Climate Change and Severe Weather

The ‘climate change and severe weather’ category (IUCN 11) includes threats from long-term climatic changes which may be linked to global warming and other severe climatic/weather events that are outside of the natural range of variation, and potentially can alter the composition of species in a given habitat as species die or move in response to these changes. These threats include increased flooding, increased winter and summer temperatures, changes in the amount and distribution of precipitation, reduced winter conditions, and sea level rise. In addition, the human response to these changes such as the building of flood control structures to accommodate more severe precipitation events can also pose a threat to species and habitats.

The following details represent predicted changes in New Hampshire’s climate by 2099. The results are provided for both the low and high emissions scenarios, i.e. the minimum and maximum climate changes expected based on whether greenhouse gas emissions are curbed or continue to grow at the current rate (data compiled from Wake et al 2014a and 2014b except where indicated). It is important to recognize that these changes are based on predictions from models, and there is already compelling evidence to indicate that actual changes in climate may exceed the most extreme predictions with corresponding effects on wildlife and their habitats.

Annual average precipitation is predicted to increase 14 to 20% with higher increases in southern NH. These changes vary by season, with summer and fall increasing less. Precipitation may be less evenly distributed, with up to three times more extreme events than currently occurs, i.e. we can expect to see a general shift in New Hampshire from relatively frequent low intensity precipitation events to more infrequent severe storm events with longer dry periods in between.

Average annual temperatures are predicted to rise 4 to 9°F with winter temperatures and summer temperatures rising similar amounts. As a consequence, the number of days the temperature could be above 90°F will increase to 10-47 days, up from the current average of 3-7 days. This may combine with changes in extreme precipitation events to double the frequency of 1-6 month droughts. Extreme cold days (below 0°) may correspondingly decrease by 9-21 days and the days below freezing may decline 19-45 days. This will shorten the winter season and snowpack. Snow-covered days are predicted to decrease by 23-52 days. While the growing season is expected to lengthen, increased severe precipitation events and short term drought may mean that growing conditions are not improved, particularly for crops. Freezing soils due to lack of snow cover may also impact trees and other forest plants by damaging roots and killing vegetation, degrading habitats (Campbell et al 2014). Hotter summers are likely to increase the temperatures in some coldwater streams too high for native species such as brook trout to thrive.

Sea level is expected to rise 1.6 to 6.6 feet over the next century (Kirshen et al 2014). This will lead to inundation of coastal habitats and saltwater intrusion into freshwater habitats. The extent to which tidal habitats such as estuaries and salt marshes can respond to these changes by moving inland will be limited by the concentration of land development in coastal New Hampshire. Other ocean changes that may affect wildlife include ocean acidification, and temperature and salinity changes.

Scientific research has also shown that some of the most significant effects of climate change and severe weather on wildlife and their habitats result from interactions with other threats. In the past, organisms have responded to climate change by moving to stay within conditions they can tolerate, but habitat fragmentation means that this movement is no longer possible in many places leading to a greater risk of local extinction. Climate change has also been linked to an increased spread in invasive species and more severe disturbance events; for example the 2015 wildfires in the western United States. While these "synergistic" effects likely represent some of the most damaging effects of climate change on wildlife, they are difficult to predict and further scientific study is warranted.

Risk Assessment Summary

The threats assessment determined that 45 species and 16 habitats were affected at least moderately by climate change (see Table 4-13). However, there was considerable uncertainty about the actual extent, severity and immediacy of the effects of climate change on species and habitats. All 27 habitats had a least one type of climate threat associated with it, and 91 species did as well.

IUCN Level II categories Habitat Shifting & Alteration and Storms & Flooding affected the most species and habitats. Habitat shifts are caused by changing temperatures, precipitation, and sea level rise as well as chemical changes in water and soil. These changing conditions alter the distribution of suitable habitat for species and communities, thus wildlife must move to remain within conditions they can tolerate. Flooding alters flows of stream and rivers and increases the amount of pollutants and sediments that wash into them, altering habitat, affecting reproduction, and causing direct mortality.

