NO REFUGE FROM WARMING

Climate Change Vulnerability of the Mammals of the arctic national wildlife refuge

By Aimee Delach & Noah Matson

Save something wild.

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INTRODUCTION: MAMMALS OF THE ARCTIC NATIONAL WILDLIFE REFUGE

THE ARCTIC NATIONAL WILDLIFE REFUGE, ENCOMPASSING 19 MILLION ACRES OF FORESTS, MOUNTAINS, TUNDRA, RIVERS AND COASTLINES OF NORTHERN ALASKA, IS THE CROWN JEWEL OF OUR NATIONAL WILDLIFE REFUGE SYSTEM. THE REFUGE VIES WITH YELLOWSTONE NATIONAL PARK FOR THE TITLE OF "AMERICA'S SERENGETI" ON ACCOUNT OF THE STUNNING ARRAY OF ANIMALS THAT MAKE A LIFE IN THIS HARSH AND BEAUTIFUL LAND. AMONG ITS 38 SPECIES OF TERRESTRIAL MAMMALS, THE REFUGE IS HOME TO ONE OF THE LARGEST CARNIVORES ON EARTH, THE POLAR BEAR (WHICH CAN REACH 1600 POUNDS), AS WELL AS THE SMALLEST MAMMAL IN NORTH AMERICA, THE PYGMY SHREW, WHICH BARELY OUTWEIGHS A PENNY. AND THESE ANIMALS' ADAPTATIONS TO LIFE AT HIGH LATITUDE ARE AS VARIED AS THEIR BODY SIZE: SOME ANIMALS SPEND THE WINTERS HIBERNATING, LIKE THE ARCTIC GROUND SQUIRREL, WHICH IS CAPABLE OF "SUPERCOOLING" ITS BODY TO 27°F, THE LOWEST TEMPERATURE OF ANY MAMMAL. OTHERS STAY ACTIVE ALL WINTER, INCLUDING THE CARIBOU, WHOSE CONTINUAL SEARCH FOR FEEDING AND CALVING GROUNDS TAKE IT ON A 2,500-MILE ODYSSEY EVERY YEAR, THE LONGEST MIGRATION OF ANY LAND ANIMAL.

Despite their variety, the mammals of the Arctic Refuge all have a few things in common. They are all adapted to life in one of the coldest places in North America, and they are all already experiencing the effects of climate changes that will inevitably accelerate in coming decades. According to the U.S. Global Change Research Program, much of Alaska has warmed over 4°F over the past 50 years, and the northern part of the state where the Refuge is located is projected to warm faster than any part of the continent (USGCRP 2009). The area is experiencing more freezing rain events that encase vital food plants in a tough coating of ice. Coastal erosion is on the rise as protective sea ice retreats from the coast earlier, laying the region bare to damaging storm surges. And this is just the beginning. Climate models project that the average annual temperature will increase by 3.5 to more than 7 degrees Fahrenheit by mid-century (USGCRP 2009).

What will these changes mean for the animals of the Arctic National Wildlife Refuge, some of which are highly specialized to the current climate conditions? Will they all be equally imperiled by the changes ahead? If not, then which of the 38 mammal species in the Arctic Refuge are likely to be most susceptible to climate change, and which are likely to be less so? A clearer understanding of which animals are most vulnerable to climate change and why will help refuge managers, scientists, and the public act to prevent the loss of these species. In this report, we present the results of a systematic comparison of climate change vulnerability for mammals in the Arctic National Wildlife Refuge over the next 50 years.

Climate Change Vulnerability

Vulnerability refers to the degree to which a species (or habitat, or community) is likely to experience harm due to exposure to perturbations or stresses. Vulnerability assessments can provide information about which species are most vulnerable to climate change, and identify the factors that make

species vulnerable. This information allows wildlife managers, scientists and other conservation practitioners to design effective adaptation strategies and prioritize limited conservation resources (Williams et al. 2008; Fussel et al. 2006). Vulnerability assessments can also help to identify important gaps in knowledge and areas of uncertainty where more research is needed.

