little is known about the life history of this species (Yozzo and Ottman 2003). Abundance and population trends are unknown for Massachusetts, as are threats in the region (Natural Heritage and Endangered Species Program 2015). Invasive Phragmites commonly replaces the native species with which the spotfin killifish is strongly associated, and can severely impair feeding, breeding and nursery habitats (Able et al. 2004).

**Climate Impacts:** Climate change may result in habitat loss for spotfin killifish. Sea level rise and altered hydrology will adversely impact coastal marsh and wetland habitats (Adaptation Subcommittee to the Governor’s Steering Committee on Climate Change 2010, Manomet Center for Conservation Science and Massachusetts Division of Fisheries and Wildlife 2010). Some coastal wetlands and marshes may entirely disappear because accretion may not be able to keep pace with sea level rise (Galbraith et al. 2002). Finally, climate-mediated shifts in regional abundance of many species are expected to alter both the structure of wetland communities, and prey populations (Kelly and Condeso 2014).

Spotfin killifish are however found in waters of varying temperature, salinity, and dissolved oxygen content, and are thought to be quite environmentally tolerant and adaptable (Yozzo and Ottman 2003). For instance, the shallow ditches, tidal rivulets and mud holes in which they are commonly found at low tide are sometimes extremely oxygen deficient (Marsh and Byrne 1978).
Swamp darter

Scientific Name: Etheostoma fusiforme

Species Stressors: Changes in hydrology, Changes in winter, Development and habitat loss, Precipitation changes, Temperature change

Background: The swamp darter is a small fish of about 2 inches that ranges from southern Maine to Louisiana, and west to Kentucky, Mississippi, and southeastern Oklahoma. The swamp darter is found in all major drainages in the eastern portion of Massachusetts, and is still common in the state, though their overall distribution has declined as a result of urbanization (Natural Heritage and Endangered Species Program 2015m). This species occupies murky and slow moving water bodies including freshwater ponds, swamps, lakes, marshes, and slow moving streams that are characterized by muddy bottoms and substantial submerged aquatic vegetation (Maine Dept. of Inland Fisheries and Wildlife Endangered Species Program 2015, New York Natural Heritage Program 2015). However, in Cape Cod, they are also found in clear-water ponds with only modest vegetation (Natural Heritage and Endangered Species Program 2015m). They spawn beginning in April (Natural Heritage and Endangered Species Program 2015m) depositing eggs on leaves of aquatic vegetation (Maine Dept. of Inland Fisheries and Wildlife Endangered Species Program 2015). Eggs hatch in about 10 days, and fry are pelagic for roughly a month before they join adults near the bottom, within dense vegetation (New York Natural Heritage Program 2015). This species typically lives for less than 2 years, and feeds on a wide variety of small aquatic prey including insect larvae and adults, copepods, and amphipods (New York Natural Heritage Program 2015).

Climate Impacts: Little is known about the ecology of this species (Maine Dept. of Inland Fisheries and Wildlife Endangered Species Program 2015), and not much is published about the expected impacts of climate change. It is likely that the habitats that this species occupies will be altered under climate change, though their response is uncertain. Climate change will increase water temperatures in many aquatic habitats (Manomet Center for Conservation Sciences and National Wildlife Federation 2013). The swamp darter is tolerant of a wide range of water temperatures, pH levels and oxygen concentrations, but may be constrained by harsh winter temperatures in New England, where it is at the northern edge of its range (Maine Dept. of Inland Fisheries and Wildlife Endangered Species Program 2015, New York Natural Heritage Program 2015). Warm water fishes with a 2 °C lower thermal constraint are expected to see gains of up to 31% in thermally suitable habitat nationwide under a doubling of atmospheric carbon dioxide (Mohseni et al. 2003); however, the distribution of this species was not explicitly included in models. The timing of peak flows is also expected to be altered under climate change, and water levels may be more dynamic (Manomet Center for Conservation Sciences and National Wildlife Federation 2013). While swamp darters are quite robust, they are believed to be sensitive to water level fluctuations (New York Natural Heritage Program 2015).
**Tessellated darter**

**Scientific Name:** Etheostoma olmstedi

**Species Stressors:** Changes in hydrology, Development and habitat loss, Precipitation changes, Storms and floods, Temperature change

**Background:** The tessellated darter is a small fish of 2-4 inches found throughout the eastern US from southern New Hampshire to northern Florida (Lyzer and Reed 1978). It is common in most of the river drainages in Massachusetts except for the northeastern portion of the state (Natural Heritage and Endangered Species Program 2015n). The tessellated darter is typically found in sandy and muddy pools of headwaters, creeks and small to medium rivers, and in lakeshores (Page and Burr 1991), and prefers slowly moving water, some aquatic vegetation, and rocks or logs for spawning (Natural Heritage and Endangered Species Program 2015n). Tessellated darters primarily eat fly larva and are an important prey species for smallmouth bass, walleye, and American eel in some locations (Lyzer and Reed 1978). They typically live a maximum of 3 years (Lyzer and Reed 1978).

**Climate Impacts:** There is limited published information about how climate change is expected to impact this species. Climate change is predicted to increase the frequency and severity of floods and droughts, which is expected to impact fish species to varying degrees (Dolloff et al. 1989, Manomet Center for Conservation Sciences and the National Wildlife Federation 2013). Tessellated darters occupy smaller streams that tend to be more heavily impacted by floods and drought (Dolloff et al. 1989). However, because they tend to use deeper pool microhabitats, tessellated darters appear to be more tolerant of drought conditions than other small fishes that use riffles (Henry and Grossman 2008). In addition, after Hurricane Hugo, darter densities were either unchanged or increased, suggesting that this species can be resilient to these events, provided they do not occur during spawning, and there are adequate refugia to avoid displacement during flooding (Dolloff et al. 1989). There is also concern that some waterbodies may warm beyond the physiological tolerances of some fish species (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013), so this may be a factor for tessellated darters that tend to occupy waters that are from 10°C - 24°C (Page and Burr 1991).
Threespine stickleback

Scientific Name: Gasterosteus aculeatus

Species Stressors: Aquatic connectivity loss, Changes in hydrology, Changes in winter, Development and habitat loss, Pests and diseases, Precipitation changes, Temperature change

Background: The Threespine stickleback is widely distributed throughout coastal regions of the boreal northern hemisphere, and has marine populations, as well as anadromous and freshwater resident populations (Svenning et al. 2015). The one and only population in Massachusetts (near Boston) is the southernmost completely freshwater population of this species (Natural Heritage and Endangered Species Program 2015). Freshwater populations of this species tend to inhabit small streams, but can also be found in lakes and rivers (Page and Burr 1991). Males build the nests in small depressions with sand and plant material in shallow water, exhibit an elaborate courtship routine, fan the fertilized eggs in order to assure adequate oxygenation, and defend the nesting territory (Hopkins et al. 2011). Threespine sticklebacks live 1 to 2 years, and are an important component of temperate and sub-polar aquatic food webs (Hopkins et al. 2011). This species is highly adapted to cold water, but has a wide geographic distribution, and temperature preferences range between 4 and 20 °C (Mehlis and Bakker 2014). Similarly, spawning season varies greatly across the geographic range, and the spawning period tends to increase in duration with latitude (Svenning et al. 2015).

Climate Impacts: Climate change could cause habitat loss and distributional changes for this species. Under a projected doubling of atmospheric carbon dioxide levels, the number of water bodies in the contiguous US with suitable cold water fish habitat is expected to decrease by 30% (Stefan et al. 2001); this trend will likely be more severe in more northern region, where temperature increases have been more drastic. Cold-adapted species are also predicted to shift north and move deeper in the water column, with warmer-adapted species filling the niches they leave behind (Lynch et al. 2010). Indeed, first records of the threespine stickleback in Svalbard freshwaters occurred in 2001, indicating that this fish may be expanding northward in response to climate change (Svenning et al. 2015).

Climate change is also likely to affect the physiology and demography of threespine sticklebacks. Increases in surface water temperature and longer periods of thermal stratification and ice-free conditions are expected under climate change, and can impact cold water fishes because they have narrow niches at which they achieve maximum growth rates, activity levels, and swimming performance (Shuter and Meisner 1992). Warmer waters can also lead to differences in age of maturity of adults and survival rate of juveniles (Shuter and Meisner 1992). Increased water temperature can also reduce reproductive success by changing the metabolic rate and hatching time of eggs, as well as the size, growth rate, and mortality rate of larva for threespine sticklebacks (Hopkins et al. 2011). In addition, greater water temperatures can also reduce adult survival rates for this species and impact reproduction by increasing the swimming speed of sperm and fertilization rates, but decreasing the life span of sperm (Mehlis and Bakker 2014). At higher water temperatures, male threespine sticklebacks have also been shown to put more effort into fanning the fertilized eggs, which incurred significant mortality of adults (Hopkins et al. 2011). Although this response was nearly consistent across nearly all males, a few individuals showed markedly high reproductive rates at increased temperatures, suggesting some genetic variability, and thus capability for adaptation (Hopkins et al. 2011).

Finally, climate change can also alter the interaction of parasites with fishes. Higher water temperatures can increase metabolism in parasites, and thus their spread, however, thermal maxima may be reached for
growth and transmission of parasites in some waterbodies (Lohmus and Bjorklund 2015). For instance, growth and transmission of the parasite Schistocephalus solidus was increased in threespine sticklebacks with higher water temperatures (Mehlis and Bakker 2014). Increases in water temperatures also cause sticklebacks to occupy bottoms substrates and vegetated areas more often, where they incur greater parasite loads (Lohmus and Bjorklund 2015). Moreover, experimental exposure to a heat wave resulted in long-term immune disorders in threespine sticklebacks, which could further facilitate the spread of infectious diseases (Dittmar et al. 2014).
**White sucker**

**Scientific Name:** Catostomus commersoni

**Species Stressors:** Aquatic connectivity loss, Change in timing of seasons, Changes in hydrology, Changes in winter, Development and habitat loss, Invasive plants and animals, Precipitation changes, Storms and floods, Temperature change

**Background:** In the eastern portion of North America white suckers range from Newfoundland south to the Tennessee River drainage. White suckers occupy cool water lakes and ponds primarily, but migrate into tributaries to spawn in the spring (McManamay et al. 2012). They are a cool water adapted species which means they require water temperatures of 15 to 25 °C (59 to 77 °F) (Huff and Thomas 2014). They have an estimated maximum tolerance of 27.4 °C (Eaton and Scheller 1996). White suckers inhabit shallow water at night where they feed on deep water invertebrates, mayfly nymphs, chironomid larvae and detritus, and move into cooler, deeper sections of water during the day (Logan et al. 1991). In north-temperate fish communities, white suckers have a significant influence on the growth and production of other fishes (Logan et al. 1991).

**Climate Impacts:** Climate change is likely to affect white suckers through habitat loss and distributional changes. Under a projected doubling of atmospheric carbon dioxide levels, the number of water bodies in the contiguous US with suitable cool water fish habitat is expected to decrease by 30%, with the largest impact on cool water habitats occurring in shallow lakes < 4m in depth (Stefan et al. 2001). Cold-adapted species are also predicted to shift north and move deeper in the water column, with warmer-adapted species filling the niches they leave behind (Lynch et al. 2010). For instance, lake whitefish (*Coregonus clupeaformis*) that are also adapted to cool temperatures and lower levels of oxygen in the winter (Shuter et al. 2012) closely track temperature in their lake habitats in May, indicating that the species’ distribution may be affected by climate change (Gorsky et al. 2012).

Increases in water temperature area also expected to have a number of impacts on the physiology and demography of cool water fishes like white suckers. Temperature increases are expected to cause greater surface water temperatures, and longer periods of thermal stratification and ice-free conditions in lakes and ponds (Shuter and Meisner 1992). Cool water fish have temperature niches centered around 24° C that define the range at which these fish achieve maximum growth rates, activity levels, and swimming performance (Shuter and Meisner 1992). In turn, changes in growth rates due to temperature shifts can also lead to differences in important demographic parameters such as age of maturity of adults and survival rate of juveniles (Shuter and Meisner 1992). For instance, white suckers that inhabit deep lakes with cooler temperatures tend to grow faster and be larger bodied, whereas shallow lake habitats tend to contain slower growing, smaller-bodied suckers (Logan et al. 1991). An even more cold-adapted species, the burbot (*Lota lota*), showed significant decrease in hatchling and larval success with increasing temperatures and have declined over the last 50 years in Lake Oneida, New York in conjunction with rising summer temperatures, apparently from reduced access to prey (Lahnsteiner et al. 2012). In addition, increased summerkill (in response to high temperature and low dissolved oxygen content in the water) is also expected to have significant adverse effects on cool water habitats (Stefan et al. 2001).

Phenological shifts related to climate change may also affect white suckers. 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, Monika and 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). Warming water temperatures also advance hatching in lake whitefish which suggests that for cool temperature fish, climate change might cause a timing mismatch between the larvae and the availability of prey and increase mortality (Patrick et al. 2013).

Beyond intrinsic physiological thermal limitations, habitat fragmentation and land conversion are negatively impacting some fish populations (Argent and Kimmel 2013, National Wildlife Federation and Manomet Center for Conservation Sciences 2014). Catostomids like white suckers make considerable migrations to access spawning habitats; thus, habitat connectivity is important to consider in their conservation (McManamay et al. 2012).

Finally, changes in community structure can also 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 (Swink 1993). Changes in community structure can also be caused by extreme events, stemming from or exacerbated by climate change (van Vrancken and O’Connell 2010, Boucek and Rehage 2014). For instance, a population of slimy sculpin (*Cottus cognatus*), a cool-adapted species declined significantly as a result of a mid-winter ice break-up and the associated flood and ice scour disturbance it caused (Edwards and Cunjak 2007).
Species lacking profiles due to inadequate information

Banded sunfish (*Enneacanthus obesus*)

Fallfish (*Semotilus corporalis*)

Longnose sucker (*Catostomus catostomus*)
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**Alewife floater**

**Scientific Name:** Anodonta implicata

**Species Stressors:** Aquatic connectivity loss, Changes in the timing of seasons, Changes in hydrology, Development and habitat loss, Precipitation changes, Invasive plants and animals, Storms and floods, Temperature change

**Background:** The alewife floater is a medium to large bodied freshwater mussel that is found along the Atlantic slope in North America from Quebec and Nova Scotia to North Carolina. They are found in rivers, streams, and lakes in Massachusetts that have unobstructed passage to the ocean, and can occur in a wide variety of habitats (Natural Heritage and Endangered Species Program 2015a). Alewife floaters reproduce in August; the glochidia (larva) are released in the spring (Perkins 2015) and attach to the gills or fins of host fish in order to complete their metamorphosis (Pandolfo et al. 2010). Alewife, river herring, and blueback herring are the primary hosts (Perkins 2015) but American shad, white sucker, threespine stickleback, pumpkinseed, white perch, and striped bass have also been reported (Natural Heritage and Endangered Species Program 2015a). After metamorphosis, the adults are free living (Natural Heritage and Endangered Species Program 2015a). Adults are sessile and consume algae, detritus, and bacteria (Perkins 2015).

The introduction of exotic zebra mussels has caused drastic declines in populations of Alewife floaters, though a small degree of recovery is evident in some areas (Strayer and Malcom 2007). Alewife floaters showed 90% declines in the Hudson River following invasions (Perkins 2015). Declines of their host fish are likely one of the greatest threats to this species (Natural Heritage and Endangered Species Program 2015a); one of their primary hosts, the alewife, has declined by 99.9% in several major rivers from Maine to the Chesapeake Bay (Perkins 2015). The Alewife floater has recently exhibited range expansions and recovery in the Connecticut and Delaware Rivers, likely in response to successful efforts to restore the migration of shad and alewife (Smith 1985, Perkins 2015).

**Climate Impacts:** Freshwater mussels are one of the most imperiled animals in the US, and have a range of life history traits that make them sensitive to many of the stressors that accompany climate change, including a sensitive larval life stage, low mobility, filter-feeding habits, dependency on specific host fishes, and slow population recoveries due to delayed reproduction and being relatively long lived (Pandolfo et al. 2010, Pinkney et al. 2014, Vaughn et al. 2015). In addition, freshwater mussels provide a variety of important ecological services such as removal of plankton and detritus, nutrient storage in their soft tissues, nitrogen excretion that supports benthic algae, macroinvertebrates, aquatic spiders and fishes, and microhabitat sites on their shells; as such loss of mussels from aquatic ecosystems can have significant negative consequences on downstream water quality (Vaughn et al. 2015).

Changes in precipitation and hydrology associated with climate change are likely to impact this species. For instance, severe drought conditions can impact freshwater mussels, and the important services that they provide to aquatic ecosystems. The low water flows that accompany drought can result in reproductive failure, and low dissolved oxygen concentrations can slow growth, inhibit reproduction, and impair respiration (Golladay et al. 2004). Mussel populations declined over 60% during drought-induced changes in flow regimes in the Kiamichi River in Oklahoma, and this population change was accompanied by subsequent declines in ecosystem services such as bio-filtration, nitrogen recycling, and
phosphorus recycling (Vaughn et al. 2015). Alewife floaters have developed adaptations to survive in fairly low levels of dissolved oxygen, which makes them able to endure limited drought conditions (Golladay et al. 2004).

Climate change may also impact this species indirectly through changes in water quality. The frequent and extreme storm events that accompany climate change are likely to increase the amount of sediments, nutrients, and contaminants released from the surrounding landscape during storm events, all of which can adversely affect freshwater mussels (Pinkney et al. 2014). In addition, increased temperatures, changes in precipitation, and changes in hydrological regimes can alter the transport, bioavailability, and trophic transfer of mercury (Pinkney et al. 2014). Alewife floaters are more tolerant of pollution, eutrophication, and habitat alteration than many other Massachusetts freshwater mussels, though severe algal blooms, which are likely to become more common with climate change, do pose a risk to this species (Natural Heritage and Endangered Species Program 2015a).