In 2013 NHFG published the Ecosystems and Wildlife Climate Change Adaptation Plan (NHFG 2013), intended as an implementation plan under the state's Climate Action Plan and as an amendment to the Wildlife Action Plan. This was a comprehensive look at the effect of climate change on species and habitats, and was conducted using an expert review assessment of the state's habitats, as it was determined that most climate effects would be due to changes in habitats. The plan includes individual habitat assessments and a compilation of the overall threats. It also outlines strategies to address the threats, separated into 12 categories. This document was referred to during the 2015 threats assessment and is incorporated in the 2015 WAP.

Known Wildlife Exposure Pathways

Extreme storms and flooding

Over the last decade, there have been several storm events which have met the standards for 100-year flood state in NH including the Mother's Day flood in 2006, April of 2007, Hurricane Irene in 2011 and Hurricane Sandy in 2012. These floods cost millions of dollars in infrastructure damage such as blown out culverts, flooded roads and severe erosion in stream banks. The resulting sediment and debris such as asphalt also polluted the streams, rivers, lakes and ponds, and changed habitat structure and function. Cleanup efforts sometimes involved driving backhoes right into the stream bed, a practice ordinarily prohibited and which is damaging to the instream habitat. For wildlife, the erosion increased sedimentation, washed away or covered spawning habitat and swept animals downstream or killed them. Mussels are particularly sensitive to sedimentation, and can be buried under the load, which also clogs their filter feeding mechanisms, killing them. Stormwater also floods nest sites along the banks of rivers and ponds or in the saltmarshes downstream, affecting loons, wood turtles and others.

The number of extreme storms is predicted to increase up to threefold by 2099 (Wake et al 2014a and

2014b). Extreme storms can disrupt bird migrations and make breeding and nesting sites inhospitable, forcing birds into marginal habitats. Coastal ecosystems are particularly susceptible to storms which disrupt dunes, salt marshes, and estuaries, and bring additional stress to species living there (Michener et al. 1997). In New Hampshire these species include nesting plovers, saltmarsh birds, and colonial seabirds. In estuarine systems, influxes of freshwater from increased storm events may alter salinity and change water temperatures leading to shifts in the distribution of species and communities, increased stress, and mortality. Floodplain habitats may experience more flooding, possibly with altered timing and duration, and will also be affected by summer droughts. The end result may be altered species composition, including more invasives and the replacement of cold-associated species with more southern species. Human responses to flooding may change flow patterns, if flood control dams or other structures alter where and how stormwater is stored. Conversely, one human response is to abandon flood prone areas, thus there is the potential for increased habitat restoration opportunities in floodplains. Storm protection ("gray") infrastructure in coastal areas may prevent the movement of sediments on beaches and dunes leading to degradation of these habitats.

Shifts in plant communities and wildlife

The structure of forests including the types of tree species, which species are most abundant, and the distribution of different ages of trees, is expected to change in response to climate change, but the degree and how it will change may differ amongst forest types. It is likely that our species-based definition of Natural Communities may change, as individual plants react differently to increases in temperature and changes in the hydrological regime (NHFG 2013). Species' ranges will shift individually based on unique tolerances, and different associations may occur. Changes will occur due to specific site conditions, so will vary across the landscape. High elevation spruce-fir forests may be the most affected, as warmer temperatures will allow species like yellow birch to migrate to higher elevations. The warmth will also reduce recruitment (seedling production) for species such as balsam fir. Other factors likely to influence forest composition and condition include disturbance, invasives, extreme weather and drought. Terrestrial wildlife whose southern range extends into New Hampshire will likely shift their range northward as climate warms. These include species such as the northern bog lemming, moose, and snowshoe hare. Similarly, species whose northern range extends into southern New Hampshire will move northwards.