A species' vulnerability to climate change is a function of three variables: **exposure**, or the degree to which it is exposed to climate change and variability (e.g., the amount of warming temperatures), its **sensitivity** to these changes, and its **adaptive capacity** to respond to these changes, as well as the management response to help the species or system adapt. Exposure is a result of regional climate changes, but may be modified by local microhabitat conditions. A species' sensitivity will be determined by factors including its ecological, genetic and physiological traits such as dependence on sensitive habitats, dietary flexibility, population growth rates and interactions with other species. The combination of exposure and sensitivity determines the potential impact of climate change on the species, which is then modified by its ability to adapt to climate changes, and the capacity of humans to manage, adapt and minimize the impacts to it (Williams et al. 2008). Assessing adaptive capacity includes considerations such as the species' dispersal ability, lack of barriers to its movement, evolutionary potential (e.g., genetic variation and reproductive rate), and plasticity, or the ability of the species to modify its physiology or behavior to match changes in its environment. Species with a high degree of adaptive capacity to climate changes will be less impacted than those with relatively low adaptive capacity.

To conduct this vulnerability assessment, we researched the known scientific information for each species, analyzed projected future climate change for the Refuge using ClimateWizard, and inputted our data into the NatureServe Climate Change Vulnerability Index (Index), a Microsoft Excel-based tool designed to provide scores of the relative vulnerability of animal and plant species to climate change in a given assessment area (www.natureserve.org/prodServices/climatechange/ccvi.jsp and Glick et al. 2011).

Vulnerability of Arctic Refuge Mammals to Climate Change

The results of our analysis indicate that almost half of the mammals of the Arctic Refuge are highly or extremely vulnerable to the impacts of climate change over the next four decades. Table 1 summarizes the results for all 38 species, including both the score for each sensitivity factor and its overall vulnerability score. Each species is profiled, with a more detailed explanation of the sensitivity factors, in the section below.

Table 1: Summary of climate change vulnerability scores for 38 mammal species of the Arctic National Wildlife Refuge

Species	Sea Level Rise	Natural Barriers to Range Shift	Dispersal and Movement Ability	Sensitivity to Temperature Change	Sensitivity to Moisture Change	Changes in Disturbance	Dependence on Ice and Snow	Restriction to Uncommon Geologic Features	Habitat Versatility	Dietary Versatility	Genetic Factors	Phenology	Modeled/Documented Response to Climate Change	Overall Vulnerability
Polar Bear														
Arctic Fox														
Musk Ox														
Collared Lemming					*						*	*	*	
Brown Lemming														
Tundra Vole					*									
Caribou														
Wolverine											*			
Dall Sheep														
Lynx							*							*
Northern Bog Lemming														
Tundra Shrew						*								
Barren Ground Shrew							*							*
Arctic Ground Squirrel						*								*
Alaska Marmot														
Singing Vole					*	*								
Brown Bear														*
Marten														
Taiga Vole					*	*								

Table 1, continued

Species	Sea Level Rise	Natural Barriers to Range Shift	Dispersal and Movement Ability	Sensitivity to Temperature Change	Sensitivity to Moisture Change	Changes in Disturbance	Dependence on Ice and Snow	Restriction to Uncommon Geologic Features	Habitat Versatility	Dietary Versatility	Genetic Factors	Phenology	Modeled/Documented Response to Climate Change	Overall Vulnerability
Snowshoe Hare														
Moose							*							
Northern Red-backed Vole														
Meadow Vole							*							
River Otter														
Mink														
Dusky Shrew							*							
Masked Shrew			*								*			
Red Squirrel									*					
Porcupine						*								
Pygmy Shrew														
Least Weasel														
Muskrat														
Ermine						*								
Gray Wolf							*							
Coyote														
Beaver														
Black Bear														
Red Fox													*	

Key to Table 1:

Box Color	Factor Key	Species Key
	This factor **greatly increases** the species' vulnerability to climate change	Extremely Vulnerable to climate change: Abundance and/or range extent within the Refuge extremely likely to substantially decrease or disappear by 2050
	This factor **increases** the species' vulnerability to climate change	Highly Vulnerable to climate change: Abundance and/or range extent within the Refuge likely to decrease significantly by 2050
	This factor **somewhat increases** the species' vulnerability to climate change	Moderately Vulnerable to climate change: Abundance and/or range extent within the Refuge likely to decrease by 2050
	This factor is **neutral**, neither increasing nor decreasing the species' vulnerability to climate change	*Not used*
	This factor **somewhat decreases** the species' vulnerability to climate change	Not vulnerable/presumed stable to climate change: Available evidence does not suggest that abundance and/or range extent within the Refuge will change substantially by 2050. Actual range boundaries may change.
	This factor **greatly decreases** the species' vulnerability to climate change	Likely to increase population with climate change: Available evidence suggests that abundance and/or range extent within the Refuge is likely to increase by 2050
	Insufficient information for assessment	*Not used*
*	Two or more factors selected, see text for details	Confidence in score is LOW, see text

ARCTIC REFUGE MAMMAL VULNERABILITY PROFILES

Polar Bear

Extremely Vulnerable

Ursus maritimus

Certainty: Very High

Current Global Conservation Status: Vulnerable

Polar bears (*Ursus maritimus*) are among the largest carnivores in the world, and are unmistakable for their numerous adaptations to life in the polar sea and ice: dense white fur which covers even their feet, a long neck and narrow skull that aid in streamlining them in the water, and a thick layer of insulating blubber. Polar bears feed almost exclusively on ringed seals and, to a lesser extent, bearded and harp seals. They are also known to eat walrus, beluga whale and bowhead whale carcasses, birds, small mammals and sometimes vegetation and kelp especially in summer when other food is unavailable.

Polar bears are only found in the Arctic region and are highly dependent on the pack ice there, since they spend much of their time hundreds of miles from land. The most important habitats for polar bears are the edges of pack ice, where currents and wind interact with the ice, forming a continually melting and refreezing matrix of ice patches. These are the areas of greatest seal abundance and accessibility. Individual polar bears can travel thousands of miles per year following the seasonal advance and retreat of sea ice. Polar bears are distributed throughout the Arctic region in 19 subpopulations. At the most recent meeting of the IUCN Polar Bear Specialist Group, scientists reported that eight of these populations are in decline, three are stable, and one is increasing (data was insufficient to determine the status of the remaining seven).

Scientists from the U.S. Geological Survey recently modeled polar bear response to climate change in four "ecoregions" (divisions of the polar bear's current range). Three of the four ecoregions as they classified had a >75% chance of "extinction" within 100 years. Overall, their modeling suggested that if loss of Arctic sea ice proceeds at currently projected rates, it would result in the loss of about 2/3 of the world's polar bears within the next 40 years.

Ursus maritimus scores as **extremely vulnerable** to climate change in the Arctic National Wildlife Refuge. Multiple aspects of its biology increase its vulnerability, and very few have a mitigating effect.