The physiological processes of mussels are highly constrained by water temperature (Vaughn et al. 2015). Even small increases in water temperature can significantly reduce survival of freshwater mussels, especially during the sensitive early life stage (Pandolfo et al. 2010). Adult mussels tend to exhibit reduced growth and high mortality at water temperatures of 32 to 34 °C (Pinkney et al. 2014). Increased water temperatures can also cause a variety of sub-lethal responses in mussels, including changes in filtration rate, reduced immune response, increased metabolic demand, changes in behavior, altered timing of reproduction, and decreased fertilization (Pandolfo et al. 2010). Freshwater mussels are also more sensitive to ammonia toxicity at higher water temperatures (Pinkney et al. 2014). Finally, shifts in water temperature can also adversely affect freshwater mussels by causing asynchrony between reproduction and the presence of host fish (Pandolfo et al. 2010).
**Brook Floater**

**Scientific name:** Alasmidonta varicosa

**Species stressors:** Aquatic connectivity loss

**Background:** The brook floater is a freshwater mussel species that inhabits streams and rivers with low to moderate flows (Nedeau 2008). When present in fast water, they will often be found in protected pockets behind boulders. Brook floaters are never found in lakes or reservoirs. They appear to require relatively undisturbed stream reaches and have little tolerance for stressors such as dams, urban areas, and poor water quality. Brook floaters are found in Atlantic coastal rivers from South Carolina to Nova Scotia and New Brunswick. As with other mussel species, the larval phase is an obligate parasite that requires a fish host for development, after which it will drop off to continue development as a benthic adult. Several potential host fish species for brook floaters have been identified in lab settings, but it is unknown if these all act as hosts under natural conditions. Adults live partially buried in the sediment where they filter algae, bacteria, zooplankton, and sediment from the water column.

Freshwater mussels in general have experienced large declines (Strayer and Malcom 2012) and the brook floater is no exception. It is one of the most endangered mussels in northeastern North America and is listed as endangered in Massachusetts (Nedeau 2008). Remaining populations in Massachusetts are fragmented and appear to consist mostly of older adults showing little evidence of recent reproduction.

**Climate Impacts:** Upper thermal tolerances for brook floaters appear to be high enough that even significant warming of Massachusetts waters is not likely to reach them. Lethal temperatures for the most sensitive developmental stage are approximately 35°C (Pandolfo et al. 2010), about 10°C warmer than for the cold water fish species, brook trout, currently found in Massachusetts (McCormick et al. 1972). It is unknown how sublethal temperatures may affect brook floaters, although water temperature directly relates to water quality parameters such as dissolved oxygen. As water temperature increases, the amount of dissolved oxygen that water can hold decreases (Watt 2000). Additionally, a lengthened growing season and increased evapotranspiration are projected to increase the frequency of short-term drought conditions (Huntington et al. 2009). Potentially, such changes could impact water quality in ways that affect brook floater populations (Vaughn et al. 2015).

Because mussels require a host fish species for larval development (Nedeau 2008, Vaughn et al. 2015), impacts upon these fish could also impact mussels. Species identified as potential hosts for brook floaters include cold to cool water species that have lower thermal tolerances than brook floaters themselves (Pandolfo et al. 2010). These species include blacknose dace and slimy sculpin. If these do act as hosts under natural conditions, significant warming of stream water could impact brook floaters indirectly through these relationships.
Eastern Lampmussel

Scientific Name: Lampsilis radiata

Species Stressors: Aquatic connectivity loss, Changes in the timing of seasons, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Storms and floods, Temperature change

Background: The eastern lampmussel can be found along the Atlantic slope from the St. Lawrence River Basin to North Carolina, and as far west as Lake Ontario. It can be found in many areas of Massachusetts, though it is not typically abundant (Natural Heritage and Endangered Species Program 2015b). The eastern lampmussel is a habitat generalist that can be found in a variety of habitats (large and small rivers, streams, lakes, and ponds) and a range of substrate types and water conditions (Matter and Francisco 2013). They breed in late summer to early fall and the glochidia (larva) remain in a specialized structure in the female for a year before they are released (Chagon et al. 1998, Natural Heritage and Endangered Species Program 2015b). Glochidia can be released year round, but the summer months are most common (Matter and Francisco 2013). Glochidia attach to host fish for 3 weeks, then detach and bury into detritus for 2-3 years (Chagon et al. 1998). Northern pike, yellow perch, pumpkinseed, largemouth bass, smallmouth bass, black crappie and rock bass are thought to be potential hosts, though this is unconfirmed (Chagon et al. 1998, Natural Heritage and Endangered Species Program 2015b).

This species is relatively common, and is considered secure throughout most of its range (Matter and Francisco 2013, Natural Heritage and Endangered Species Program 2015b). Threats to this species include algal blooms, pollution, and introduced zebra mussels, and dams which can block dispersal (Hallac and Marsden 2001, Natural Heritage and Endangered Species Program 2015b).

Climate Impacts: Freshwater mussels are one of the most imperiled taxa in the US, and have a range of life history traits that make them sensitive to many of the stressors that accompany climate change, including a sensitive larval life stage, low mobility, filter-feeding habits, dependency on specific host fishes, and slow population recoveries due to delayed reproduction and being relatively long lived (Pandolfo et al. 2010, Pinkney et al. 2014, Vaughn et al. 2015). In addition, freshwater mussels provide a variety of important ecological services such as removal of plankton and detritus, nutrient storage in their soft tissues, nitrogen excretion that supports benthic algae, macroinvertebrates, aquatic spiders and fishes, and microhabitat sites on their shells; as such loss of mussels from aquatic ecosystems can have significant negative consequences on downstream water quality (Vaughn et al. 2015).

The physiological processes of mussels are highly constrained by water temperature (Vaughn et al. 2015). Even small increases in water temperature can significantly reduce survival of freshwater mussels, especially during the sensitive early life stage (Pandolfo et al. 2010). Adult mussels tend to exhibit reduced growth and high mortality at water temperatures of 32 to 34 °C (Pinkney et al. 2014). Small increases in water temperature, immediately downstream from a small mill dam benefitted eastern lampshells in an Alabama river by extending the shell growth period (Singer and Gangloff 2011). However, median lethal temperatures for eastern lampmussel range from 29.9 to 35.6 °C, indicating that significant changes to water temperature expected under climate change could cause mortality to this species in some areas (Archambault et al. 2014). Increased water temperatures can also cause a variety of sub-lethal responses in mussels, including changes in filtration rate, reduced immune response, increased metabolic demand, changes in behavior, altered timing of reproduction, and decreased fertilization.
(Pandolfo et al. 2010). Warmer water reduced burrowing behavior of the eastern lampmussel and production of byssus, a glandular secretion from the foot of bivalves that is used for attachment and drift (Archambault et al. 2014). This suggests that increases in water temperature expected under climate change may reduce predator evasion and access to thermal refugia (from reduced burying), and adversely impact the ability of larva to attach to host fish (Archambault et al. 2014). Freshwater mussels are also more sensitive to ammonia toxicity at higher water temperatures (Pinkney et al. 2014). Finally, shifts in water temperature can also adversely affect freshwater mussels by causing asynchrony between reproduction and the presence of host fish (Pandolfo et al. 2010).

Changes in precipitation and hydrology associated with climate change are also likely to impact this species. For instance, severe drought conditions can impact freshwater mussels, and the important services that they provide to aquatic ecosystems. The low water flows that accompany drought can result in reproductive failure, and low dissolved oxygen concentrations can slow growth, inhibit reproduction, and impair respiration (Golladay et al. 2004). The eastern lampmussel is thought to be adversely affected by changes in hydrology, and is seldom found in otherwise suitable habitats on regulated (dammed) waterbodies (Natural Heritage and Endangered Species Program 2015b). Diminished water flows reduced burrowing behavior of the eastern lampmussel and production of byssus, a glandular secretion from the foot of bivalves that is used for attachment of juveniles to the host fish (Archambault et al. 2014). In another study, overall mussel populations declined over 60% during drought-induced changes in flow regimes in the Kiamichi River in Oklahoma, and this population change was accompanied by subsequent declines in ecosystem services such as bio-filtration, nitrogen recycling, and phosphorus recycling (Vaughn et al. 2015).

Climate change may also impact this species indirectly through changes in water quality. Reduced food availability and algal-toxicity from eutrophication are threats to eastern lampmussels (Natural Heritage and Endangered Species Program 2015b). The frequent and extreme storm events that accompany climate change are likely to increase the amount of sediments, nutrients, and contaminants released from the surrounding landscape during storm events, all of which can adversely affect freshwater mussels (Pinkney et al. 2014). In addition, increased temperatures, changes in precipitation, and changes in hydrological regimes can alter the transport, bioavailability, and trophic transfer of mercury (Pinkney et al. 2014).
**Eastern Pearlshell**

**Scientific Name:** Margaritifera margaritifera

**Species Stressors:** Aquatic connectivity loss, Changes in the timing of seasons, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Sea level rise, Storms and floods, Temperature change

**Background:** The eastern pearlshell is patchily distributed throughout northeastern North America, and northwestern Europe, between 40 and 70°N (Hastie et al. 2003). In Massachusetts the eastern pearlshell is mostly found in the western and central portion of the state (Natural Heritage and Endangered Species Program 2015c). This species inhabits cold water streams and rivers, and prefers pristine small streams with high dissolved oxygen, excellent water quality, and intact riparian vegetation with canopy cover (Natural Heritage and Endangered Species Program 2015c). The eastern pearlshell reproduces from late summer through October and females discharge the larva (glochidia) after several weeks, based on temperature cues (Hastie et al. 2003, Natural Heritage and Endangered Species Program 2015c). Glochidia of eastern pearlshell can only complete their development while attached to the gills or fins of Atlantic salmon or brown trout (Hastie et al. 2003). This species has the highest fecundity of all freshwater mussels, the smallest larva and is the longest lived (Natural Heritage and Endangered Species Program 2015c). Eastern pearlshells can live to over 100 years, and do not reach sexual maturity until 12-20 years of age (Hastie et al. 2003).

Massachusetts appears to have a stable population of the eastern pearlshell; however, the age structure in Massachusetts streams suggests very low reproductive success, which can lead to future population crashes (Natural Heritage and Endangered Species Program 2015c).

**Climate Impacts:** Freshwater mussels are one of the most imperiled animals in the US, and have a range of life history traits that make them sensitive to many of the stressors that accompany climate change, including a sensitive larval life stage, low mobility, filter-feeding habits, dependency on specific host fishes, and slow population recoveries due to delayed reproduction and being relatively long lived (Pandolfo et al. 2010, Pinkney et al. 2014, Vaughn et al. 2015). In addition, freshwater mussels provide a variety of important ecological services such as removal of plankton and detritus, nutrient storage in their soft tissues, nitrogen excretion that supports benthic algae, macroinvertebrates, aquatic spiders and fishes, and microhabitat sites on their shells; as such loss of mussels from aquatic ecosystems can have significant negative consequences on downstream water quality (Vaughn et al. 2015).

The eastern pearlshell is considered extremely vulnerable to climate change as it is found in cold, pristine, nutrient-poor, unpolluted streams and smaller rivers with moderate flow rates (Furedi 2013). Climate change is likely to directly reduce habitat for this species through increases in water temperature, declines in overall water levels, and loss of microhabitat from scouring during severe weather events; rising sea levels could also be a problem in some coastal streams, as this species is not tolerant of salt water (Hastie et al. 2003).

The physiological processes of mussels are highly constrained by water temperatures (Vaughn et al. 2015), which will continue to increase with climate change. A slight warming in water temperatures is expected to benefit eastern pearlshells through more rapid growth and increased survival of larva, and they can acclimate to slow increases in water temperature; however, even small increases in water
temperature can significantly reduce survival of freshwater mussels during the sensitive early life stage (Pandolfo et al. 2010). Moreover, rapid temperature increases - as can occur during prolonged summer heatwaves/droughts- can cause mortality in eastern pearlshells (Hastie et al. 2003). Increased water temperatures can also cause a variety of sub-lethal responses in mussels, including changes in filtration rate, reduced immune response, increased metabolic demand, changes in behavior, altered timing of reproduction, and decreased fertilization. Freshwater mussels are also more sensitive to ammonia toxicity at higher water temperatures (Pinkney et al. 2014). Another study, however, found that the eastern pearlshell might have some capacity to adapt to increasing temperatures and shifting flows (Hastie et al. 2003).

Reproduction and survival of eastern pearlshells is strongly affected by precipitation and hydrological patterns. For instance, long droughts can cause high mortality for eastern pearlshells, particularly since they like to colonize stream banks that can become exposed early in drought periods (Santos et al. 2015). In addition, changes in the seasonality of water flows, higher water temperatures, and lower oxygen content of waters from dams can adversely affect eastern pearlshells (Santos et al. 2015). In small water bodies, eastern pearlshells have exhibited higher recruitment during periods of increased rainfall, and lower recruitment during low flows because strong flows oxygenate the water, and clean the river bed, creating and improving microhabitat (Hastie et al. 2003). Although small scale infrequent floods can benefit this species (Hastie et al. 2003), eastern pearlshells can experience high rates of mortality during historic floods in rivers in Scotland and Portugal (Santos et al. 2015). Finally, reduced water flows can significantly impact reproduction, because it can fragment aquatic habitats and reduce connectivity for the host fishes that it relies upon for dispersal and reproduction (Santos et al. 2015).

Climate change may also impact this species indirectly through changes in water quality. The frequent and extreme storm events that accompany climate change are likely to increase the amount of sediments, nutrients, and contaminants released from the surrounding landscape during storm events, all of which can adversely affect freshwater mussels (Pinkney et al. 2014). The eastern pearlshell is highly sensitive to nutrient pollution which lowers oxygen content in water (Natural Heritage and Endangered Species Program 2015c, Santos et al. 2015), and has exhibited reduced survival and grown have in nutrient-rich streams in Europe (Perkins 2015). In addition, increased temperatures, changes in precipitation, and changes in hydrological regimes can alter the transport, bioavailability, and trophic transfer of mercury (Pinkney et al. 2014). This species has already been extirpated as a result of pollution from coal mining in certain areas of the Northeast (Furedi 2013, Santos et al. 2015). The eastern pearlshell is also highly sensitive to wildfires, which are expected to increase in frequency and intensity in response to climate change, because the fine particulates that drain off of burned landscapes can very easily clog bivalve gills (Santos et al. 2015).

Finally, the timing of spawning and reproduction, and pace of metamorphosis is highly influenced by temperature in the eastern pearlshell, with warmer water temperatures leading to earlier reproduction (Hastie et al. 2003, Natural Heritage and Endangered Species Program 2015c). There is concern that changes in water temperature associated with climate change could lead to a mismatch between the timing of when the eastern pearlshell larvae are released and the presence of spawning salmonid host fish (Hastie et al. 2003). Asynchrony between reproduction and the presence of host fish can adversely affect freshwater mussels (Pandolfo et al. 2010).
Eastern Pondmussel

**Scientific Name:** Ligumia nasuta

**Species Stressors:** Aquatic connectivity loss, Changes in the timing of seasons, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Storms and floods, Temperature change

**Background:** The eastern pondmussel can be found from the St. Lawrence River basin to South Carolina, and westward to Lake Erie. The eastern pondmussel seems to prefer quiet, sheltered waters in lakes, ponds, canals, and rivers and substrates of fine sand and mud (COSEWIC 2007), but can be found in a wide range of habitats, substrates, water depths, and flow levels (Natural Heritage and Endangered Species Program 2015d). In Massachusetts it is most common in the southeastern portion of the state in large coastal plain ponds, and in a few tributaries of the central Connecticut River Valley (Natural Heritage and Endangered Species Program 2015d). It was historically more widespread in Massachusetts (Natural Heritage and Endangered Species Program 2015d). The eastern pondmussel spawns in late summer, and the females brood the glochidia (larva) until the subsequent spring (COSEWIC 2007). After being released from the female, the glochidia must attach to a host fish to complete metamorphosis. Hosts for the eastern pondmussel include yellow perch, largemouth bass, bluegill and pumpkinseed; the female eastern pondmussel lures these host fishes to it with a display (Eads et al. 2015).

The eastern pondmussel is listed as a species of special concern in Massachusetts, and is threatened by eutrophication, sedimentation, habitat fragmentation, changes in flow regimes and hydrology, exotic invasive species, and contamination (Natural Heritage and Endangered Species Program 2015d). Eastern pondmussel populations have undergone drastic declines in response to introduction of exotic zebra mussels, particularly in the lower Great Lakes, where this species used to be one of the more common mussels (COSEWIC 2007).

**Climate Impacts:** Climate change is predicted to impact this species severely, however little empirical research has been done to address this directly (COSEWIC 2007, Natural Heritage and Endangered Species Program 2015d). Eastern pondmussels do have a range of life history traits that makes them sensitive to many of the stressors that accompany climate change, including a sensitive larval life stage, low mobility, filter-feeding habits, dependency on specific host fishes, and slow population recoveries due to delayed reproduction and being relatively long lived (Pandolfo et al. 2010, Pinkney et al. 2014, Vaughn et al. 2015). Freshwater mussels provide a variety of important ecological services such as removal of plankton and detritus, nutrient storage in their soft tissues, nitrogen excretion that supports benthic algae, macroinvertebrates, aquatic spiders and fishes, and microhabitat sites on their shells; as such loss of mussels from aquatic ecosystems can have significant negative consequences on downstream water quality (Vaughn et al. 2015).

Changes in precipitation and hydrology associated with climate change may impact this species. For instance, severe drought conditions can impact freshwater mussels, and the important services that they provide to aquatic ecosystems. The low water flows that accompany drought can result in reproductive failure, and low dissolved oxygen concentrations can slow growth, inhibit reproduction, and impair respiration in many mussels (Golladay et al. 2004). Rapid drops in water levels in lakes and ponds can cause large-scale mortality in eastern pondmussel (New Hampshire Fish and Game Department 2005). River populations of this species are also thought to be adversely affected by changes in flow regimes.
Climate change is also expected to result in significant loss of habitat for the eastern pondmussel as water levels decline (COSEWIC 2007).

Climate change may also impact this species indirectly through changes in water quality. The frequent and extreme storm events that accompany climate change are likely to increase the amount of sediments, nutrients, and contaminants released from the surrounding landscape during storm events, all of which can adversely affect freshwater mussels (Pinkney et al. 2014). As with many other species of freshwater mussels, the eastern pondmussel is believed to be impacted by eutrophication and sedimentation (Natural Heritage and Endangered Species Program 2015d). In addition, increased temperatures, changes in precipitation, and changes in hydrological regimes can alter the transport, bioavailability, and trophic transfer of mercury (Pinkney et al. 2014).