There is some uncertainty regarding climate-induced changes in alpine habitats in New Hampshire. Alpine habitats in New Hampshire tend to occur above the planetary boundary layer (the lowest part of the atmosphere directly influenced by the planet surface). Above that the winds and temperatures move more freely above the earth. This means that climatic trends are usually decoupled from those at lower elevations (e.g. temperatures have not risen as significantly at the highest elevations) (Seidel et al 2009). As a result, this habitat may be more resilient to climate change than previously believed. However, other studies conclude that alpine herbaceous communities are strongly affected by climate change (Walker et al. 1995, Kimball and Weihrauch 2000, Lesica and McCune 2004, Sperduto and Nichols 2004). In a review of ecological changes over the last third of the 20th century, Walther et al (2002) documented climate-related elevation shift of alpine plants, rising tree line, and northward range shifts of 39 butterfly species. For two state-listed butterflies, *Boloria titania montinus* and *Oeneis melissa semidea*, the combination of climate change and isolation may result in local extirpation without a northward range shift (e.g. extinction). That said, there could be increased encroachment of trees if snowfall increases at high elevation and shelters woody growth against the effects of wind and ice. Earlier snowmelt may allow alpine plants to bloom earlier, making them more susceptible to frost and potentially lowering seed production (NHFG 2013).

Phenology
Phenology is the timing of biological events throughout the year. This includes events like leaf out, arrival of migrating birds, emergence of adult insects and the like. In the last 50 years, dates of the last hard frost and lilac blooming have both become significantly earlier in New England (Cooter and Leduc 1995, Schwartz and Reiter 2000). This trend is predicted to continue, with leaf out occurring 6.7-15 days earlier, and lilacs blooming 6.3-16 days earlier by 2100 (Hayhoe et al 2008). Scientists in Wisconsin studied 55 springtime events—from the appearance of pussywillows to robins to trillium blooms—and found that for all combined, these events occurred an average of 0.12 days earlier per year over 61 years (7.3 days) (Bradley et al. 1999). Many species of migratory birds have shifted their arrival dates as much as 3 weeks earlier over the last several decades (Price and Root 2002). Such shifts in migration phenology have the potential to decouple bird migration peaks from peaks in food supply (e.g., McCarty 2001). This phenological decoupling may occur in other circumstances where the timing of some key biological events changes in response to climate change while other key events do not.

Snow depth and winter ice
In New Hampshire, average wintertime air temperatures increased by 3.5 F during the period from 1895-1999 (well above the regional average) (NERA 2001). By 2099, average winter temperatures will increase 3.8-9.2 F (Wake et al 2014a and 2014b) similar to the entire northeast (5-13 F, Northeast Climate Impacts Assessment 2007 and 3.1-9.7 F (Rustad et al 2012). Freeze-free periods have increased, snow cover has decreased, and lake ice duration (as measured by ice-out dates) has decreased (NERA 2001, Hodgkins et al. 2002, Huntington and Hodgkins 2004, Wake and Markham 2005). The number of snow covered days is expected to decrease by 27-42 days by 2099 (Wake et al 2014a). Snow depth and frequency are important factors affecting distribution of American marten (Krohn et al. 1995, Raine 1983) and lynx (Hoving et al. 2005). They also have direct effects on species that change their winter coat color to white such as snowshoe hare and weasel. These species may become more vulnerable due to loss of snow camouflage in the late fall and early spring. Changes to lake ice duration and surface water temperatures will strongly affect primary productivity, dissolved oxygen, thermal habitat, and invertebrate and fish communities (Rustad et al 2014). However, in the more near term, there will also be more extremes of cold and snow due to the shifting polar jet stream, which is caused by melting of artic regions (Francis and Skific 2015).

Loss of thermal habitat
Many fish species, such as brook trout and salmon, have narrow temperature tolerances. Others, such as yellow perch and smallmouth bass, are more tolerant. As climate change causes water to warm, many of New Hampshire’s coldwater fish will be replaced by warmwater species (Eaton and Scheller 1996). Some of the fish hosts of New Hampshire’s two endangered freshwater mussel species (dwarf wedgemussel and brook floater) are coldwater fish whose thermal habitat will likely diminish as climate warms, ultimately affecting the reproductive success of the mussels.