Critical Factors Affecting Polar Bear Vulnerability to Climate Change

Natural barriers		Polar bears face larger natural barriers than most other species assessed, since melting of sea ice will result in them facing larger expanses of open ocean.
Sea level rise		More than 90% of the bear's range within the Refuge is coastal, so their terrestrial habitat, such as for denning, could be lost to rising sea levels and increased erosion.
Dispersal and movements		One factor possibly mitigating their vulnerability is the fact that the polar bear is capable of long-distance movements.
Sensitivity to temperature change		Polar bears are found exclusively in cold habitats and are dependent on Arctic ice. Their habitat is extremely sensitive to changes in air and ocean temperature.
Dependence on ice or snow		Polar bears are among the world's most ice-dependent species. In its listing decision for the polar bear, the U.S. Fish and Wildlife Service stated: "Moore and Huntington (in press) classify the polar bear as an 'ice obligate' species because of its reliance on sea ice as a platform for resting, breeding, and hunting, while Laidre et al. (in press) similarly describe the polar bear as a species that principally relies on annual sea ice over the continental shelf and areas toward the southern edge of sea ice for foraging."
Dietary versatility		Polar bears are rely on a fairly limited set of species for food; namely, ice-dependent seals, especially ringed seals (*Phoca hispida*), and bearded seals (*Erignathus barbatus)*, which may themselves face serious threats from climate change.
Genetic variability		Genetic studies indicate that variability is relatively low; in particular, inter-population genetic variation among populations of polar bears is less than that of black bears and brown bears, but that intra-population variation is similar (Paetkau et al. 1995, 1999).
Documented response to recent change		The IUCN Polar Bear Specialist Group reports that eight of the world's 19 subpopulations of polar bears are in decline (IUCN PBSG 2009), and climate change is widely regarded as an important factor in this decline.
Modeled future change in range or population size		One population model for polar bears found that if sea ice continues to be lost at the rates currently projected, that "would mean loss of ~2/3 of the world's current polar bear population by mid-century" (Amstrup et al. 2007).

Arctic Fox
Vulpes lagopus

Extremely Vulnerable
Certainty: Very High

Arctic fox (*Vulpes lagopus*), like the polar bear, is highly specialized to the most northerly regions of the world. Their thick, dense fur turns white in the winter, and they have better hearing than other foxes, which helps them find prey even under the snow. Lemmings and voles are the staple foods for arctic foxes. However, they will eat whatever is available out on the frozen tundra such as birds, marine invertebrates, fish and carcasses of sea mammals and even reindeer calves as scavenging leftover from polar bears and wolves. The arctic fox is found throughout the entire Arctic tundra, through Alaska, Canada, Greenland, Russia, Norway, Scandinavia, and even Iceland, where it is the only native land mammal.

Our analysis found the arctic fox in the Refuge to be **extremely vulnerable** to climate change, due to habitat loss, competition with red foxes and changes in prey abundance. The species' sensitivity to climate change results from its physiological thermal regime, occurrence in conditions of historically stable temperature and moisture regimes in the past, dietary versatility, dependence on ice, ice-edge, or snow habitats, and low genetic diversity. The arctic fox is severely restricted (>90% of occurrences or range) to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change.

Its vulnerability is in large part due to the fact that its tundra habitat is located in a narrow strip of the Refuge, with ocean directly to the North and boreal forest (uninhabitable by arctic fox) to the south. Large expenses of tundra habitat could be replaced by forest (Feng et al. 2011), which is unsuitable to the arctic fox. There is also evidence that the arctic fox may not have been able to track habitat shifts during the last interglacial as cold habitats moved northward (Dalen et al. 2007). Results from a DNA analysis suggest that the arctic fox became extinct in mid-latitude Europe at the end of the Pleistocene and did not track the habitat when it shifted north during the interglacial (Dalen et al. 2007) suggesting it may be particularly vulnerable to future increases in global temperatures.

In addition to habitat loss, boreal forest encroachment will allow for expansion of populations of the red fox. Red foxes are larger and more effective hunters than arctic foxes, and also directly kill the latter. Red fox expansion may have been responsible for the decline of the arctic fox during the last interglacial (Dalen et al. 2005).

Finally, prey for the arctic fox may decline. Three species that figure prominently in arctic fox diets, the brown and collared lemming and the tundra vole, are themselves among the most vulnerable species in the Refuge according to our analysis (see profiles for those species).

Critical Factors Affecting Arctic Fox Vulnerability to Climate Change

Natural barriers

Arctic fox range in Alaska runs along the northern coast in a narrow band and the northern range of the species is essentially limited by ocean. As the climate warms the boreal forest, which is habitat for its main competitor the red fox, will encroach on the tundra where the arctic fox makes it home. The arctic fox will effectively be trapped between rapidly encroaching unsuitable forest habitat to the south and open ocean to the north.