The physiological processes of mussels are also highly constrained by water temperature (Vaughn et al. 2015). Even small increases can significantly reduce survival of glochidia (Pandolfo et al. 2010). Increased water temperatures can also cause a variety of sub-lethal responses in mussels, including changes in filtration rate, reduced immune response, increased metabolic demand, changes in behavior, altered timing of reproduction, and decreased fertilization (Pandolfo et al. 2010). Freshwater mussels are also more sensitive to ammonia toxicity at higher water temperatures (Pinkney et al. 2014). Finally, shifts in water temperature could also and adversely affect freshwater mussels by causing asynchrony between reproduction and the presence of host fish (Pandolfo et al. 2010).
**Tidewater Mucket**

**Scientific Name:** Leptodea ochracea

**Species Stressors:** Aquatic connectivity loss, Changes in the timing of seasons, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Storms and floods, Temperature change

**Background:** The tidewater mucket can be found in coastal drainages from Nova Scotia to Georgia. They are typically found across a variety of substrates in coastal lakes and ponds, and slow moving portions of rivers, but can also tolerate impoundments (Maine Dept. of Inland Fisheries and Wildlife 2003). In Massachusetts it is primarily found in ponds on the coastal plains that have springtime Alewife runs, and seems to prefer muddy sandy and gravely substrates and slow currents (Natural Heritage and Endangered Species Program 2015e). The tidewater mucket breeds in the late summer, and the glochidia (larvae) are eventually released by the female so that they can attach to the gills or fins of a host fish to complete metamorphosis (Maine Dept. of Inland Fisheries and Wildlife 2003). The white perch and banded killifish are the only confirmed host species for the tidewater mucket, but Alewife and striped bass are also suspected (Natural Heritage and Endangered Species Program 2015e). Tidewater muckets have a lifespan of at least 15 years, but don’t reproduce until 4-6 years of age (Maine Dept. of Inland Fisheries and Wildlife 2003).

The tidewater mucket has been extirpated from many rivers in the northeast, and has declined throughout its range (Maine Dept. of Inland Fisheries and Wildlife 2003). It is listed as a species of special concern in Massachusetts where it is found in high densities in some coastal ponds and very low densities of individuals in poor health in others (Natural Heritage and Endangered Species Program 2015e). Exotic Eurasian Milfoil, zebra mussels and Asian clams pose a serious threat to the tidewater mucket as do dams that restrict flow between coastal lakes and the ocean (Maine Dept. of Inland Fisheries and Wildlife 2003, Natural Heritage and Endangered Species Program 2015e).

**Climate Impacts:** Climate change is expected to pose severe risks to the tidewater mucket though there has been little direct study or data collected per se (Natural Heritage and Endangered Species Program 2015e). They do have a range of life history traits that make them sensitive to many of the stressors that accompany climate change, including a sensitive larval life stage, low mobility, filter-feeding habits, dependency on specific host fishes, and slow population recoveries due to delayed reproduction and being relatively long lived (Pandolfo et al. 2010, Pinkney et al. 2014, Vaughn et al. 2015). Freshwater mussels provide a variety of important ecological services such as removal of plankton and detritus, nutrient storage in their soft tissues, nitrogen excretion that supports benthic algae, macroinvertebrates, aquatic spiders and fishes, and microhabitat sites on their shells; as such loss of mussels from aquatic ecosystems can have significant negative consequences on downstream water quality (Vaughn et al. 2015).

Changes in precipitation and hydrology associated with climate change may impact this species. For instance, severe drought conditions can impact freshwater mussels, and the important services that they provide to aquatic ecosystems. The low water flows that accompany drought can result in reproductive failure, and low dissolved oxygen concentrations can slow growth, inhibit reproduction, and impair respiration (Golladay et al. 2004). Mussel populations declined over 60% during drought-induced changes in flow regimes in the Kiamichi River in Oklahoma, and this population change was accompanied by subsequent declines in ecosystem services such as bio-filtration, nitrogen recycling, and phosphorus recycling (Vaughn et al. 2015). River populations of the tidewater mucket are thought to be adversely
affected by changes in flow regimes (Natural Heritage and Endangered Species Program 2015e). However, tidewater mukets are one of the few mussel species that appear to fare well in impoundments (Maine Dept. of Inland Fisheries and Wildlife 2003) where high water temperatures and low oxygen content are more prevalent so it is possible that they may be less sensitive to changes in flow regime than some other mussel species.

Climate change may also impact this species indirectly through changes in water quality. The frequent and extreme storm events that accompany climate change are likely to increase the amount of sediments, nutrients, and contaminants released from the surrounding landscape during storm events, all of which can adversely affect freshwater mussels (Pinkney et al. 2014). As with many other species of freshwater mussels tidewater mucket are believed to be impacted by eutrophication (Natural Heritage and Endangered Species Program 2015e). In addition, increased temperatures, changes in precipitation, and changes in hydrological regimes can alter the transport, bioavailability, and trophic transfer of mercury (Pinkney et al. 2014).

The physiological processes of mussels are also highly constrained by water temperature (Vaughn et al. 2015). Even small increases can significantly reduce survival of glochidia (Pandolfo et al. 2010). Increased water temperatures can also cause a variety of sub-lethal responses in mussels, including changes in filtration rate, reduced immune response, increased metabolic demand, changes in behavior, altered timing of reproduction, and decreased fertilization (Pandolfo et al. 2010). Freshwater mussels are also more sensitive to ammonia toxicity at higher water temperatures (Pinkney et al. 2014). Finally, shifts in water temperature could also adversely affect freshwater mussels by causing asynchrony between reproduction and the presence of host fish (Pandolfo et al. 2010).
Triangle Floater

Scientific Name: Alasmidonta undulata

Species Stressors: Aquatic connectivity loss, Changes in the timing of seasons, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Storms and floods, Temperature change

Background: The triangle floaters is a small freshwater mussel that inhabits slow to medium flowing water in small to large rivers and lakes, and a wide range of substrates (Natural Heritage and Endangered Species Program 2015f). They range from Nova Scotia to Florida, and west to the St. Lawrence drainage (Pennsylvania Natural Heritage Program 2007). The triangle floater reproduces in the summer, and the glochidia (larva) are released in the subsequent spring (Natural Heritage and Endangered Species Program 2015f). The glochidia must attach the gills or fins of host fish in order to undergo metamorphosis. They have a much wider range of host fishes than many freshwater mussels, including largemouth bass, blacknose and longnose dace, pumpkinseed, fallfish, common and rosyface shiner, slimy sculpin, white sucker, fantail darter, and northern hogsucker (Pennsylvania Natural Heritage Program 2007). This species is thought to live from 8-20 years, and is thought to not move much after dropping from the host fish (Natural Heritage and Endangered Species Program 2015f).

The triangle floater is widespread in Massachusetts, though some populations are small, and not much is known about recruitment or reproductive output in the state (Natural Heritage and Endangered Species Program 2015f). They appear to be experiencing population declines in the southern portion of their range (Pennsylvania Natural Heritage Program 2007). Threats to the triangle floater include eutrophication, pollution, altered flow regimes, invasive species, and loss of aquatic connectivity for host fishes (Natural Heritage and Endangered Species Program 2015f).

Climate Impacts: Climate change is expected to pose severe risks to the triangle floater, though there has been little direct study per se (Natural Heritage and Endangered Species Program 2015f). They do have a range of life history traits that make them sensitive to many of the stressors that accompany climate change, including a sensitive larval life stage, low mobility, filter-feeding habits, dependency on specific host fishes, and slow population recoveries due to delayed reproduction and being relatively long lived (Pandolfo et al. 2010, Pinkney et al. 2014, Vaughn et al. 2015). Freshwater mussels provide a variety of important ecological services such as removal of plankton and detritus, nutrient storage in their soft tissues, nitrogen excretion that supports benthic algae, macroinvertebrates, aquatic spiders and fishes, and microhabitat sites on their shells; as such loss of mussels from aquatic ecosystems can have significant negative consequences on downstream water quality (Vaughn et al. 2015).

Climate change may impact this species indirectly through changes in water quality. The frequent and extreme storm events that accompany climate change are likely to increase the amount of sediments, nutrients, and contaminants released from the surrounding landscape during storm events, all of which can adversely affect freshwater mussels (Pinkney et al. 2014). In addition, increased temperatures, changes in precipitation, and changes in hydrological regimes can alter the transport, bioavailability, and trophic transfer of mercury (Pinkney et al. 2014). The triangle floater is however thought to be less sensitive to habitat degradation than other mussels (Pennsylvania Natural Heritage Program 2007).

Changes in precipitation and hydrology associated with climate change may also impact this species. For instance, severe drought conditions can impact freshwater mussels, and the important services that they
provide to aquatic ecosystems. The low water flows that accompany drought can result in reproductive failure, and low dissolved oxygen concentrations can slow growth, inhibit reproduction, and impair respiration (Golladay et al. 2004). Mussel populations declined over 60% during drought-induced changes in flow regimes in the Kiamichi River in Oklahoma, and this population change was accompanied by subsequent declines in ecosystem services such as bio-filtration, nitrogen recycling, and phosphorus recycling (Vaughn et al. 2015). Triangle floaters are one of the few mussel species that appear to fare well in standing water (Pennsylvania Natural Heritage Program 2007) where elevated water temperature and low oxygen content are more prevalent, so it is possible that they may be less sensitive to changes in flow regime than other mussel species.

The physiological processes of mussels are highly constrained by water temperature (Vaughn et al. 2015). Even small increases in water temperature can significantly reduce survival of glochidia (Pandolfo et al. 2010). Increased water temperatures can also cause a variety of sub-lethal responses in mussels, including changes in filtration rate, reduced immune response, increased metabolic demand, changes in behavior, altered timing of reproduction, and decreased fertilization (Pandolfo et al. 2010). Freshwater mussels are also more sensitive to ammonia toxicity at higher water temperatures (Pinkney et al. 2014). Finally, shifts in water temperature could also cause asynchrony between reproduction and the presence of host fish can adversely affect freshwater mussels (Pandolfo et al. 2010). However, the triangle floater has one of the most diverse assemblages of host fish, so it may be less sensitive to any shifts in life history timing.
INVERTEBRATES - TERRESTRIAL

**Frosted Elfin**

**Scientific Name:** Callophrys irus

**Species Stressors:** Temperature changes, Change in timing of seasons, Development and habitat loss

**Background:** The frosted elfin is a non-migratory butterfly associated with dry, sandy, relatively open habitats arising from natural or human induced disturbance (Wagner et al. 2003, Bried et al. 2012). This habitat is essential for growth of its larval host plant species, which are primarily wild indigo or wild lupine (Albanese et al. 2007). In Massachusetts, the majority of this habitat is found in sandplain communities on the coastal plain. Frosted elfin overwinter as pupa, and in Massachusetts emergence of adults occurs from late April to early June (Albanese et al. 2008). The flight period lasts through mid-June, peaking in mid-May. Females lay eggs on host plants and larvae pupate by late July.

The range of frosted elfin originally extended from southeastern Canada and the northeastern US, south to Florida, and west to Texas (Bried et al. 2012). The species has declined over the past 50 years and is now probably extirpated from Canada and Maine, and is rare throughout much of its range. In Massachusetts, it is a species of special concern, although Massachusetts is considered to be a stronghold for the species (Albanese et al. 2007). Declines are associated with loss of habitat through urban encroachment and forest expansion following suppression of fire (Pfitsch and Williams 2009).

**Climate Impacts:** Several studies have noted that the observed date of first flight for frosted elfin is strongly related to temperature (Breed et al. 2012, Polgar et al. 2013). Warmer temperatures during the spring advance the timing of adult emergence, implying that a warmer climate will alter the timing of life cycle events. Over the period from 1986-2009, sighting dates of frosted elfins advanced 7.6 days in Massachusetts.

In addition, in the period from 1992 to 2010, butterfly species with a northern distribution have generally been declining in abundance in Massachusetts while those with a southern distribution have generally been increasing in abundance (Breed et al. 2012). These trends were not found to be correlated with habitat or landscape change. The observed trends in abundance for these species strongly support the conclusion that these trends are being driven by changes in climate. Frosted elfin are considered to be at the northern extent of their range in Massachusetts, and were found to have one of the fastest growing populations over this period. This growth may be partly due to management actions aimed at protecting this rare species, however, the authors suggest that it may be partially due to a more favorable climate in Massachusetts. Based on these observations, it seems likely that a warmer climate in Massachusetts will be favorable for populations of frosted elfin.
**Hessel’s Hairstreak**

**Scientific Name:** Callophrys hesseli

**Species Stressors:** Change in timing of seasons, Changes in hydrology, Development and habitat loss, Temperature change, Terrestrial connectivity loss

**Background:** The Hessel’s hairstreak is found in spotty distributions on the Atlantic Coastal Plain from southern Maine to the Florida Panhandle. They are currently a species of special concern in the state of Massachusetts, with the greatest densities occurring in the southeastern part of the state, including Worcester Norfolk, and Bristol Counties (Natural heritage). The Hessel’s hairstreak is typically in flight in Massachusetts between May and June (Natural Heritage and Endangered Species Program 2015g). This species is highly reliant on the Atlantic white cedar (*Chamaecyparis thyoides*) (Mason 2015). It lays its eggs on the branch tips of Atlantic cedars, the larva feed on new growth of the cedars, and the pupa overwinter in the white cedar swamps (Natural Heritage and Endangered Species Program 2015g). Hessel’s hairstreak is threatened by habitat loss, exotic invasive plants and parasitoids, insecticides, and loss of its limited habitat through harvest or excessive deer browse (Natural Heritage and Endangered Species Program 2015g). This species is also unable to disperse through matrix upland habitat to colonize different Atlantic cedar swamps (Sneddon and Hammerson 2014).

**Climate Impacts:** Hessel’s hairstreak is highly reliant on Atlantic cedar swamps that have already seen sharp declines through human impacts. These forests are considered less vulnerable to climate change because they extend along a broad latitudinal range into regions that already reflect climate conditions that Massachusetts is likely to experience in the future, and benefits from wildfire, which is expected to increase under climate change (Manomet Center for Conservation Sciences and National Wildlife Federation 2013). However, Atlantic white cedar germination and establishment is impacted by surface hydrology which could be altered under climate change (Manomet Center for Conservation Sciences and National Wildlife Federation 2013).

Changes in phenology could adversely impact the Hessel’s hairstreak. 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. For instance, there is evidence that between the years 1895 and 2009, Lycaenid butterflies in general have been emerging significantly earlier in the spring; since temperature was the most important factor determining the date of first sighting (an index of emergence) for hairstreaks in Massachusetts this trend is believed to be related to temperature changes (Polgar et al. 2013). 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).
Northeastern Beach Tiger Beetle

**Scientific Name:** Cicindela dorsalis dorsalis

**Species Stressors:** Sea level rise, Storms and floods, Development and habitat loss

**Background:** The Northeastern beach tiger beetle is a subspecies of the polytypic species *Cicindela dorsalis* (Boyd and Rust 1982). *C. d. dorsalis* historically occurred on beaches from Cape Cod to the shorelines of Chesapeake Bay in Virginia (Fenster et al. 2006). It has been extirpated from much of its range (Fenster et al. 2006) and in Massachusetts is limited to two naturally occurring populations, the largest of which inhabits an offshore barrier beach that is relatively pristine and undisturbed by human activity (MDFW n.d.). The species is currently listed as endangered in Massachusetts (MDFW 2015).

Northeastern beach tiger beetles are restricted to sandy beaches that are at least six meters wide (Fenster et al. 2006). Wider beaches are required to minimize mortality from powerful storms. They have a two-year life cycle. Larvae form burrows in the sand, where they capture small arthropods, adults emerge from pupal chambers in the sand in mid-June and numbers peak in late June to early July. Mating occurs throughout the adult period, which lasts throughout the summer before adults die (Fenster et al. 2006). Because they are tied to beaches and larvae are sedentary, human disturbance can greatly impact populations. Compaction of sand through recreational vehicle or heavy foot traffic, beach stabilization for erosion control, and other forms of beach development all have been implicated in population declines (Schlesinger and Novak 2011).

**Climate Impacts:** Due to their proximity to the surf, Northeastern beach tiger beetles are vulnerable to significant mortality during severe storms (Knisley et al. 2009). Populations were significantly reduced and in some cases lost from sites in Virginia following hurricanes Isabel and Ernesto. The populations remaining in Massachusetts have the potential to be entirely lost as a result of a severe summer storm event (MDFW n.d.). Projected changes in climate for the Northeast indicate that the frequency of severe storm events is likely to increase in the future, increasing the possibility that this could happen (Fan et al. 2014).

Sea levels are projected to rise over the next century (Lentz et al. 2016). Though there is uncertainty surrounding the magnitude and resulting impacts, sea level rise will probably impact Northeastern beach tiger beetles. Impacts will likely come directly through inundation and increased beach erosion (Leatherman et al. 2000), but also indirectly through engineering projects designed to mitigate the effects of sea level rise on coastal communities (Nicholls and Tol 2006).
Terrestrial Invertebrates lacking profiles due to inadequate information

Chain-dotted Geometer (*Cingilia catenaria*)

Chain-fern Borer (*Papaipema stenocelis*)

Cord-grass Borer (*Photedes inops*)

Dion Skipper (*Euphyes dion*)

Drunk Apamea Moth (*Apamea inebriate*)

Dune Sympistis (*Sympistis riparia*)

Early Hairstreak (*Erora laeta*)

Heath Metarranthis (*Metarranthis pilosaria*)

Northern Brocade Moth (*Neoligia semicana*)

Pale Green Pinion (*Lithophane viridipallens*)

Precious Underwing (*Catocala pretiosa pretiosa*)

Slender Clearwing (*Hemaris gracilis*)
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**Mammals**

**Big brown bat**

**Scientific Name:** Eptesicus fuscus

**Species Stressors:** Change in timing of seasons, Pests and diseases, Precipitation changes, Temperature change

**Background:** The big brown bat ranges throughout North America from southern Canada to northern South America. It roosts during the day in rock crevices, in the hollows or bark of trees, and in man-made structures. It is a non-migratory species, though females join maternity colonies after the breeding season (Wilkinson and Barclay 1997). Big brown bats forage in riparian habitats (Holloway et al. 2000; Menzel et al. 2005) and in canopy gaps in forested habitats (Ford et al. 2005, Titchenell et al. 2011). Although big brown bats hibernate in caves and mines in the winter, and can show symptoms of white-nose syndrome, they appear overall to be fairly resistant to *Pseudogymnoascus (Geomyces) destructans* (Pd) fungus that is responsible for white-nose syndrome (Frank et al. 2014).

**Climate Impacts:** Increasing climate variability may have a large effect on some bat species, with both increases and decreases in precipitation having potentially negative impacts. Big brown bats have shown higher mortality in response to the extreme droughts that may increase in the future, especially for some areas of the Midwest (O’Shea et al. 2011). 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).

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 foraging habitat for 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).