In marine systems, more problematic are trophic cascades (where an effect of climate on one level of a food chain, for example a predator, has subsequent effects on other levels, for example prey) and northward species migrations in response to warmer temperatures. Plankton blooms may no longer coincide with fish breeding and migration, thus impacting survival and reproduction. Invasive species and pathogens may also increase as the ocean warms. Marine productivity may also be affected by changes in thermohaline circulation of coastal waters, a changing thermal regime, and reduced oxygen availability.

Some terrestrial species at the southern limit of their range may also be directly affected by warmer temperatures. At summer temperatures above 57 F and winter temperatures above 23 F moose start to show symptoms of heat stress. When moose experience heat stress, their respiration and heart rates increase, they seek shade and cooling winds or cool water and they bed down and eventually cease foraging increasing their risk of mortality (Franzmann & Schwartz 1998).

Rising sea level

One of the most dramatic predicted effects of climate change in coastal habitats will be sea level rise. Sea level in the United States is rising 2.5 to 3.0 mm/yr. Global warming could raise the sea level by 0.6 to 2 feet by 2050 and 1.6 to 6.6 feet by 2100 (Kirshen et al 2014). The predicted high water levels will inundate salt marshes, deepen estuaries, and convert marsh grass to mudflat and mudflats to subtidal zones. If the rate of sea level rise is rapid, affected habitats will be inundated more frequently, putting their associated species at high risk. Total habitat and species losses are particularly likely in developed areas where there are no natural habitat retreat areas to allow for salt marsh migration.

Dune and beach habitats are important for nesting and loafing seabirds, including Roseate terns, common terns, and marine mammals. Sea level rise may affect habitat availability and the timing of nesting and migration for seabirds (Kushlan et al. 2002, Galbraith et al. 2002). The sand and sediment making up coastal dunes will be driven inland by high tides and storm surges, with the lack of natural sediment movement and coastal development meaning that in many places dunes will be lost altogether. The degradation and loss of dunes will increase the impacts of storms and high tides further inland.

As well as being inundated, salt marsh habitats may also lose pioneer species and salt pannes due to reduced incidence of ice scour. This habitat is also sensitive to changes in salinity from freshwater inputs (NHFG 2013). Rocky shores and islands will not be as affected except in low lying areas. Most intertidal species may shift to higher elevations but will be subject to more heavy surf during storms. Island-nesting birds may lose habitat or experience reduced productivity as a result of changes to available prey (NHFG 2013).

Invasive Species

Climate change will facilitate the introduction and spread of invasive species (including new diseases and pathogens) in New Hampshire. For instance, the hemlock woody adelgid, whose range is limited by temperature, has been steadily pushing north and has reached Moultonborough New Hampshire (NH Forests and Lands 2015). Loss of hemlock would have dramatic effects on forest composition, wildlife habitat, and ecosystem processes in terrestrial and aquatic ecosystems. New pest invasions are also likely including spruce-fir pests currently attacking southern Appalachian forest. The wasting disease pathogen (*Labyrinthula zosterae*), which has decimated eelgrass beds in the past, might become more of a problem because it prefers higher salinity waters (which are expected in some estuaries because of sea-level rise) and warmer water. Many non-native warmwater fish will become more predominant in many watersheds, especially where they are currently limited by temperature. West Nile Virus will likely become more of a threat if climate conditions (milder winters, wetter summers) facilitate mosquito survival and breeding. Floodplain habitats may experience increased erosion due to floods and provide more disturbed habitat for invasive plants. Transmission lines create areas of shrublands and avenues for invasive species. Control of invasive could exacerbate existing issues if chemical or biological controls are used in sensitive areas, affect non-target organisms or are used improperly.

Research Needs

- Use data from Anderson et al. 2012 and other studies and models with New Hampshire-based data to create a statewide/local map showing habitats and areas that may be most resilient to climate change.
- Incorporate the resiliency work and other adaptation issues into the ranking for creating the Wildlife Action Plan Highest Ranked Habitat map. Use this to identify key high-priority areas for conservation in the context of climate change for both natural and ecosystem service demands.
- Identify priority landscapes to provide connectivity between habitat patches.
  - Perform connectivity analyses throughout the state to identify key road crossings and current and incipient bottlenecks for movement of plant propagules and wildlife. These analyses could be done statewide or in smaller regions.
  - Identify networks of corridors and associated fragmentation barriers whose restoration facilitate species movement over the long term.
  - Develop predictive models and assess accuracy based on permanent monitoring sites (including Surface Elevation Tables (SETs), which measure saltmarsh accretion rates in salt marshes; and rocky shore, aerial mapping of rocky shores and dune extent; and biomonitoring for key indicators of climate change in all habitats.) Then develop an understanding of the feasibility of modifying policies on development and sea level rise, etc.
- Identify, through modeling, watersheds where water conflicts between humans and natural systems due to drought and flooding are likely to occur and protect a broad suite of interrelated ecosystem services that also protect natural habitats.
- Model hydrologic change based on climate models including the new US Geological Survey precipitation models for NH.
- Use Sea Level Affecting Marshes Model (SLAMM) and associated sea level rise measurement infrastructure to understand where sea level rise will most affect the coast and where habitats might migrate. Create future scenarios that show the differences if obstacles to habitat migration are removed or mitigated (e.g. roads and other infrastructure abandoned or removed, culverts appropriately sized, head-of-tide dams removed). Assess feasibility of these mitigation measures. Then re-zone and work to protect these areas that may be able to evolve to productive coastal habitats.
- Use Forest Inventory Analysis (FIA) and other data to assess how forest communities have already changed to demonstrate potential associations with climate patterns, and use this information to project changes onto future landscapes.
- Research how climate impacts soil and soil ecology, and use this to begin to determine how natural communities and habitats may change.
- Connect soil-water movements across different catenas (topographic complex of soils) to shifts in plant community structure to better understand future effects of shifting groundwater.
- Promote research on silvicultural techniques that can be used to manage forests for likely future species composition. Explore forest management techniques in the southern states with similar geology and soils so we can prepare for possible impacts.
- Evaluate biomass projects for potential impacts on forest type (e.g., does it speed community shifts in certain habitats?). Develop new BMPs for biomass harvesting as appropriate.
- Assess potential changes of fire risk from drier weather and increased downed wood.

- Assess potential phenological decoupling which may cause species to become endangered with a focus on species/taxa that are reliant on synchronized phenology for critical life history events, and where climate change is likely to shift the timing of some of these biological events at a pace different from that of others.
- Establish or expand a network of monitoring plots to observe climate related changes, and coordinate among monitoring efforts. This includes continuing existing chemical and physical monitoring and the addition of new parameters and locations. Monitoring should include long-term wildlife population monitoring, invasive plant species, forest tree and other plant species composition, wetland hydrology, and phenology. In coastal areas, sentinel monitoring for climate change approaches should be instituted to track primary stressors such as temperature, sea level rise and changing physical and chemical regimes that affect ecosystem health. Monitoring efforts should integrate and take advantage of existing programs such as FIA and work in partnership with state and federal agencies, NGOs, universities, co-ops and others. This monitoring should provide data to inform adaptive management of species and habitats and to direct necessary changes in policies.
- Establish locally relevant tide gauges and SETs in order to measure and predict sea level change hydrodynamics within Great Bay and Hampton/Seabrook. These could be set up on a short-term basis in order to establish the elevation relationship and changes in SLR between Fort Point data (the nearest active National Water Level Observation Network tide station) and other areas of the coast.

Table 4-13. Habitats and species at highest risk from the effects of climate change and severe weather (threats ranked as *Low* not included here). IUCN Level 2 provided if evaluated to that level (if not evaluated to level 2, text reads *not specified*). Some habitats and species were evaluated for multiple specific threats separately and therefore listed multiple times below. See Appendix E for additional information on specific threats and rankings.