Bats must store enough energy reserves over the summer to enable them to survive winter hibernation (Humphries et al. 2002). Changes in precipitation and temperature are likely to have effects on the availability of the insects they eat and thus on their stored energy reserves (Rodenhouse et al. 2009). Additionally, it is possible that warmer temperatures could cause bats to wake up from hibernation more often, which takes more energy (Rodenhouse et al. 2009). Moreover, stored energy reserves are depleted at a rate that is dependent on the temperature of the hibernaculum (shelter where they hibernate), with temperatures above or below 2°C/36°F increasing the rate of depletion (Humphries et al. 2002). On the other hand, a longer growing season is likely to reduce the length of time that they hibernate.

It is unclear how these climate change effects will interact to influence bats. However, models based on energy needs related to hibernation conditions correctly predicted the distribution of the little brown bat in Canada (a northward range shift over the next century (Humphries et al. 2002). Based on these models, similar range shifts are anticipated for other bat species, and have already been seen for eastern red bats (Willis and Brigham 2003).
**Black Bear**

**Scientific Name:** Ursus americanus

**Species Stressors:** Temperature changes, Changes in winter, Change in timing of seasons, Terrestrial connectivity loss

**Background:** The black bear is a widespread species in North America; its presence in Massachusetts is unlikely to be greatly affected by climate change (Kerr and Packer 1998, Groffman et al. 2012). The pre-colonial range of black bear covered forested areas of North America into Mexico and the species is highly adaptable in terms of diet and habitat use (Pelton 2003). This wide range and adaptive capacity should make black bears well-suited to persist in the face of climate change.

**Climate Impacts:** However, black bears do have a variable life-history that may be impacted by climate change. In northern portions of their range, black bears hibernate for up to seven months, while in more southern regions this period of hibernation is greatly reduced (Garshelis et al. 2008). Bears may enter dens as early as October and as late as January (Pelton 2003) and emergence dates appear to be tied to weather (Rayl et al. 2014). Hibernation is an adaptation to winter food shortages and severe weather (Pelton 2003). In Massachusetts, milder winters may reduce the length of time that bears spend in hibernation. Increased bear activity combined with the potential for low food availability during winter months may increase the potential for human-bear conflict, as bears are more likely to visit urbanized areas in search of food during shortages (Baruch-Mordo et al. 2014, Obbard et al. 2014). Such conflict is tied to increases in human-induced bear mortality (Baruch-Mordo et al. 2014).
Blue whale

Scientific Name: Balaenoptera musculus

Species Stressors: Changes in hydrology, Changes in winter, Development and habitat loss, Pests and diseases, Temperature change

Background: Blue whales occur in all oceans. Cape Cod is believed to be the southern edge of the blue whale’s feeding range, where they can occasionally be seen feeding in the summer and fall (Natural Heritage and Endangered Species Program 2015a). Blue whales are often found near areas of cool upwelling waters (Learmonth et al. 2006). They are the largest of the whales, and are tremendously dependent on dense krill patches in their northern feeding grounds (Hazen et al. 2015). They must accumulate massive fat stores in order to migrate long distances to tropical and subtropical waters to calve; however, recent evidence does suggest that the populations that feed in the North Atlantic may forage on occasion along their migratory route at discreet areas with high productivity (Silva et al. 2013). Blue whales do not become sexually mature until 10 years of age and can live upwards of 80-90 years (Natural Heritage and Endangered Species Program 2015a).

Blue whales were the first species to be depleted severely by whaling, and the North Atlantic population has not increased to anywhere near its former size (Thomas et al. 2016). Ship strikes are the most frequent cause of mortality currently (Natural Heritage and Endangered Species Program 2015a, Thomas et al. 2016). It is currently listed as Endangered both federally, and in Massachusetts.

Climate Impacts: Climate change is expected to influence the distribution of whales and their prey resources, alter important demographic parameters like mortality and reproductive success, and change the timing and range of migrations (Learmonth et al. 2006, Simmonds and Isaac 2007). Climate change can alter patterns of sea surface temperature and upwellings, which is likely to affect prey composition and availability for whale species through changes in distributional shifts in feeding areas (Fleming, Alyson et al. 2016). For instance, with increasing ambient temperatures, the northeastern North Atlantic has experienced some of the most drastic increases in sea surface temperature, which has caused some copepod species that the Sei whale is highly dependent upon to shift poleward more than 10° in latitude and others to decrease in abundance (Prieto et al. 2012). Some species may track these shifts in temperature and prey, as has been already been seen for cetaceans in Australia (MacLeod et al. 2005). Fin and Humpback whales also have recently expanded northward into Arctic waters (Thomas et al. 2016). Distributional shifts can be particularly problematic if they cause a species moves out of range of areas specifically designated for their protection (MacLeod et al. 2005). Loss of sea ice is also expected to lead to a severe decrease in the krill populations upon which blue whales heavily rely (Wiedenmann et al. 2011).

Changes in prey composition and structure can also have detrimental impacts on whale physiology. For instance, Calanus finmarchicus shows severe fluctuations linked to climate change, and northern right whales that feed heavily on this species exhibit reduction in blubber thickness (indicating they are nutritionally challenged), and reduced calf production during periods of low prey availability (Meyer-Gutbrod et al. 2015). Sperm whales have exhibited lower conception rates in response to increases in sea surface temperature, and fin whales lower calving rates in response to reduced prey abundance (Learmonth et al. 2006). Whales that undertake long migrations are particularly vulnerable to nutritional deficiencies because they need to forgo foraging while they are pregnant and migrating to and from the feeding grounds, and while they are calving (Meyer-Gutbrod et al. 2015).
There is also evidence that increases in sea surface temperature and earlier ice break up are triggering shifts in migration schedules, and changes in species assemblages. For instance, both fin whales and humpback whales shifted their arrival date in the Gulf of St. Lawrence, Canada by more than 1 day/year (Ramp et al. 2015). These species also departed the region earlier, but at very different rates, such that they are not as separated temporally in feeding niche as they have been historically (Ramp et al. 2015).

Finally, indirect effects of climate change may also impact some whale species. Many species are exposed to neurotoxins created through harmful algal blooms (HAB) that can adversely affect health and reproduction; these HABs are expected with great confidence to become more frequent under climate change projection (Doucette et al. 2012). In addition, climate-change induced shifts in human behavior such as increased shipping, oil and gas exploration in regions where Arctic sea disappears are also likely to lead to increases in noise exposure, boat strikes, fishing gear entanglement, and depletion of prey species (Alter et al. 2010). Moreover, warmer waters can also affect the prevalence and spread of diseases for marine mammals (Huntington 2009). Finally, climate change appears to be causing hybridization in blue whales (Attard et al. 2012).
**Bobcat**

**Scientific Name:** Lynx rufus

**Species Stressors:** Development and habitat loss, Pests and diseases, Terrestrial connectivity loss

**Background:** Bobcats can be found throughout much of the US and southern Canada, with the exception of some portions of the Midwest, and can inhabit a very wide range of habitats including deserts, boreal forests, rugged mountainous regions, and humid bottomlands (Massachusetts Division of Fisheries and Wildlife 2015). In all habitats, they favor areas with thick undergrowth (DeGraaf and Rudis 1986). They are common in Massachusetts, where they tend to occupy early successional habitats within cedar swamps, spruce thickets, mixed forests, and deciduous forests, and even farmland (DeGraaf and Rudis 1986, Massachusetts Division of Fisheries and Wildlife 2015). Snowshoe hare and cottontails are an important prey species for bobcats in the northeast and their availability can limit populations (Litvaitis et al. 1986). Bobcat can however also consume squirrels, mice, and birds, and deer may be an important component of the diet in the fall (DeGraaf and Rudis 1986). Bobcats have litters of 1-4 kittens, and require rocky ledges and crevices for den sites (DeGraaf and Rudis 1986). They are moderately sensitive to habitat fragmentation, and require contiguous tracts of forest for connectivity (Crooks 2002), since they have quite large home ranges (9-125 square miles) and can disperse large distances, even in a single night (3–11 miles) (DeGraaf and Rudis 1986).

Bobcats showed a significant decline throughout the northeast in the late eighties, but populations appear to have recovered since that time, likely due to harvest restrictions (Lavoie et al. 2009). Current threats include habitat loss and degradation, road mortality, and parasites (Litvaitis et al. 1987, Hiestand et al. 2014, Massachusetts Division of Fisheries and Wildlife 2015).

**Climate Impacts:** Carnivores in the Northeast and Midwest could see a mix of effects from climate change. Snowpack, competition, and prey availability may be the key drivers of these effects. For example, unlike the Canada lynx that have been shown to be negatively affected by decreased snowpack (Stenseth et al. 2004, Yan et al. 2013), bobcat movement is restricted in deep snow, as is access to prey, particularly for females and juveniles (Litvaitis et al. 1986). The decreased snowpack predicted for the Northeast may therefore be beneficial to bobcats; however, changes in climate may also reduce the abundance and distribution of small mammals.

Climate change is expected to cause northward expansion in the range of the bobcat such that they interact more with Canada lynx (Peers et al. 2013), and even hybridize (Koen et al. 2014). Although this range overlap likely to adversely affect lynx more than bobcat, more contact between the two species is likely to increase the spread and prevalence of the tapeworm, fluke and roundworm parasites that regularly afflict bobcats (Hiestand et al. 2014).
Eastern red bat

Scientific Name: Lasiurus borealis

Species Stressors: Change in timing of seasons, Changes in winter, Pests and diseases, Precipitation changes, Temperature change

Background: Eastern red bats occur throughout most of the US and range into the southern reaches of Canada (Willis and Brigham 2003). They are associated with forested habitats, and typically roost on forest edges in open foliage (Willis and Brigham 2003). Eastern red bats forage in both aquatic and terrestrial habitats (Whitaker 2004). This species is a long distance migrant (moving > 500km) and winters in the southern reaches of the US in the foliage or cavities of trees (Britzke et al. 2009).

Climate Impacts: Increasing climate variability may have a large effect on this species, with both increases and decreases in precipitation having potentially negative impacts. Some species have shown higher mortality in response to the extreme droughts that may increase in the future, especially for some areas of the Midwest (O’Shea et al. 2011). Decreases in spring and summer precipitation and an increase in temperatures both have been linked to reduced weight gain (Drumm et al. 1994) and higher mortality in other bat species (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). 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).

Bats must store enough energy reserves over the summer to enable them to survive winter hibernation (Humphries et al. 2002). Changes in precipitation and temperature are likely to have effects on the availability of the insects they eat and thus on their stored energy reserves (Rodenhouse et al. 2009). Additionally, it is possible that warmer temperatures could cause bats to wake up from hibernation more often, which takes more energy (Rodenhouse et al. 2009). Moreover, stored energy reserves are depleted at a rate that is dependent on the temperature of the hibernaculum (shelter where they hibernate), with temperatures above or below 2°C/36°F increasing the rate of depletion (Humphries et al. 2002). On the other hand, a longer growing season is likely to reduce the length of time that they hibernate.

It is unclear how these climate change effects will interact to influence bats. However, models based on energy needs related to hibernation conditions correctly predicted the distribution of the little brown bat in Canada (a northward range shift over the next century) (Humphries et al. 2002). Based on these models, similar range shifts are anticipated for other bat species. There is evidence that the eastern red bat may indeed be expanding its range into Canada in response to climate change (Willis and Brigham 2003).

Finally, disease is an important consideration when discussing bats in the Northeast and Midwest. The connection between white-nose syndrome and climate change is still unclear, but warming climates could ultimately reduce vulnerability to this fungal pathogen (Ehman et al. 2013). Tree-roosting bats are less impacted by white-nose syndrome. As such, eastern red bats have not yet shown symptoms of white-nose syndrome, but have recently tested positive for the Pseudogymnoascus (Geomyces) destructans (Pd) fungus that is responsible for the disease (Bernard et al. 2015).
**Fin whale**

**Scientific Name:** Balaenoptera physalus

**Species Stressors:** Changes in hydrology, Changes in winter, Development and habitat loss, Pests and diseases, Temperature change

**Background:** Fin whales occur worldwide, mainly in deeper offshore waters, and are rare in the tropics. There is believed to be a major feeding ground for this species off the coast of Massachusetts where they can be found year round, with peak abundance from April to November (Natural Heritage and Endangered Species Program 2015b). Their winter distribution and migration routes are poorly known (Ramp et al. 2015) but they are believed to fast throughout the winter (Natural Heritage and Endangered Species Program 2015b). Some populations of fin whales are believed to remain throughout the year within their range (Natural Heritage and Endangered Species Program 2015b), while others engage in complex migrations (Learmonth et al. 2006). Although they are a baleen whale, they feed primarily on sand lance and herring, and less so on krill and squid (Natural Heritage and Endangered Species Program 2015b).

Fin whales have been reduced in population size by approximately 70% through commercial whaling (Thomas et al. 2016). Threats to this species include frequent vessel collisions, occasional entanglement in fishing gear, and overexploitation of their prey species (Natural Heritage and Endangered Species Program 2015b, Thomas et al. 2016).

**Climate Impacts:** Climate change is expected to influence the distribution of whales and their prey resources, alter important demographic parameters like mortality and reproductive success, and change the timing and range of migrations (Learmonth et al. 2006, Simmonds and Isaac 2007). Climate change can alter patterns of sea surface temperature and upwellings, which is likely to affect prey composition and availability for whale species through changes in distributional shifts in feeding areas (Fleming, Alyson et al. 2016). For instance, with increasing ambient temperatures, the northeastern North Atlantic has experienced some of the most drastic increases in sea surface temperature, which has caused some copepod species that the Sei whale is highly dependent upon to shift poleward more than 10° in latitude and others to decrease in abundance (Prieto et al. 2012). Some species may track these shifts in temperature and prey, as has been already been seen for cetaceans in Australia (MacLeod et al. 2005). Fin and Humpback whales also have recently expanded northward into Arctic waters (Thomas et al. 2016). Distributional shifts can be particularly problematic if they cause a species moves out of range of areas specifically designated for their protection (MacLeod et al. 2005).

Changes in prey composition and structure can also have detrimental impacts on whale physiology. For instance, *Calanus finmarchicus* shows severe fluctuations linked to climate change, and northern right whales that feed heavily on this species exhibit reduction in blubber thickness (indicating they are nutritionally challenged), and reduced calf production during periods of low prey availability (Meyer-Gutbrod et al. 2015). Sperm whales have exhibited lower conception rates in response to increases in sea surface temperature, and fin whales lower calving rates in response to reduced prey abundance (Learmonth et al. 2006). Whales that undertake long migrations are particularly vulnerable to nutritional deficiencies because they need to fast while they are migrating and calving (Meyer-Gutbrod et al. 2015).

There is also evidence that increases in sea surface temperature and earlier ice break up are triggering shifts in migration schedules, and changes in species assemblages. For instance, both fin whales and humpback whales shifted their arrival date in the Gulf of St. Lawrence, Canada by more than 1 day/year.
(Ramp et al. 2015). These species also departed the region earlier, but at very different rates, such that they are not as separated temporally in feeding niche as they have been historically (Ramp et al. 2015).

Finally, indirect effects of climate change may also impact some whale species. Many species are exposed to neurotoxins created through harmful algal blooms (HAB) that can adversely affect health and reproduction; these HABs are expected with great confidence to become more frequent under climate change projection (Doucette et al. 2012). In addition, climate-change induced shifts in human behavior such as increased shipping, oil and gas exploration in regions where Arctic sea disappears are also likely to lead to increases in noise exposure, boat strikes, fishing gear entanglement, and depletion of prey species (Alter et al. 2010). Moreover, warmer waters can also affect the prevalence and spread of diseases for marine mammals (Huntington 2009).
**Hoary bat**

**Scientific Name:** Lasiurus cinereus

**Species Stressors:** Change in timing of seasons, Development and habitat loss, Invasive plants and animals, Pests and diseases, Precipitation changes, Temperature change

**Background:** The hoary bat occurs throughout most of North America, though during the summer males tend to occupy western North America and females the eastern portion of the continent (Cryan 2003). In the summer, hoary bats roost almost entirely in foliage, and in the Northeast, they appear to do so almost exclusively in eastern hemlock (*Tsuga canadensis*) trees (Veilleux et al. 2009). They forage in riparian habitats, and in large canopy gaps in forested areas (Ford et al. 2005, Menzel et al. 2005). Hoary bats are long distance migrants, and based on stable isotope analyses of fur samples, have been determined to travel up to 2000km during the migratory period (Britzke et al. 2009). Migratory movements are poorly studied but they are believed to winter in Mexico and the Southern US (Cryan 2003). Wind energy installations have caused an increase in mortality for many migratory tree-roosting bats over the last decade, including hoary bats.

**Climate Impacts:** Climate change induced habitat loss may impact hoary bats in the Northeast, because this species is known to roost exclusively in eastern hemlock (*Tsuga canadensis*) trees (Veilleux et al. 2009). The eastern hemlock, is expected to be substantially reduced by the hemlock wooly adelgid (*Adelges tsugae*), a tree pest that appears to be increasing due to climate change (Paradis et al. 2008). Increasing climate variability may have a large effect on this species, with both increases and decreases in precipitation having potentially negative impacts. Some species have shown higher mortality in response to the extreme droughts that may increase in the future, especially for some areas of the Midwest (O’Shea et al. 2011). Decreases in spring and summer precipitation and an increase in temperatures both have been linked to reduced weight gain (Drumm et al. 1994) and higher mortality in other bat species (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 foraging habitat for this species (Ford et al. 2005, 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).

Bats must store enough energy reserves over the summer to enable them to survive winter hibernation (Humphries et al. 2002). Changes in precipitation and temperature are likely to have effects on the availability of the insects they eat and thus on their stored energy reserves (Rodenhouse et al. 2009). Additionally, it is possible that warmer temperatures could cause bats to wake up from hibernation more often, which takes more energy (Rodenhouse et al. 2009). Moreover, stored energy reserves are depleted at a rate that is dependent on the temperature of the hibernaculum (shelter where they hibernate), with temperatures above or below 2°C/36°F increasing the rate of depletion (Humphries et al. 2002). On the other hand, a longer growing season is likely to reduce the length of time that they hibernate.

It is unclear how these climate change effects will interact to influence bats. However, models based on energy needs related to hibernation conditions correctly predicted the distribution of the little brown bat in Canada (a northward range shift over the next century (Humphries et al. 2002). Based on these models, similar range shifts are anticipated for other bat species, and have already been seen for eastern red bats (Willis and Brigham 2003).
Humpback whale

Scientific Name: Megaptera novaeangliae

Species Stressors: Changes in hydrology, Changes in winter, Development and habitat loss, Pests and diseases, Temperature change

Background: The humpback whale is found nearly all over the globe, but the population that is found feeding in the ocean off of Massachusetts from April to October is part of the geographically and reproductively isolated North Atlantic stock (Natural Heritage and Endangered Species Program 2015c). They are a baleen whale, but are rather flexible in diet feeding on both zooplankton and schooling fish like sardine, anchovy, sand lance and herring (Fleming, Alyson et al. 2016). Humpback whales from most North Atlantic feeding areas mate and calve in the West Indes and Cape Verde Islands in the winter months (Waring et al. 2013). These individuals must accumulate vast energy reserves to fuel long periods of fasting while the migrate and breed (Fleming, Alyson et al. 2016). The population is recovering, but mortality from vessel collisions and entanglements with fishing gear is approximately 10% above Potential Biological Removal (PBR) for humpback whales and is slowing the recovery of the population (Waring et al. 2013). Humpback whales are listed as Endangered at the federal level, and in Massachusetts.

Climate Impacts: Climate change is expected to influence the distribution of whales and their prey resources, alter important demographic parameters like mortality and reproductive success, and change the timing and range of migrations (Learmonth et al. 2006, Simmonds and Isaac 2007). Climate change can alter patterns of sea surface temperature and upwellings, which is likely to affect prey composition and availability for whale species through changes in distributional shifts in feeding areas (Fleming, Alyson et al. 2016). For instance, with increasing ambient temperatures, the northeastern North Atlantic has experienced some of the most drastic increases in sea surface temperature, which has caused some copepod species that the Sei whale is highly dependent upon to shift poleward more than 10° in latitude and others to decrease in abundance (Prieto et al. 2012). Some species may track these shifts in temperature and prey, as has been already been seen for cetaceans in Australia (MacLeod et al. 2005). Fin and Humpback whales also have recently expanded northward into Arctic waters (Thomas et al. 2016). Distributional shifts can be particularly problematic if they cause a species moves out of range of areas specifically designated for their protection (MacLeod et al. 2005).

Changes in prey composition and structure can also have detrimental impacts on whale physiology. For instance, Calanus finmarchicus shows severe fluctuations linked to climate change, and northern right whales that feed heavily on this species exhibit reduction in blubber thickness (indicating they are nutritionally challenged), and reduced calf production during periods of low prey availability (Meyer-Gutbrod et al. 2015). Sperm whales have exhibited lower conception rates in response to increases in sea surface temperature, and fin whales lower calving rates in response to reduced prey abundance (Learmonth et al. 2006). Whales that undertake long migrations are particularly vulnerable to nutritional deficiencies because they need to fast while they are migrating and calving (Meyer-Gutbrod et al. 2015). There is however evidence that the Humpback whale may be more resilient to changes in ocean climate because they exhibit high flexibility in foraging, consuming krill during periods of cool sea temperatures and strong upwellings, and to schooling fish during periods of warmer surface temperatures and delayed seasonal upwellings (Fleming, Alyson et al. 2016).
There is also evidence that increases in sea surface temperature and earlier ice break up are triggering shifts in migration schedules, and changes in species assemblages. For instance, both fin whales and humpback whales shifted their arrival date in the Gulf of St. Lawrence, Canada by more than 1 day/year (Ramp et al. 2015). These species also departed the region earlier, but at very different rates, such that they are not as separated temporally in feeding niche as they have been historically (Ramp et al. 2015).

Finally, indirect effects of climate change may also impact some whale species. Many species are exposed to neurotoxins created through harmful algal blooms (HAB) that can adversely affect health and reproduction; these HABs are expected with great confidence to become more frequent under climate change projection (Doucette et al. 2012). In addition, climate-change induced shifts in human behavior such as increased shipping, oil and gas exploration in regions where Arctic sea disappears are also likely to lead to increases in noise exposure, boat strikes, fishing gear entanglement, and depletion of prey species (Alter et al. 2010). Moreover, warmer waters can also affect the prevalence and spread of diseases for marine mammals (Huntington 2009).
Indiana bat

Scientific Name: Myotis sodalis

Species Stressors: Changes in winter, Development and habitat loss, Pests and diseases, Precipitation changes, Temperature change

Background: The Indiana bat ranges in the eastern US from Vermont to Mississippi, Alabama and Georgia, and ranges as far west as Arkansas, Iowa and Michigan. This species was last observed in Massachusetts in 1939 and is listed as endangered (Natural Heritage and Endangered Species Program 2015d). Indiana bats forage in both riparian areas, and in the foliage of trees (DeGraaf and Rudis 1986), and roost in the hollows or bark of live trees and snags (Pauli et al. 2015). Maternity roosts of one to a few dozen individuals tend to be in hollow trees or under loose bark (DeGraaf and Rudis 1986), and require high solar exposure for thermoregulation and fetal development as well as access to perennial water sources for foraging habitat (Pauli et al. 2015). The Indiana bat has only one young per year, and may begin migration as early as late July (Natural Heritage and Endangered Species Program 2015d). They have been recorded migrating distances of up to 500km (DeGraaf and Rudis 1986). This species hibernates in abandoned mines and caves that have cool stable temperatures throughout the winter; over 97% of the total population is believed to hibernate in four large caves in southern Indiana, Illinois, Missouri and Kentucky (DeGraaf and Rudis 1986).

The Indiana bat is one of the species heavily impacted by white-nose syndrome, and is particularly susceptible since they are so aggregated during their hibernation (Natural Heritage and Endangered Species Program 2015d). They are also one of the more common mortalities at wind energy installations, and are sensitive to losses of their very specific hibernacula.

Climate Impacts: Increasing climate variability may have a large effect on this species, with both increases and decreases in precipitation having potentially negative impacts. Some species have shown higher mortality in response to the extreme droughts that may increase in the future (O’Shea et al. 2011). Decreases in spring and summer precipitation and an increase in temperatures both have been linked to reduced weight gain (Drumm et al. 1994) and higher mortality in other bat species (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). 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).

Bats must store enough energy reserves over the summer to enable them to survive winter hibernation (Humphries et al. 2002). Changes in precipitation and temperature are likely to have effects on the availability of the insects they eat and thus on their stored energy reserves (Rodenhouse et al. 2009). Additionally, it is possible that warmer temperatures could cause bats to wake up from hibernation more often, which takes more energy (Rodenhouse et al. 2009). This factor could be particularly important for small-footed bats that tend to already rouse often during hibernation. Moreover, stored energy reserves are depleted at a rate that is dependent on the temperature of the hibernaculum (shelter where they hibernate), with temperatures above or below 2°C/36°F increasing the rate of depletion (Humphries et al. 2002). On the other hand, a longer growing season is likely to reduce the length of time that they hibernate.

It is unclear how these climate change effects will interact to influence bats. However, models based on energy needs related to hibernation conditions correctly predicted the distribution of the little brown bat in
Canada (a northward range shift over the next century (Humphries et al. 2002). Based on these models, similar range shifts are anticipated for other bat species, and have already been seen for eastern red bats (Willis and Brigham 2003).

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

**Scientific Name:** Myotis lucifugus

**Species Stressors:** Changes in winter, Development and habitat loss, Pests and diseases, Precipitation changes, Temperature change

**Background:** In the Eastern US little brown bats range from Labrador to Georgia and Arkansas, and in the Western US from southern Alaska to southern California. Little brown bats were widespread and common in Massachusetts, however, they have experienced rapid and severe population declines (90-100% in some New England hibernacula) due to white-nose syndrome and are listed as endangered in Massachusetts (Fenton 2012, Natural Heritage and Endangered Species Program 2015e).

Little brown bats tend to occupy lower altitude riparian areas more so than upland areas, and prefer forests with canopy gaps (Ford et al. 2005). This species forages over both land and water, including seasonal pools (Francl 2008). They have one of the most diverse diets of any bat species in the eastern US (Carter et al. 2003), and have a very broad and diverse dietary niche across their range (Broders et al. 2014). Little brown bats roost in caves, buildings, quarries, mine tunnels and hollow trees, and under rock and wood piles, with females using dark warmer sites for maternity colonies (often man-made), and males seeking cool and moist sites (DeGraaf and Rudis 1986, Natural Heritage and Endangered Species Program 2015e). They mate in the fall, produce one young a year, and are quite long-lived, with individuals upwards of 10 years commonly found (Natural Heritage and Endangered Species Program 2015e). Little brown bats are found in Massachusetts year round; however some individuals are known to migrate, even long distances (Natural Heritage and Endangered Species Program 2015e). They hibernate by October in large colonies, with fairly constant temperatures and high humidity in the winter for hibernation (DeGraaf and Rudis 1986). Loss of hibernacula is a threat to this species.

**Climate Impacts:** Increasing climate variability may have a large effect on little brown bats, with both increases and decreases in precipitation having potentially negative impacts. Some species have shown higher mortality in response to the extreme droughts that may increase in the future (O’Shea et al. 2011). Decreases in spring and summer precipitation and an increase in temperatures both have been linked to reduced weight gain (Drumm et al. 1994) and higher mortality in little brown bats (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). 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).

Bats must store enough energy reserves over the summer to enable them to survive winter hibernation (Humphries et al. 2002). Changes in precipitation and temperature are likely to have effects on the availability of the insects they eat and thus on their stored energy reserves (Rodenhouse et al. 2009). Additionally, it is possible that warmer temperatures could cause bats to wake up from hibernation more often, which takes more energy (Rodenhouse et al. 2009). This factor could be particularly important for small-footed bats that tend to already rouse often during hibernation. Moreover, stored energy reserves are depleted at a rate that is dependent on the temperature of the hibernaculum with temperatures above or below 2°C/36°F increasing the rate of depletion (Humphries et al. 2002). On the other hand, a longer growing season is likely to reduce the length of time that they hibernate.

It is unclear how these climate change effects will interact to influence bats. However, models based on energy needs related to hibernation conditions correctly predicted the distribution of the little brown bat in
Canada (a northward range shift over the next century (Humphries et al. 2002). Based on these models, similar range shifts are anticipated for other bat species, and have already been seen for eastern red bats (Willis and Brigham 2003).

Finally, disease is an important consideration when discussing bats in the Northeast and Midwest. The connection between white-nose syndrome and climate change is still unclear, but warming climates could ultimately reduce vulnerability to this fungal pathogen (Ehlman et al. 2013).
**Moose**

**Scientific Name:** Alces americanus

**Species Stressors:** Temperature changes, Changes in winter, Change in timing of seasons, Pests and diseases, Development and habitat loss, Terrestrial connectivity loss

**Background:** The moose is a cold-adapted species that is distributed across much of the northern United States and throughout Canada, as well as Europe and Asia. A dense coat and large body size helps moose deal with extremely cold temperatures. They spend much of their time foraging on the buds, stems, and occasionally bark of woody vegetation throughout the year, as well as newly growing green shoots and leaves in the spring. Because they are so big, moose require a large volume of food, and some individuals consume more than 40-60 pounds of forage in a day.

In eastern North America, moose are at the southern limit of their range in Massachusetts and Connecticut (Wattles and DeStefano 2011). Historically, they were found as far south as Pennsylvania and New Jersey, but were extirpated (went locally extinct) from these states and southern New England during colonial times. Currently, southern New England appears to have a healthy, relatively stable moose population, despite the recent dramatic declines seen elsewhere, such as in Minnesota.

**Climate Impacts:** Moose populations in Massachusetts are at low densities but do not appear to be declining (van Beest et al. 2012). Likewise, sightings in Connecticut have been increasing (van Beest et al. 2012). Conditions in Massachusetts are currently favorable for moose because thermal refuges, such as wetlands and closed canopy forest that allow moose to remain cool during hot days, are well interspersed with young, vigorously growing forest, which is their main forage habitat. Interactions with white-tailed deer, which can act as carriers for diseases to moose, do not seem as harmful to moose in Massachusetts, probably because the moose population itself is not very dense. In addition, lack of important predators, such as wolves, reduces overall mortality and allows moose to remain in food patches and thermal shelters for longer periods of time, rather than being pushed and moved by predators, which can increase energy demands and thermal stress (Broders et al. 2012). However, given increased temperatures associated with future climate change scenarios, several experts predict moose distributions will retreat northward (Murray et al. 2010, Dou et al. 2013, Wattles and DeStefano 2013).

In southern areas, moose experience heat stress and demonstrate behavioral responses to elevated temperatures (Kilpatrick et al. 2002, Lenarz et al. 2009). In contrast to Massachusetts, several of these southern populations are currently declining, including populations in Minnesota (Rempel 2011), Nova Scotia (Kilpatrick et al. 2002), China (Murray et al. 2010), and southern Norway (Lenarz et al. 2009). Studies have linked these declines to changes associated with climate change, including increased densities of winter tick (*Dermacentor albipicuts*) and perhaps other pathogenic parasites such as meningeal worm or brainworm (*Parelaphostrongylus tenuis*) carried by increasing white-tailed deer populations. Thermoregulatory stress associated with rising temperatures may also play an important role (Murray et al. 2010, Rempel 2011).

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. Severe winters can greatly reduce tick survival, but the milder
winters predicted are expected to increase tick densities. This increase in ticks is likely to result in increased mortality of moose in the Northeast (Rodenhouse et al. 2009).
New England Cottontail

Scientific Name: Sylvilagus transitionalis

Species Stressors: Temperature changes, Changes in winter, Development and habitat loss

Background: The New England cottontail occurred historically throughout most of New England and eastern New York; it is highly dependent on densely vegetated areas such as coastal thickets or early-successional habitat (Fenderson et al. 2011). The reforestation of New England combined with extensive development has resulted in a large decline in this habitat type, which has greatly reduced numbers of New England cottontail (DeGraaf and Yamasaki 2001, Fenderson et al. 2011). As a result, this species is currently limited to five disjunct populations scattered across New England that have little to no gene flow among them and has come under consideration for federal listing under the Endangered Species Act (Fenderson et al. 2011). Fenderson et al. (2011) concluded that without immediate human intervention, short-term persistence of populations in Maine, New Hampshire, and Cape Cod is at great risk.

Climate Impacts: Predators are the major source of mortality in this species, and the duration of snow cover in the winter can have a strong effect on this source of mortality (Barbour and Litvaitis 1993, Tash and Litvaitis 2007). Because New England cottontails have a brown pelage, they are more conspicuous to predators when there is snow cover (Tash and Litvaitis 2007). Additionally, snow cover restricts diet and movement of cottontails (Dalke and Sime 1941). As a result, the New England cottontail may benefit from decreased snow cover and forest disturbance in the northeast. However, indirect effects through changing relationships with other species such as predators and competitors are difficult to predict. For example, if climate change affects eastern cottontails positively, there may be increased competition for New England cottontails (Fuller and Tur 2012).
Northern flying squirrel

Scientific Name: Glaucomys sabrinus

Species Stressors: Changes in winter, Development and habitat loss, Precipitation changes, Temperature change, Terrestrial connectivity loss, Pests and diseases

Background: The northern flying squirrel inhabits boreal, coniferous, and mixed forests of the northern United States and Canada (Weigl 2007). Massachusetts is at the southern periphery of this species main range in the Eastern US, though there are isolated populations at higher elevations in the Appalachians (Weigl 2007). This species reaches its highest abundance in mature coniferous forest, although it is able to utilize a variety of forest types (Smith 2007, Patterson 2010). The northern flying squirrel is highly sensitive to forest fragmentation and cannot disperse effectively across large forest fragments, so closed canopies of mature forests are therefore important to allow for efficient locomotion via gliding (Smith et al. 2013).

The northern flying squirrel is considered a keystone species because it distributes fecal pellets with fungal spores and nitrogen fixing bacteria throughout the forest, and is an important prey species for birds and other mammals (Smith 2012). These small mammals also provide important prey for birds and other mammals. Throughout the range, mycorrhizal fungi are an important constituent of the diet of northern flying squirrels; the fungi also form mutualistic associations with tree root systems, making northern flying squirrels an important component of the forests they inhabit (Weigl 2007).

Climate Impacts: Northern flying squirrels are threatened by the indirect effects of climate change. The northern forests that the northern flying squirrel inhabits are shifting northward (Iverson and Prasad 2001, Smith 2007, Iverson et al. 2008). Climate change may decrease the fungi and lichen that are important food sources for the northern flying squirrel.

Changes in interactions related to climate change also already seem to be having negative effects. In the southern end of their range, northern flying squirrels appear to be limited by the presence of southern flying squirrels, as northern flying squirrels are not found in habitats that they do occupy where southern flying squirrels are absent (Smith 2007, Weigl 2007). However, in the coldest parts of the range of the southern flying squirrel, such as the Great Lakes area, New England, Ontario, and Nova Scotia, the two species may be found in the same habitat (Weigl 2007). In addition to being superior competitors, southern flying squirrels carry an intestinal parasite that causes significant mortality to northern flying squirrels, but is not deleterious to southern flying squirrels (Smith 2007). This parasite appears to be limited by cold weather, allowing for co-occurrence of the two squirrel species at the northern limits of the range of southern flying squirrels (Weigl 2007). However, habitat and temperature changes are already allowing southern flying squirrels to expand northward, and are causing a subsequent decline of northern flying squirrels (Garroway 2010). A warmer climate within the state of Massachusetts is likely to be favorable to the southern flying squirrel, and its pathogen, with negative impacts for northern flying squirrels. In addition to this potential negative interaction between the two species, documented recent range expansions in southern flying squirrels in response to warm winters have been associated with hybridization of the two species in the Great Lakes region and Pennsylvania (Garroway 2010).
Northern Myotis

Scientific Name: Myotis septentrionalis

Species Stressors: Change in timing of seasons, Development and habitat loss, Pests and diseases, Precipitation changes, Temperature change

Background: The northern long-eared bat, also commonly called the northern myotis, is found in Canada from northeastern British Columbia to southern Quebec and the island of Newfoundland. Its range extends south to eastern Kansas, Oklahoma, and east to South Carolina (Thompson 2006, Burns et al. 2015). Northern long-eared bats eat insects within the forest interior (Johnson et al. 2011a, Broders et al. 2014). Bats begin to emerge from hibernation in northern areas during April and May (Frank et al. 2014), though this may occur as early as March in southern latitudes (Thompson 2006). During summer, northern long-eared bats can be found in trees during the day; they leave their resting trees to feed immediately after sunset, returning to the trees to rest again immediately before sunrise (Johnson et al. 2011a, 2012).

Historically, this species was frequently seen in the northeastern US. However, many bats have died as a result of a fungus that causes white nose disease (DOI 2015). It is currently the greatest cause of death in wintering northern long-eared bats (Frank et al. 2014). In 2013 and 2014, surveys of known hibernation sites in Massachusetts found either zero or one northern long-eared bat individual per site, much lower than is considered normal (DOI 2015). In 2015, the US Fish and Wildlife Service labeled the northern long-eared bat “threatened” under the Endangered Species Act (DOI 2015).