Habitat	**IUCN Level 2**	**Overall Threat Score**
Appalachian Oak Pine Forest	Habitat shifting & alteration	M
Coastal Islands	Habitat shifting & alteration	M
Coldwater rivers and streams	Storms & flooding	M
Coldwater rivers and streams	Temperature extremes	M
Dunes	Habitat shifting & alteration	M
Estuarine	Storms & flooding	M
Hemlock-hardwood-pine forest	Habitat shifting & alteration	M
High Elevation Spruce-Fir Forest	Habitat shifting & alteration	M
Large warmwater rivers	Storms & flooding	M
Lowland Spruce-Fir Forest	Habitat shifting & alteration	M
Marine	Habitat shifting & alteration	M
Marine	Temperature extremes	H
Northern Hardwood-Conifer Forest	Habitat shifting & alteration	M

Northern Swamp	Temperature extremes	M
Peatlands	Droughts	M
Peatlands	Temperature extremes	M
Salt Marsh	Habitat shifting & alteration	H
Warmwater rivers and streams	Storms & flooding	M

Common Name	IUCN Level 2	Overall Threat Score
Alewife Floater	Storms & flooding	H
American Black Duck	Lowered reproduction	M
American Bumble Bee	Changes in phenology	H
American Marten	Habitat shifting & alteration	M
American Oysters	Habitat shifting & alteration	M
American Oysters	Storms & flooding	M
Atlantic Sea Scallop	Habitat shifting & alteration	M
Atlantic Sea Scallop	Temperature extremes	H
Bank Swallow	Droughts	M
Brook Floater	Storms & flooding	H
Chimney Swift	Storms & flooding	M
Cliff Swallow	Droughts	M
Common Loon	Lowered reproduction	M
Common Nighthawk	Temperature extremes	M
Common Tern	Altered food chains	M
Creeper (Mussel)	Storms & flooding	M
Dwarf Wedgemussel	Storms & flooding	H
Eastern Brook Trout	Temperature Extremes	M
Eastern Pearlshell	Storms & flooding	H
Horseshoe Crab	Habitat shifting & alteration	M
Horseshoe Crab	Storms & flooding	M
Horseshoe Crab	Temperature extremes	H
Karner Blue Butterfly	Lowered reproduction	M
Least Terns	Storms & flooding	M
Lynx	Habitat shifting & alteration	M
Margined Tiger Beetle	Habitat shifting & alteration	H
Moose	Changes in temperatures	H
Nelson's Sparrow	Habitat shifting & alteration	H

Nelson's Sparrow	Storms & flooding	H
Northern Shrimp	Habitat shifting & alteration	M
Northern Shrimp	Temperature extremes	H
Peregrine Falcon	Storms & flooding	M
Piping Plover	Storms & flooding	M
Purple Martin	Storms & flooding	M
Purple Sandpiper	Habitat shifting & alteration	M
Red Knot	Habitat shifting & alteration	M
Roseate Tern	Altered food chains	M
Ruddy Turnstone	Habitat shifting & alteration	M
Rusty-patched Bumble Bee	Changes in phenology	H
Saltmarsh Sparrow	Habitat shifting & alteration	H
Saltmarsh Sparrow	Storms & flooding	H
Sanderling	Habitat shifting & alteration	M
Seaside Sparrow	Habitat shifting & alteration	H
Seaside Sparrow	Storms & flooding	M
Semipalmated Sandpiper	Habitat shifting & alteration	M
Softshell Clam	Habitat shifting & alteration	M
Softshell Clam	Storms & flooding	M
Spruce Grouse	Habitat shifting & alteration	H
Timber Rattlesnake	Storms & flooding	M
Triangle Floater	Storms & flooding	M
Whimbrel	Habitat shifting & alteration	M
Willet	Habitat shifting & alteration	H
Willet	Storms & flooding	M
Wood Turtle	Storms & flooding	M
Yellow Bumble Bee	Changes in phenology	H
Yellowbanded Bumble Bee	Changes in phenology	H

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