Climate Impacts: Bats must store enough energy reserves over the summer to enable them to survive winter hibernation (Humphries et al. 2002). Changes in precipitation and temperature are likely to have effects on the availability of the insects they eat and thus on stored energy reserves in bats (Rodenhouse et al. 2009). Additionally, it is possible that warmer temperatures could cause bats to wake up from hibernation more often, which takes more energy (Rodenhouse et al. 2009). Moreover, stored energy reserves are depleted at a rate that is dependent on the temperature of the hibernaculum, with temperatures above or below 2°C increasing the rate of depletion (Humphries et al. 2002). On the other hand, a longer growing season is likely to reduce the length of the hibernation period. It is unclear how these climate change effects will interact to influence bats. However, models based on energy needs related to hibernation conditions correctly predicted the distribution of the little brown bat in Canada, and these models predicted a northward range shift over the next century. Based on these models, similar range shifts are anticipated for other bat species, including the northern long-eared bat.
Northern right whale

Scientific Name: Eubalaena glacialis

Species Stressors: Changes in hydrology, Changes in winter, Development and habitat loss, Pests and diseases, Temperature change

Background: The northern right whale used to occur coastal and shelf waters of all the oceans of the world but currently are found only from the Bay of Fundy to northern Florida. They concentrate in and around Cape Cod Bay in April and May, and occur in lower numbers in this region from December to March, where they find very rich concentration of zooplankton, and migrate to Nova Scotia later in the summer and fall (Natural Heritage and Endangered Species Program 2015f). They feed almost exclusively on the older development stage of Calanus finmarchicus a very common copepod (Meyer-Gutbrod et al. 2015). Females calve in the waters off of Georgia and Florida (Natural Heritage and Endangered Species Program 2015f), and spend at least 3 months fasting in order to migrate to and from the calving grounds (Meyer Gutbrod). They are not sexually mature until 10 years of age and can live up to 50 years (Natural Heritage and Endangered Species Program 2015f).

After extreme persecution from whaling, northern right whales are listed as endangered under both the federal and the Massachusetts ESA (Natural Heritage and Endangered Species Program 2015f), and the North Atlantic population is one of the most severely endangered populations of whales globally, with only 552 individuals believed to remain (Meyer-Gutbrod et al. 2015). Northern right whale populations are currently experiencing widespread compromised health (Doucette et al. 2012), low to variable birth rates and significant mortality from ship collisions and fishing gear entanglement (Meyer-Gutbrod et al. 2015).

Climate Impacts: Climate change is expected to influence the distribution of whales and their prey resources, alter important demographic parameters like mortality and reproductive success, and change the timing and range of migrations (Learmonth et al. 2006, Simmonds and Isaac 2007). Climate change can alter patterns of sea surface temperature and upwellings, which is likely to affect prey composition and availability for whale species through changes in distributional shifts in feeding areas (Fleming, Alyson et al. 2016). For instance, with increasing ambient temperatures, the northeastern North Atlantic has experienced some of the most drastic increases in sea surface temperature, which has caused some copepod species that the Sei whale is highly dependent upon to shift poleward more than 10° in latitude and others to decrease in abundance (Prieto et al. 2012). Some species may track these shifts in temperature and prey, as has been already been seen for cetaceans in Australia (MacLeod et al. 2005). Fin and Humpback whales also have recently expanded northward into Arctic waters (Thomas et al. 2016). Distributional shifts can be particularly problematic if they cause a species moves out of range of areas specifically designated for their protection (MacLeod et al. 2005).

Changes in prey composition and structure can also have detrimental impacts on whale physiology. For instance, Calanus finmarchicus shows severe fluctuations linked to climate change, and northern right whales that feed heavily on this species exhibit reduction in blubber thickness (indicating they are nutritionally challenged), and reduced calf production during periods of low prey availability (Meyer-Gutbrod et al. 2015). Sperm whales have exhibited lower conception rates in response to increases in sea surface temperature, and fin whales lower calving rates in response to reduced prey abundance (Learmonth et al. 2006). Northern right whales are particularly vulnerable to nutritional deficiencies because they need to fast while they are migrating and calving (Meyer-Gutbrod et al. 2015).
There is also evidence that increases in sea surface temperature and earlier ice break up are triggering shifts in migration schedules, and changes in species assemblages. For instance, both fin whales and humpback whales shifted their arrival date in the Gulf of St. Lawrence, Canada by more than 1 day/year (Ramp et al. 2015). These species also departed the region earlier, but at very different rates, such that they are not as separated temporally in feeding niche as they have been historically (Ramp et al. 2015).

Finally, indirect effects of climate change may also impact some whale species. Northern right whales are exposed regularly and for long durations of up to half the year to neurotoxins created through harmful algal blooms (HAB) that spatially and temporally overlap to a great degree with their seasonal movements and can adversely affect health and reproduction (Doucette et al. 2012). These HABs are expected with great confidence to become more frequent under climate change projection (Doucette et al. 2012). In addition, climate-change induced shifts in human behavior such as increased shipping, oil and gas exploration in regions where Arctic sea disappears are also likely to lead to increases in noise exposure, boat strikes, fishing gear entanglement, and depletion of prey species (Alter et al. 2010). Moreover, warmer waters can also affect the prevalence and spread of diseases for marine mammals (Huntington 2009).
Rock shrew

Scientific Name: Sorex dispar

Species Stressors: Aquatic connectivity loss, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Pests and diseases, Precipitation changes, Storms and floods

Background: The rock shrew is found in the Appalachian mountains from New Brunswick to Georgia (Trani et al. 2007) and in Massachusetts is only known to occur in Berkshire county (Natural Heritage and Endangered Species Program 2015g). It prefers moist sites near shady protective crevices or wooded talus slopes in coniferous and mixed-hardwood forests (DeGraaf and Rudis 1986), especially old growth forest with hemlock and spruce (Natural Heritage and Endangered Species Program 2015g). Little is known about its reproductive behavior or diet; it is thought to feed mainly on insects and other small invertebrates (DeGraaf and Rudis 1986), and have litters of 2 to 5 young (Trani et al. 2007). It is listed as a species of special concern in Massachusetts.

Climate Impacts: The rock shrew may be adversely affected by changes in precipitation and hydrology. Precipitation patterns, which can drive small mammal abundance and distribution, are changing across the Midwest and Northeast. Changes in precipitation may affect the already limited dispersal ability of the rock shrew. For instance, some small mammals, such as smoky shrews and star-nosed moles require precipitation for dispersal (Brannon 2002), and thus may be adversely affected in areas where rainfall events are projected to become less common (McCay et al. 1999). Loss of riparian habitats will also likely impact the dispersal ability of rock shrews, which appear to rely on these features to colonize new areas (Trani et al. 2007). Extreme events can also have a detrimental effect on small mammal populations (Pauli et al. 2006).

Climate change could also reduce habitats for the rock shrew. For one, it inhabits northern hardwood and montane boreal communities that are likely to be impacted by climate change (Trani et al. 2007). Climate change is expected to shift the ranges of boreal species northward causing fragmentation and loss of southern populations (Cheng et al. 2014). In addition the rock shrew is often associated with eastern hemlock forests, that are in decline due to the hemlock woolly adelgid (Adelges tsugae) (Trani et al. 2007), a tree pest that seems to be increasing due to climate change (Paradis et al. 2008).
Sei whale

Scientific Name: Balaenoptera borealis

Species Stressors: Changes in hydrology, Changes in winter, Development and habitat loss, Pests and diseases, Temperature change

Background: Sei whales are found worldwide, and migrate between northern latitude feeding areas and lower latitude breeding areas. They are most commonly sighted off the coast of Massachusetts in the spring and fall, and Massachusetts waters are thought to be at the lower edge of their summer feeding range (Natural Heritage and Endangered Species Program 2015h). They are thought to migrate from high-latitude summer feeding grounds to low-latitude wintering grounds, though calving ground locations are still unknown (Prieto et al. 2012). The Sei whale tends to inhabit deeper waters, and reside relatively far offshore; however, they do appear to enter shallower, more inshore waters in episodic waves (NOAA 2010). They have the most extensive and varied diet of any baleen whale, and are known to feed on calanoid copepods and euphausiids, and consume a significant amount of small schooling fishes and squid in some areas; however in the North Atlantic the copepod Calanus finmarchicus appears to be the favored prey (Prieto et al. 2012). They are sexually mature at 8 to 10 years of age (Natural Heritage and Endangered Species Program 2015h).

The Sei whale population was decimated by whaling by an estimated 70% (Thomas et al. 2016), and current population trends are poorly understood (NOAA 2010). Mortality from collisions and entanglement are less common for this species (Thomas et al. 2016).

Climate Impacts: Climate change is expected to influence the distribution of whales and their prey resources, alter important demographic parameters like mortality and reproductive success, and change the timing and range of migrations (Learmonth et al. 2006, Simmonds and Isaac 2007). Climate change can alter patterns of sea surface temperature and upwellings, which is likely to affect prey composition and availability for whale species through changes in distributional shifts in feeding areas (Fleming, Alyson et al. 2016). For instance, with increasing ambient temperatures, the northeastern North Atlantic has experienced some of the most drastic increases in sea surface temperature, which has caused some copepod species that the Sei whale is highly dependent upon to shift poleward more than 10° in latitude and others to decrease in abundance (Prieto et al. 2012), and has altered food and habitat availability for this species (National Marine Fisheries Service 2011). Some species may track these shifts in temperature and prey, as has been already been seen for cetaceans in Australia (MacLeod et al. 2005). Fin and Humpback whales also have recently expanded northward into Arctic waters (Thomas et al. 2016). Distributional shifts can be particularly problematic if they cause a species moves out of range of areas specifically designated for their protection (MacLeod et al. 2005).

Changes in prey composition and structure can also have detrimental impacts on whale physiology. For instance, Calanus finmarchicus shows severe fluctuations linked to climate change, and northern right whales that feed heavily on this species exhibit reduction in blubber thickness (indicating they are nutritionally challenged), and reduced calf production during periods of low prey availability (Meyer-Gutbrod et al. 2015). Sperm whales have exhibited lower conception rates in response to increases in sea surface temperature, and fin whales lower calving rates in response to reduced prey abundance (Learmonth et al. 2006). Whales that undertake long migrations are particularly vulnerable to nutritional deficiencies because they need to fast while they migrating and calving (Meyer-Gutbrod et al. 2015).
There is also evidence that increases in sea surface temperature and earlier ice break up are triggering shifts in migration schedules, and changes in species assemblages. For instance, both fin whales and humpback whales shifted their arrival date in the Gulf of St. Lawrence, Canada by more than 1 day/year (Ramp et al. 2015). These species also departed the region earlier, but at very different rates, such that they are not as separated temporally in feeding niche as they have been historically (Ramp et al. 2015).

Finally, indirect effects of climate change may also impact some whale species. Many species are exposed to neurotoxins created through harmful algal blooms (HAB) that can adversely affect health and reproduction; these HABs are expected with great confidence to become more frequent under climate change projection (Doucette et al. 2012). In addition, climate-change induced shifts in human behavior such as increased shipping, oil and gas exploration in regions where Arctic sea disappears are also likely to lead to increases in noise exposure, boat strikes, fishing gear entanglement, and depletion of prey species (Alter et al. 2010). Moreover, warmer waters can also affect the prevalence and spread of diseases for marine mammals (Huntington 2009).
Silver-haired bat

Scientific Name: Lasionycteris noctivagans

Species Stressors: Changes in winter, Development and habitat loss, Pests and diseases, Precipitation changes, Temperature change

Background: In the eastern US silver-haired bats range from southern Canada to South Carolina and Texas and in the western US from southern Canada to central California. While they are one of the most common bats in forested areas of North America, they are uncommon to rare in New England (DeGraaf and Rudis 1986), and only occur in Massachusetts during migration or summertime, not while breeding or hibernating (Natural Heritage and Endangered Species Program 2015i). They roost singly in the bark and cavities of trees, and are found in coniferous and mixed forests, particularly near rivers and lakes in which they hunt (Dunbar 2007). Small maternity colonies can be found in similar roost site conditions (Natural Heritage and Endangered Species Program 2015i). Silver-haired bats feed both over ponds and streams, seasonal forest pools, and among trees (DeGraaf and Rudis 1986, Francl 2008), primarily on Lepidoptera and Diptera (Carter et al. 2003). They are considered migratory, but may be sedentary in part of their range (Cryan 2003) Unlike many bat species, silver haired bats tend to hibernate in forests, under tree bark, but can also be found in mines, caves, rock crevices and buildings (Dunbar 2007).

Threats to silver-haired bats include the precipitous decline in large moths due to parasitism by the exotic wasp Compsilura concinnata, mortality from wind turbines, decline in insect prey due to insecticide, and habitat destruction through timber harvest (Natural Heritage and Endangered Species Program 2015i). This species is not known to be affected by white-nose syndrome, but is one of the more common mortalities at wind energy installations.

Climate Impacts: Increasing climate variability may have a large effect on this species, with both increases and decreases in precipitation having potentially negative impacts. Some species have shown higher mortality in response to the extreme droughts that may increase in the future (O’Shea et al. 2011). Decreases in spring and summer precipitation and an increase in temperatures both have been linked to reduced weight gain (Drumm et al. 1994) and higher mortality in other bat species (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). 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).

Bats must store enough energy reserves over the summer to enable them to survive winter hibernation (Humphries et al. 2002). Changes in precipitation and temperature are likely to have effects on the availability of the insects they eat and thus on their stored energy reserves (Rodenhouse et al. 2009). Additionally, it is possible that warmer temperatures could cause bats to wake up from hibernation more often, which takes more energy (Rodenhouse et al. 2009). Moreover, stored energy reserves are depleted at a rate that is dependent on the temperature of the hibernaculum (shelter where they hibernate), with temperatures above or below 2°C/36°F increasing the rate of depletion (Humphries et al. 2002). On the other hand, a longer growing season is likely to reduce the length of time that they hibernate.

It is unclear how these climate change effects will interact to influence bats. However, models based on energy needs related to hibernation conditions correctly predicted the distribution of the little brown bat in Canada (a northward range shift over the next century (Humphries et al. 2002). Based on these models,
similar range shifts are anticipated for other bat species, and have already been seen for eastern red bats (Willis and Brigham 2003).
Small-footed myotis

Scientific Name: Myotis leibii

Species Stressors: Change in timing of seasons, Changes in hydrology, Changes in winter, Development and habitat loss, Pests and diseases, Precipitation changes, Temperature change

Background: The small-footed bat is one of the rarest bats in North America (Moosman et al. 2007). It is uncommon and patchy throughout its range, which roughly follows the eastern mountains from Ontario and Quebec to Georgia and Alabama and extends west to Oklahoma, Arkansas, and Missouri (Thompson 2006). The small-footed bat occupies hilly and mountainous terrain in the summer, where females form small maternity and nursery colonies in vacant buildings, bridges, exposed and rocky ridges, and in loose tree bark, and males roost either singly or in small groups, in small rock shelters, talus slopes, caves, cliffs, trees, abandoned mines and railroad tunnels (Thompson 2006, Johnson et al. 2011b, O’Keefe and Lavoie 2011). The roost sites tend to have strong solar exposure, and be near sheltering vegetation, and maternity roosts in particular also tend to be near water sources (Johnson et al. 2011b). This species has been observed foraging above ponds and streams (Thompson 2006). However, they prey upon a relatively diverse assemblage of arthropods, specializing on moths, and their diet includes some species that would most likely be acquired through gleaning (Moosman et al. 2007).

Small-footed bats hibernate singly, or occasionally in small groups in caves, mines and rock crevices (Johnson et al. 2011b). They are believed to be one of the hardiest bats, and able to tolerate extreme temperatures during hibernation. For instance, they do not enter hibernacula until mid-November and depart by early March often hibernate close to the entrance of caves and mines where temperatures are more extreme, and exhibit periods of activity during the hibernation period, indicating less time in deep torpor as other cave-hibernating bats (Thompson 2006).

Though little is known about population trends for small-footed bats, the species is believed to be impacted by loss of hibernacula through natural collapse or flooding, disturbance from recreational use of caves, and environmental contaminants associated with the mines in which it frequently roosts (Thompson 2006). In addition in the Northeast, other cave-dwelling Myotis bat populations have declined significantly due to white-nose syndrome, and cases have been reported for small-footed bats (Turner et al. 2011).

Climate Impacts: Climate change induced habitat loss, particularly shifts in hydrology may impact the small-footed bat because it relies on fairly specific roosting habitat: ground-level rock roosts with high solar exposure that are close to vegetative cover and water sources (Johnson et al. 2011b). The species does occasionally occupy other day roosts, but the flexibility in its roosting behavior is unknown.

Increasing climate variability may have a large effect on this species, with both increases and decreases in precipitation having potentially negative impacts. Some species have shown higher mortality in response to the extreme droughts that may increase in the future (O’Shea et al. 2011). Decreases in spring and summer precipitation and an increase in temperatures both have been linked to reduced weight gain (Drumm et al. 1994) and higher mortality in other bat species (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). 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).
Bats must store enough energy reserves over the summer to enable them to survive winter hibernation (Humphries et al. 2002). Changes in precipitation and temperature are likely to have effects on the availability of the insects they eat and thus on their stored energy reserves (Rodenhouse et al. 2009). Additionally, it is possible that warmer temperatures could cause bats to wake up from hibernation more often, which takes more energy (Rodenhouse et al. 2009). This factor could be particularly important for small-footed bats that tend to already rouse often during hibernation. Moreover, stored energy reserves are depleted at a rate that is dependent on the temperature of the hibernaculum (shelter where they hibernate), with temperatures above or below 2°C/36°F increasing the rate of depletion (Humphries et al. 2002). On the other hand, a longer growing season is likely to reduce the length of time that they hibernate.

It is unclear how these climate change effects will interact to influence bats. However, models based on energy needs related to hibernation conditions correctly predicted the distribution of the little brown bat in Canada (a northward range shift over the next century (Humphries et al. 2002). Based on these models, similar range shifts are anticipated for other bat species, and have already been seen for eastern red bats (Willis and Brigham 2003).

Finally, disease is an important consideration when discussing bats in the Northeast and Midwest. The connection between white-nose syndrome and climate change is still unclear, but warming climates could ultimately reduce vulnerability to this fungal pathogen (Ehlman et al. 2013).
**Southern bog lemming**

**Scientific Name:** Synaptomys cooperi

**Species Stressors:** Aquatic connectivity loss, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Storms and floods, Terrestrial connectivity loss

**Background:** The southern bog lemming can be found from southeastern Canada into Tennessee, and as far west as Minnesota. It inhabits a wide range of forested and unfrosted habitats including glades and old fields, grassy woodland openings, moist meadows, marshes, shrubby bogs, high elevation balds, wooded areas, roadside rights of way, and riparian communities with abundant rhododendron (Trani et al. 2007, Campbell et al. 2010), but is generally uncommon to rare (Kirkland and Hart 1999). It occurs in small colonies, and is active year round (Natural Heritage and Endangered Species Program 2015j). It consumes fruits, leaves, shoots and roots of grasses and sedges, and hypogaeal fungi (Trani et al. 2007). They typically live less than 2 years, and breed from early spring to late autumn, producing multiple litters of one to eight young (Natural Heritage and Endangered Species Program 2015j).

The southern bog lemming is listed as a species of special concern in Massachusetts, where habitat destruction and habitat loss through successional change is likely its greatest threat (Trani et al. 2007, Natural Heritage and Endangered Species Program 2015j). Southern bog lemmings also compete with the meadow vole, which is highly favored when habitats are invaded by exotic invasive grasses (Trani et al. 2007). They do not disperse rapidly, and populations are very likely isolated (Natural Heritage and Endangered Species Program 2015j).

**Climate Impacts:** The southern bog lemming may be adversely affected by changes in precipitation and hydrology. Precipitation patterns, which can drive small mammal abundance and distribution, are changing across the Midwest and Northeast. Changes in precipitation may affect the already limited dispersal ability of the bog lemming. For instance, some small mammals, such as smoky shrews and starnosed moles require precipitation for dispersal (Brannon 2002), and thus may be adversely affected in areas where rainfall events are projected to become less common (McCay et al. 1999). Loss of riparian habitats could also impact the dispersal ability of some small mammals (Trani et al. 2007). Extreme events can also have a detrimental effect on small mammal populations (Pauli et al. 2006).
**Sperm whale**

**Scientific Name:** Physeter macrocephalus

**Species Stressors:** Changes in hydrology, Changes in winter, Development and habitat loss, Pests and diseases, Temperature change

**Background:** Sperm whales are in all the oceans of the world, but are primarily above and below 45° latitude. They are rarely seen in Massachusetts waters, likely because they tend to inhabit deeper waters of at least 1000m (Natural Heritage and Endangered Species Program 2015k). The geographic distribution of sperm whales is believed to be related to complex social structures. This species is highly social and forms a number of demographically different social units (Whitehead et al. 1991), each of which has distinct geographical distributions (Reeves and Whitehead 1997). Sperm whales have particularly low reproductive rates, with males not reaching sexual maturity until at least 20 years old (Natural Heritage and Endangered Species Program 2015k). Their diet consists of sharks, skates, large squids, and other fishes (Natural Heritage and Endangered Species Program 2015k).

The total abundance of sperm whales in the western North Atlantic is unknown, as are population trends. The best estimate for the northern U.S. Atlantic is 2,607 individuals (NOAA 2007). Sperm whale mortality from humans occurs from entanglement in fishing gear, collisions with vessels, harvest, and accumulation of stable pollutants (e.g., polychlorobiphenyls (PCBs), chlorinated pesticides (DDT, DDE, dieldrin, etc.), polycyclic aromatic hydrocarbons (PAHs), and heavy metals; NOAA 2007). They are one of the most common of the large whale species, but are listed as Endangered in Massachusetts and under the federal ESA.

**Climate Impacts:** Climate change is expected to influence the distribution of whales and their prey resources, alter important demographic parameters like mortality and reproductive success, and change the timing and range of migrations (Learmonth et al. 2006, Simmonds and Isaac 2007). Climate change can alter patterns of sea surface temperature and upwellings, which is likely to affect prey composition and availability for whale species through changes in distributional shifts in feeding areas (Fleming, Alyson et al. 2016). For instance, with increasing ambient temperatures, the northeastern North Atlantic has experienced some of the most drastic increases in sea surface temperature, which has caused some copepod species that the Sei whale is highly dependent upon for prey to shift poleward more than 10° in latitude and others to decrease in abundance (Prieto et al. 2012). Some species may track these shifts in temperature and prey, as has already been seen for cetaceans in Australia (MacLeod et al. 2005). Fin and Humpback whales also have recently expanded northward into Arctic waters (Thomas et al. 2016). Distributional shifts can be particularly problematic if they cause a species moves out of range of areas specifically designated for their protection (MacLeod et al. 2005).

Changes in prey composition and structure can also have detrimental impacts on whale physiology. For instance, *Calanus finmarchicus* shows severe fluctuations linked to climate change, and northern right whales that feed heavily on this species exhibit reduction in blubber thickness (indicating they are nutritionally challenged), and reduced calf production during periods of low prey availability (Meyer-Gutbrod et al. 2015). Sperm whales have exhibited lower conception rates in response to increases in sea surface temperature, and fin whales lower calving rates in response to reduced prey abundance (Learmonth et al. 2006). Whales that undertake long migrations are particularly vulnerable to nutritional deficiencies because they need to fast while they are migrating and calving (Meyer-Gutbrod et al. 2015).
There is also evidence that increases in sea surface temperature and earlier ice break up are triggering shifts in migration schedules, and changes in species assemblages. For instance, both fin whales and humpback whales shifted their arrival date in the Gulf of St. Lawrence, Canada by more than 1 day/year (Ramp et al. 2015). These species also departed the region earlier, but at very different rates, such that they are not as separated temporally in feeding niche as they have been historically (Ramp et al. 2015).

Finally, indirect effects of climate change may also impact some whale species. For instance, climate-change induced shifts in human behavior such as increased shipping, oil and gas exploration in regions where Arctic sea disappears are also likely to lead to increases in noise exposure, boat strikes, fishing gear entanglement, and depletion of prey species (Alter et al. 2010). Moreover, warmer waters can also affect the prevalence and spread of diseases for marine mammals (Huntington 2009).
**Tricolored bat**

**Scientific Name:** Perimyotis subflavus

**Species Stressors:** Changes in winter, Development and habitat loss, Pests and diseases, Precipitation changes, Temperature change

**Background:** The tricolored bat ranges over much of the eastern US and Midwest, from southeastern Canada to Central America, though it is absent from northern New England. They use a wide range of open forest habitats (Thompson 2006), but tend to avoid deep contiguous forest (DeGraaf and Rudis 1986). Tricolored bats use the forest canopy for day and night roosts during the summer season, and occasionally man-made structures (Natural Heritage and Endangered Species Program 2015). Maternity colonies occur in caves, rock crevices, road culverts, buildings, and other manmade structures, and commonly in dead needles of pine trees (Thompson 2006, Natural Heritage and Endangered Species Program 2015). This species typically bears 2 young each year, and can live up to 15 years (Thompson 2006). Tricolored bats tend to forage along forest edges in partly open landscapes such as forests with large canopy gaps, and over open water (Natural Heritage and Endangered Species Program 2015), and consume flies, beetles, ants, moths and wasps, with a preference for leaf hoppers (DeGraaf and Rudis 1986). Tricolored bats are believed to be short distance migrants (Natural Heritage and Endangered Species Program 2015). They hibernate in caves, mines, culverts and other manmade structures, either singly or in very small groups, and commonly with other species (Thompson 2006). They require hibernacula that are warm, draft free and consistently humid for hibernation (Degraaf). Tricolored bats are one of the first species to begin hibernation in the fall, and one of the last to break hibernation in the spring, and do not rouse often during hibernation (Natural Heritage and Endangered Species Program 2015).

The tricolored bat is listed as Endangered in Massachusetts. Pesticide use significantly impacted populations in the mid-1900s (Natural Heritage and Endangered Species Program 2015). Tricolored bats are also currently experiencing significant mortality from white-nose syndrome (Frank et al. 2014), and have seen declines of up to 90% in some northeastern hibernacula (Natural Heritage and Endangered Species Program 2015).

**Climate Impacts:** Increasing climate variability may have a large effect on tricolored bats with both increases and decreases in precipitation having potentially negative impacts. Some species have shown higher mortality in response to the extreme droughts that may increase in the future (O’Shea et al. 2011). Decreases in spring and summer precipitation and an increase in temperatures both have been linked to reduced weight gain (Drumm et al. 1994) and higher mortality in little brown bats (Frick et al. 2010). Weather conditions can influence reproductive timing (birthing in specific) in insectivorous bats, and later birthing has been shown to have negative consequences for growth and survival of tricolored bats in Massachusetts (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). 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).

Bats must store enough energy reserves over the summer to enable them to survive winter hibernation (Humphries et al. 2002). Changes in precipitation and temperature are likely to have effects on the availability of the insects they eat and thus on their stored energy reserves (Rodenhouse et al. 2009). Additionally, it is possible that warmer temperatures could cause bats to wake up from hibernation.
more often, which takes more energy (Rodenhouse et al. 2009). This factor could be particularly important for small-footed bats that tend to already rouse often during hibernation. Moreover, stored energy reserves are depleted at a rate that is dependent on the temperature of the hibernaculum with temperatures above or below 2°C/36°F increasing the rate of depletion (Humphries et al. 2002). On the other hand, a longer growing season is likely to reduce the length of time that they hibernate.

It is unclear how these climate change effects will interact to influence bats. However, models based on energy needs related to hibernation conditions correctly predicted the distribution of the little brown bat in Canada (a northward range shift over the next century (Humphries et al. 2002). Based on these models, similar range shifts are anticipated for other bat species, and have already been seen for eastern red bats (Willis and Brigham 2003). Western range expansion has been documented for tricolored bats (Thompson 2006).

Finally, disease is an important consideration when discussing bats in the Northeast and Midwest. The connection between white-nose syndrome and climate change is still unclear, but warming climates could ultimately reduce vulnerability to this fungal pathogen (Ehlman et al. 2013).
Water shrew

Scientific Name: Sorex palustris

Species Stressors: Aquatic connectivity loss, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Precipitation changes, Storms and floods, Terrestrial connectivity loss

Background: The water shrew can be found in the eastern US from Nova Scotia and Southern Quebec to the southern Appalachians. The species is also found in the mountains of the west, and throughout much of southern Canada. The water shrew prefers wet habitats with cover, such as grass-sedge marshes, shrubby riparian areas in coniferous forests and wooded shorelines with extensive boulder and tree root cover (DeGraaf and Rudis 1986). It is particularly common along water bodies with high water quality (Kirkland and Hart 1999). The water shrew eats aquatic insect larva, snails, flatworms and small fishes (DeGraaf and Rudis 1986). They typically have 2-3 litters a year, with an average of 6 young, and live for 12 to 18 months (Natural Heritage and Endangered Species Program 2015m).

The water shrew is listed as a species of special concern in Massachusetts, and has rarely been observed in the state; however this may in part be due to its reclusive habits (Natural Heritage and Endangered Species Program 2015m). Threats to the water shrew include habitat and population fragmentation, loss and degradation of riparian habitats from logging, agriculture and road construction, warming and siltation of headwater streams, acid rain, declines in water quality, loss of wetland habitats, and introduction of large and small mouth bass predators (Trani et al. 2007, Natural Heritage and Endangered Species Program 2015m).

Climate Impacts: The water shrew may be adversely affected by changes in precipitation and hydrology. Precipitation patterns, which can drive small mammal abundance and distribution, are changing across the Midwest and Northeast. Changes in precipitation may affect the already limited dispersal ability of the water shrew. For instance, some small mammals, such as smoky shrews and star-nosed moles require precipitation for dispersal (Brannon 2002), and thus may be adversely affected in areas where rainfall events are projected to become less common (McCay et al. 1999). Loss of riparian habitats could also impact the dispersal ability of some small mammals (Trani et al. 2007). Extreme events can also have a detrimental effect on small mammal populations, and thus overall diversity, favoring particular species (Pauli et al. 2006). The water shrew is also highly impacted by water quality, which is likely to be adversely affected by the increased flooding events predicted by climate change and increases in temperature.
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**Reptiles**

**Blanding’s turtle**

**Scientific Name:** *Emydoidea blandingii*

**Species Stressors:** Aquatic connectivity loss, Temperature changes, Precipitation changes, Development and habitat loss, Terrestrial connectivity loss

**Background:** The distribution of Blanding’s turtle is centered in the Great Lakes region and west to Nebraska. There are also three disjunct populations in New York, eastern Massachusetts into southern Maine, and southern Nova Scotia (Spooner et al. 2014). Habitat fragmentation and road kill mortality (Millar and Blouin-Demers 2012) appear to be causing a decline in populations. Mortality can significantly impact populations because the species is very long-lived (70+ years), has delayed sexual maturity, and low fecundity (Sajwaj and Lang 2000, Spooner et al. 2014). As a result the species is listed as at risk in 17 of 18 state or provincial jurisdictions across its range (Millar and Blouin-Demers 2012). In Massachusetts it is currently listed as threatened.

The Blanding’s turtle is generally considered a northern species that inhabits productive wetlands including ponds, creeks, and marshes (Sajwaj and Lang 2000, Edge et al. 2009). Compared to more southern turtle species, it tolerates lower maximal temperatures and selects microhabitats that result in lower body temperatures (Sajwaj and Lang 2000). Though largely aquatic, it can make long overland movements for nesting and while moving between wetlands (Innes et al. 2008). The species has a relatively large home size and will travel extensively between wetlands (Edge et al. 2009, Millar and Blouin-Demers 2012). Females nest in upland locations with nesting peaking in June (Innes et al. 2008, Markle and Chow-Fraser 2014). Turtles move to overwinter locations in September and October and remain moderately active until ice formation (Edge et al. 2009). They emerge from hibernation under the ice between March and April (Thiel and Wilder 2010).

**Climate Impacts:** Blanding’s turtles inhabit a fairly narrow latitudinal range (Reid and Peery 2014), and are constrained by temperature at the northern boundary (Millar and Blouin-Demers 2012, Spooner et al. 2014) while also having a relatively low tolerance for high temperatures (Sajwaj and Lang 2000, Anthonysamy et al. 2013). This suggests that optimal climatic range will likely shift north as climate changes. However, the ability of Blanding’s turtles to move north with such changes may be hampered by habitat fragmentation, as road crossings are hazardous and vehicles are a significant source of mortality (Millar and Blouin-Demers 2012, Markle and Chow-Fraser 2014). Habitat suitability for Blanding’s turtles decreases rapidly as road density increases (Millar and Blouin-Demers 2012).

Temperature can also impact male to female ratios, as some turtles, including Blanding’s turtle, exhibit temperature-dependent sex determination (Reid and Peery 2014). In such turtles, temperature changes during incubation of eggs can shift clutch sex ratios. However, to date, studies have failed to find any connection between changing climate and sex ratios in populations that are known to have experienced warming temperatures (Reid and Peery 2014).

Additionally, climate change is projected to increase the frequency of short-term summer drought conditions in the Northeast (Brooks 2009, Huntington et al. 2009). This has the potential to impact turtles through reduction of suitable habitat. In some populations, Blanding’s turtles have been observed to
reduce activity during drought conditions, and to prepare for hibernation earlier in the season (Anthonysamy et al. 2013).
**Eastern ribbonsnake**

**Scientific Name:** Thamnophis sauritus

**Species Stressors:** Changes in hydrology, Changes in winter, Development and habitat loss, Storms and floods, Temperature change, Terrestrial connectivity loss

**Background:** The eastern ribbon snake is found from southern Maine to the Florida panhandle and west into southern Indiana and Louisiana; though a sub-species of the eastern ribbonsnake is found to the north. They are semi-aquatic, and are often found in dense shrubby vegetation near the water’s edge in swampy areas, wet meadows, ponds, bogs, and in forested areas along streams (DeGraaf and Rudis 1986). They are relatively sedentary, with summer ranges rarely exceeding a 5 x 10 m area; however, in the fall the eastern ribbonsnake can move up to 173 m from water in order to hibernate (Bell et al. 2007). They eat primarily larval amphibians, though small fishes, insects and mice are occasionally taken (DeGraaf and Rudis 1986). Females reach sexual maturity around two to three years, and may not reproduce every year (Wisconsin Department of Natural Resources 2013). The female retains the eggs until they are fully incubated and hatched, and gives live birth to 10-12 young in late July to September (DeGraaf and Rudis 1986). The eastern ribbonsnake hibernates from October to March (Wisconsin Department of Natural Resources 2013). They are fairly common throughout the range (DeGraaf and Rudis 1986), though the northern sub-species is exhibiting declines, and is listed as endangered in Wisconsin, and Nova Scotia (Bell et al. 2007, Wisconsin Department of Natural Resources 2013).

**Climate Impacts:** Climate change may impact the eastern ribbonsnake through a number of mechanisms. For one, climate change is projected to increase the frequency of short-term summer drought conditions in the Northeast (Brooks 2009, Huntington et al. 2009). Coupled with increased temperatures this is expected to reduce soil moisture, and cause habitat loss and reduction of the amphibian species that they heavily rely upon for food (Wisconsin Initiative on Climate Change Impacts 2011). Changes in hydrology can also reduce habitat availability for the eastern ribbonsnake since it spends much of its time in or near water (Bell et al. 2007, Wisconsin Department of Natural Resources 2013). The increased flooding and decreased snowfall associated with climate change could also indirectly impact eastern ribbonsnakes by reducing amphibian populations (Wisconsin Initiative on Climate Change Impacts 2011).

Changes in temperature could also impact the eastern ribbonsnake. For one, temperature changes could alter behavior. The preferred body temperature for the eastern ribbonsnake is 30.1° C; the species regulates its body temperature by basking in mud and in shrubs or floating in water among aquatic vegetation (Ernst and Ernst 2003, Bell et al. 2007). During dry, hot spells the eastern ribbonsnakes can also enter a state of torpor for short periods (Ernst and Ernst 2003). It is unclear how well the species can adapt to changes in temperature, or what the consequences of behavioral adaptations might be. It is however unlikely that this species could track temperature changes through dispersal, as it is highly sedentary. In fact, the small home range and sedentary nature of the eastern ribbonsnake may make it vulnerable to local extinctions (Bell et al. 2007). Road mortality also poses a significant threat to this species and limist dispersal to new habitats (Wisconsin Department of Natural Resources 2013).
Northern diamond-back terrapin

Scientific Name: Malaclemys terrapin

Species Stressors: Aquatic connectivity loss, Development and habitat loss, Sea level rise, Storms and floods, Temperature change

Background: The northern diamond-back terrapin is a medium-sized turtle that lives in brackish water habitats such as bays, sounds and estuaries. This subspecies of the diamond-back terrapin typically inhabits coastal salt marshes form New Jersey to Massachusetts, which is the northernmost extent of its historical range (Brennessel 2006b). Other subspecies of the diamond-back terrapin extend in range along the Atlantic coastline to as far south as Florida and in Texas along the Gulf of Mexico. The northern diamond-back terrapin has a wedge-shaped top shell with ring patterns and pronounced ridges along the top. Coloration is highly variable, with the shell usually being gray, light brown, green, and black, while the skin is usually grayish to black with spots and speckle patterns (Natural Heritage and Endangered Species Program 2008). Adult females are about twice the size of adult males. In Massachusetts, females average 19 cm (7.5 inches) in length (shell) and 1000 g (2 lb) in weight, while males average 13 cm (5 inches) in length and 275 g (0.5 lb) in weight (Brennessel 2006a). Females become sexually mature at 8 to 10 years, and males mature at 5-7 years (Brennessel 2006a). They are known to live to 40 years of age and possibly longer.

Northern diamond-back terrapins hibernate during the winter months in mud by burrowing in creek beds or banks or in salt marshes. Nesting primarily occurs in shrubland, dune, and mixed grassland habitats, as well as man-made trails on sandy beaches (Feinberg and Burke 2003). They primarily feed on crustaceans such as small crabs, snails, and various mollusks. Natural predators of these terrapins include raccoons, large crabs, fish, and seagulls. Raccoons in particular are known to be significant predators of diamond-back terrapin populations, and can depredate 90% of nests where they overlap in coastal habitats (Feinberg and Burke 2003). In addition, recreational and commercial crab pots threaten terrapin populations through unintentional capture and drowning (Grosse et al. 2009). Human development bordering coastal marshes and shorelines also can have negative impacts on terrapin populations especially where they occur in low numbers (Simoes and Champber 1999). Roadside fences have been successfully used to prevent road mortality (Reses et al. 2015), but other coastal anthropogenic (engineering) structures such as bulkheads on beaches prevent terrapin access to dune nesting habitat, which has energetic costs and alters behavior (Winters 2013).

Climate Impacts: In Massachusetts, this species is at the northern edge of its range (Schlesinger et al. 2011), which may increase its vulnerability to climate change. Increased erosion from sea level rise, storm surge, and human activities will likely alter this species habitat. Sea level rise, flooding and storm surge events have a very high likelihood of disrupting terrapin nesting habitat and negatively influencing salt marsh food webs that support terrapin populations throughout their life cycles (National Park Service 2016). Because the sex of diamond-back terrapins, as well as other turtles, is determined by temperature during incubation, increasing temperatures due to climate change is likely to influence the ratio of males and females within their populations (Burke and Calichio 2014). These demographic changes may have serious implications for terrapin responses and adaptation to future environmental change (Hulin et al. 2009). Nonetheless, the mobility of this species as well as the diverse habitat conditions that terrapins can live in across their range may help this species cope with some of the impacts of climate change.
**Northern red-bellied cooter**

**Scientific Name:** Pseudemys rubriventris

**Species Stressors:** Aquatic connectivity loss, Changes in hydrology, Development and habitat loss, Invasive plants and animals, Pests and diseases, Precipitation changes, Storms and floods, Temperature change, Terrestrial connectivity loss

**Background:** Northern red-bellied cooters are found in Atlantic coastal plain rivers from New Jersey to North Carolina inland to the Potomac drainage, and in a disjunct population in Massachusetts. Northern red-bellied cooters typically occupy areas with slow-moving deep water that are characterized by an abundance of basking sites and aquatic vegetation, and are occasionally found in moderately saline portions of estuaries (Swarth 2003). In Massachusetts northern red-bellied cooters are found in ponds and rivers in Plymouth and eastern Bristol County (Natural Heritage and Endangered Species Program 2016). They are active from April to October, when they are found almost entirely in the water or basking just near it (Swarth 2003). Northern red-bellied cooters nest from late May to early July in sunny spots with sandy soil and sparse leaf litter in gardens, lawns, and roadsides (Swarth 2003). Nests are typically <100 m from water and contain 73-100 eggs that hatch within 80 days (Natural Heritage and Endangered Species Program 2016). They experience severe loss of eggs and hatchlings to predators (The US Fish & Wildlife Service 2011). Hatchlings that do survive can emerge in the spring or fall, and immediately disperse toward the water (Swarth 2003). Adults consume aquatic vegetation, especially milfoil, and hatchlings can eat vegetation and small invertebrates (Natural Heritage and Endangered Species Program 2016).

The Massachusetts population of northern red-bellied cooters is listed as endangered at both the state and federal level. Threats include habitat loss and degradation, exposure to pollutants and contaminants, direct human mortality from propeller strikes, shell rot disease, and heavy nest predation (van Dijk 2013). Loss of open nesting habitat near water sources due to urbanization and fire suppression is a particularly important issue for northern red-bellied cooters (The US Fish & Wildlife Service 2011). Isolation of the remaining small populations through habitat fragmentation, and heavy predation by introduced fishes and bullfrogs also heavily impact populations (The US Fish & Wildlife Service 2006). In addition, northern-red bellied cooters can live to more than 50 years; females do not reach sexual maturity until 13-20 years of age, and do not reproduce every year, so populations are slow to recover (Natural Heritage and Endangered Species Program 2016). Head start programs where hatchlings are collected and reared past the stage of significant predation risk are slowly working to recover this species (The US Fish & Wildlife Service 2011).

**Climate Impacts:** There is little published information on how climate change is likely to impact the northern red-bellied cooter; however climate change may exacerbate the many existing stressors for this species. For one, sedimentation and pollution are thought to adversely impact the northern red-bellied cooter (Swarth 2003, van Dijk 2013). The frequent and extreme storm events that accompany climate change are likely to increase the amount of sediments, nutrients, and contaminants released from the surrounding landscape during storm events (Pinkney et al. 2014). Temperature changes could also impact some physiological processes for the northern red-bellied cooter. The sex of northern red-bellied cooters is determined by nest site temperature with warmer sites producing females (Natural Heritage and Endangered Species Program 2016). There is concern that increasing temperatures could influence the sex ratio for many turtle species with serious implications for population dynamics (Hulin et al. 2009).
However, to date, studies have failed to find any connection between changing climate and sex ratios in populations that are known to have experienced warming temperatures (Reid and Peery 2014).

As with other turtles, northern red-bellied cooters have limited physiological control over body temperature and must regulate temperature through habitat selection and behavior (Swarth 2003). Changes in ambient temperature could therefore impact daily and seasonal activity patterns in this species. Emergence of hatchlings is also impacted by temperature and rainfall in this species (Natural Heritage and Endangered Species Program 2016), though it is unknown how changes in the timing of life history events induced by climate change could affect this species.
Smooth green snake

Scientific Name: Opheodrys vernalis

Species Stressors: Development and habitat loss, Precipitation changes, Storms and floods, Temperature change, Terrestrial connectivity loss

Background: The green snake ranges from Nova Scotia and southern Ontario, and throughout most of New England into the Appalachian Mountains of Virginia, and west into Minnesota, southern Wisconsin and Michigan. Life-history information is sparse for this species (Redder et al. 2006). They are grassland dependent, and tend to reside in open upland areas that support thick green cover such as fields, wet meadows, bogs open aspen stands, sphagnum bogs, marshes, shrublands with thick vines and brambles, and in open hardwood stands (DeGraaf and Rudis 1986, Sacerdote-Velat et al. 2014). Green snakes emerge in April or May, and lay 1-2 clutches that are highly variable in number of eggs (2-18) from June to September (DeGraaf and Rudis 1986, Redder et al. 2006). Females may hasten the hatching of eggs by incubating them internally before depositing them in rodent burrows, sawdust piles, sandy soils rotting logs, or occasionally in trees (Redder et al. 2006, Hughes 2015). Communal nesting and denning is common in this species (Natural Heritage and Endangered Species Program 2015a). Green snakes are active during the day, and feed primarily on arthropods (Sacerdote-Velat et al. 2014). They hibernate over the late fall and winter, and may use linear riparian habitat features to migrate to and from denning sites, and move among populations (Redder et al. 2006). The green snake does not however appear to move large distances, and so may be vulnerable to habitat fragmentation (Redder et al. 2006).

Green snakes appear to be declining throughout their range due primarily to habitat loss, but road mortality and pesticides are also likely important sources of mortality (Redder et al. 2006). They appear to be patchily distributed in Massachusetts, and it is unknown how common they are (Natural Heritage and Endangered Species Program 2015a). They are considered endangered, threatened, or a species of Greatest Conservation Need in several states (Redder et al. 2006).

Climate Impacts: Temperature changes associated with climate change may impact green snakes. Extremely low temperatures are thought to be an important source of mortality during hibernation (Redder et al. 2006). On the other hand, higher temperatures can increase activity, and perhaps the survival rates of ectotherms such as snakes (Cox et al. 2012). Range shifts are expected for many species of snakes, though it is unlikely that many species will be able to disperse rapidly enough to track these changes (Lawing and Polly 2011).

The severe storms, floods, and droughts associated with climate change could also have negative effects on this species. For example, flooding of communal denning sites has been known to cause mass mortality in green snakes (Redder et al. 2006). High summer rainfall could also promote disease; for instance, after a wet summer, a skin infection caused significant mortality in New Hampshire’s timber rattlesnake population (Clark et al. 2011). In addition, green snakes are thought to be vulnerable to reductions in invertebrate prey due to extreme climate events as has been seen in the rough green snake (Opheodrys aestivus) (Redder et al. 2006). Finally, green snakes have very low dispersal ability, are very localized and clustered in their distribution, are relatively short lived, and have low to moderate reproductive output, so they are likely to be adversely affected by extreme, stochastic, disturbances related to climate change and are unlikely to be able to recolonize into neighboring populations after such events (Redder et al. 2006).
**Spotted turtle**

**Scientific Name:** Clemmys guttata

**Species Stressors:** Changes in hydrology, Development and habitat loss, Precipitation changes, Temperature change, Terrestrial connectivity loss

**Background:** The spotted turtle is found along the Atlantic coastal plain from Maine to Florida, and in Ontario and Quebec. They typically occupy forested wetlands, small ponds and brooks, swamps, vernal pools, marshy meadows, and bogs (Natural Heritage and Endangered Species Program 2015b). However, they use a number of different habitats throughout the year and may travel up to 1.5 km between these areas (Rowe et al. 2013). Spotted turtles mate from April to June, and are most active during cool weather in spring and early summer (Rowe et al. 2013). The females lay 2-8 eggs in sunny open areas where they incubate for 10-12 weeks (Natural Heritage and Endangered Species Program 2015b). Adults eat plant matter, slugs, worms, insects, and larval amphibians, and juveniles eat insects and worms (DeGraaf and Rudis 1986). Northern populations spend up to 7-8 months in hibernation, and can also be inactive for several days to weeks during the spring and summer season during hot weather (Rowe et al. 2013). Habitat loss and fragmentation, destruction of wetlands, road mortality, and illegal exploitation for the pet trade are significant threats for spotted turtles (Natural Heritage and Endangered Species Program 2015b).

**Climate Impacts:** Climate change may reduce habitat availability for spotted turtles. The freshwater habitats that they occupy are very vulnerable to climate change (Kundzewicz et al. 2007). Changes in temperature and precipitation can influence wetland hydroperiod, depth, size, and persistence, and drought and increased storm intensity can adversely affect water quality (Steen and Powell 2014).

Climate change may impact activity patterns and growth of spotted turtles in Massachusetts, though the overall effects of these changes are unknown. For instance, northern populations of spotted turtles are active for a longer portion of the year than southern populations (Haxton and Berrill 2001), indicating that increases in temperature associated with climate change may reduce overall activity periods. For instance, this species becomes active around 8°C and activity begins to decline at 17.8 to 22°C (Haxton and Berrill 2001). Moreover, during periods of drought, spotted turtles either estivate in the mud and exhibit significantly reduced movements, or disperse to alternative habitats if available (Rowe et al. 2013). As such, an increase in drought conditions may also reduce activity patterns and movement during the already short active period. Temperature also strongly regulates body size and age of sexual maturity in spotted turtles; individuals in northern climates are typically larger and reach sexual maturity later than those in more southern populations (Litzgus and Brooks 1998). This suggests that climate change could impact demographic parameters for northern populations of this species to favor earlier reproduction.

The sex of turtles is determined in part by temperature during incubation, so there is concern that increases in temperature associated with climate change could influence sex ratios for some turtle species (Burke and Calichio 2014). However, studies have failed to find any connection between changing climate and sex ratios in populations that are known to have experienced warming temperatures (Reid and Peery 2014). Relative to many other turtles, the spotted turtle has a larger range of temperatures in which both sexes are produced, and are therefore expected to be able to evolve to new thermal conditions more readily than other turtles (Hulin et al. 2009).
Timber rattlesnake

**Scientific Name:** Crotalus horridus

**Species Stressors:** Changes in hydrology, Development and habitat loss, Pests and diseases, Precipitation changes, Storms and floods, Temperature change, Terrestrial connectivity loss

**Background:** The timber rattlesnake ranges along the Appalachians from southern Maine to New Jersey, and westward to Wisconsin in the north and Texas in the south. Timber rattlesnakes typically inhabit areas with rocky outcroppings on southern exposures with forest or second-growth (DeGraaf and Rudis 1986). During summer the snakes migrate into the surrounding landscape to mate and forage, with males moving 3-6 km and females 1-3 km (Clark et al. 2011). However gravid females may remain quite sedentary (Brown et al. 1982). They thermoregulate during the summer by moving in and out of rock crevices and shade, and basking, and maintain their body temperature between 12.5°C and 33.3°C (Brown et al. 1982). Timber rattlesnakes are typically active from mid-April to mid-October and can mate in the spring or fall (DeGraaf and Rudis 1986). Females retain the 5-9 eggs for 4-5 months until they hatch; this is energetically taxing and females do not typically mate every year (Natural Heritage and Endangered Species Program 2015c). They hibernate beginning in September or October in communal dens (Brown et al. 1982, Clark et al. 2011), Timber rattlesnakes typically live 10- 15 years, and females do not reach sexual maturity until 7-10 years of age (Natural Heritage and Endangered Species Program 2015c).

The timber rattlesnake was historically abundant and widespread in the eastern US, but has exhibited rapid declines in some states and has been extirpated in many others (Clark et al. 2011). The timber rattlesnake is listed as endangered in Massachusetts. Populations are heavily impacted by human persecution and variability in prey abundance (Olson et al. 2015). Road mortality is also a significant threat to this species, and loss of connectivity from roads can have striking and rapid effects on genetic variability (Clark et al. 2010). Habitat fragmentation and isolation of populations has reduced gene flow so significantly for this species that inbreeding depression is evident, and is causing reduced immunity and morphological abnormalities (Clark et al. 2011).

**Climate Impacts:** Climate change is likely to cause further reduction in habitat availability for timber rattlesnakes. For instance, under an increase of 1.1 °C over the next 90 years, available habitat is expected to expand slightly in the northeastern US, but under an increase of 6.4 °C, available habitat is expected to shrink drastically to limited high elevation pockets in the Appalachians (Lawing and Polly 2011). There is also concern that rattlesnakes could not disperse rapidly enough to track changes in habitat availability under climate change. For instance, modeling exercises indicate that rattlesnake species have moved an average of 2.3 meters per year on average over the past 320,000 years, but under projected temperature increases of 1.1 °C and 6.4 °C, their ranges are expected to be displaced at the rate of 430- 2400 meters per year (Lawing and Polly 2011).

Climate change may also affect the physiology and health of timber rattlesnakes. For example, after a year with exceptionally high summer rainfall, a skin infection caused significant mortality in New Hampshire’s timber rattlesnake 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).
**Wood turtle**

**Scientific Name:** Glyptemys insculpta

**Species Stressors:** Aquatic connectivity loss, Temperature changes, Precipitation changes, Changes in hydrology, Storms and floods, Change in timing of seasons

**Background:** The wood turtle is closely associated with rivers and streams, spending the majority of its time in the water (Hunter et al. 1999). However, during the active period of summer, it may spend considerable amounts of time away from water foraging for food items, even becoming mostly terrestrial for periods of time (Harding and Bloomer 1979, Ernst 1986). These forays into the landscape can make it vulnerable to mortality associated with road crossings, agricultural machinery, and mammal attacks (Parren 2013). In addition, the species is highly sought by collectors (Harding and Bloomer 1979). Because the species is long-lived (up to 58 years) and has low reproductive rates, removal of individuals through these means can greatly impact populations (Harding and Bloomer 1979, Hunter et al. 1999). Increased fragmentation of habitat and human disturbance has led to declines throughout the range and the species is currently listed as endangered on the IUCN Red List (van Dijk and Harding 2013).

**Climate Impacts:** As with other reptiles, wood turtles have limited physiological control over body temperature and must regulate temperature through habitat selection and behavior (Dubois et al. 2009). Wood turtles will bask in the sun to elevate body temperature and the amount of time spent basking appears to decrease during the warm months of July and August (Compton et al. 2002, Dubois et al. 2009). Initiation of basking in the spring is related to air temperature and will begin when a temperature threshold is crossed (Ernst 1986). Air temperature thus directly controls the length and intensity of the active period for wood turtles. Ambient temperature also appears to play a role in terrestrial activity. More time spent basking decreases the amount of time spent foraging in the landscape (Dubois et al. 2009), but turtles also will retreat to the stream when air temperatures are cool, using the water as a thermal refuge (Kaufmann 1992, Dubois et al. 2009).

In northern populations, requirements for thermoregulation place constraints on the spatial distribution of turtles so that terrestrial activity is decreased (Dubois et al. 2009). In these populations, turtles will remain closer to streams, using water as a thermal refuge as nighttime temperatures fall (Arvisais et al. 2004, Remsberg et al. 2006, Dubois et al. 2009). Additionally, length of hibernation is related to climate (Harding and Bloomer 1979). Because behavior is so closely tied to temperature in this species, it seems likely that climate change could directly affect behavior, though population responses are unknown. However, one study found that clutch frequency increased with increasing fall temperatures in a northern population of painted turtles, suggesting potential effects on reproductive output (Rollinson and Brooks 2007). It is possible that increased terrestrial activity associated with higher temperatures could also increase detrimental interactions with human populations.

Additionally, wood turtles may be displaced up to several kilometers downstream during flood events (Jones and Sievert 2009, Parren 2013). Increases in precipitation during winter are projected for the Northeast, coupled with more precipitation falling as rain during the winter, potentially resulting in increased frequency and severity of high flow events during this period (Fan et al. 2014). A study of wood turtles in Massachusetts showed that floods displaced nearly half of the subpopulation annually, resulting in elevated mortality rates, and decreased breeding success (Jones and Sievert 2009).
References


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