Sea level rise

Most of the fox's range in the Refuge occurs in coastal areas subject to sea level rise. The arctic fox migrates towards the sea in fall and early winter and often lives near the shore, roaming out onto the pack ice. Sea level rise and resulting loss of coastal habitat will interact with encroaching boreal forest development in the southern portion of the range to greatly shrink the current suitable habitat for the species.

Dispersal and movements

One factor possibly mitigating vulnerability is that the arctic fox is capable of long-distance movement or migration (Anthony 1997).

Sensitivity to temperature change

The arctic fox is completely or almost completely restricted to tundra and coastal habitats in the polar region. As temperatures warm, boreal forest will encroach on this habitat, providing more of a prey base to the red fox, and exposing the arctic fox to competition with and predation from the latter, which is larger and a better hunter.

Dependence on ice or snow

The arctic fox is highly dependent on ice- or snow-associated habitats. The arctic fox migrates towards the ice edge in the winter and fall, uses snow for denning and insulation in the winter, and changes color from brown/black to white in the winter to blend in with the snow. The species will likely be highly sensitive to changes in snow cover and pack ice extent.

Dietary versatility

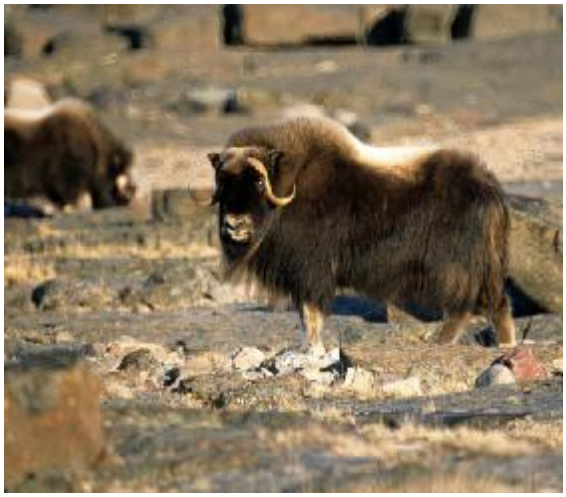
Arctic foxes in Alaska and Canada feed mainly on collared lemmings and their population cycles follow lemming population cycles. They have decreased reproductive output in low lemming years and undergo an enormous reproductive output during lemming peaks (Dalen et al. 2005). Based on one study, climate change will increase the length of the collared lemming life cycle and decrease its maximum population densities which will be detrimental to predator species including the arctic fox (Glig et al. 2009).

Genetic factors

One comparative genetic study found that nucleotide diversity was considerably lower than that in other mammals including wolves, coyotes and moose (Dalen et al. 2005).

Musk Ox
Ovibos moschatus

Extremely Vulnerable
Certainty: Very High



Musk oxen (*Ovibos moschatus*), which are more closely related to sheep and goats than to oxen, are found exclusively in Arctic areas, mostly in Canada and Greenland. Fewer than 300 musk oxen live in the Refuge. During the summer, musk oxen live in wet areas, where they graze on grasses, sedges and willows. In winter, they seek out windblown places where there is less snow to cover their forage.

Our analysis found that muskoxen ranked as **extremely vulnerable** to climate change in the Refuge, due in part to its low genetic variation and obligate association with cold climates, but also due to the possibility of changes to composition or availability of tundra vegetation. Past studies have also shown that changes in Arctic plant distributions lead to changes in muskoxen distributions (Forchhammer et al. 2005). According to one study, the historic range of musk ox, based on DNA analysis, was much larger than the current range and a warming trend over the last several thousand years is likely the result for this reduction in range (Campos et. al. 2010).

Warming winters may also be detrimental to the species if they result in more freezing rain and icing events, resulting in thicker, crustier snow that impedes grazing. Warming temperatures may also lead to higher parasite loads in muskoxen that are susceptible to lung infections from parasitic worms. These worms are now developing faster and surviving longer as the climate warms, so the muskoxen are facing higher levels of infection.

Critical Factors Affecting Musk Oxen Vulnerability to Climate Change

Natural barriers		Musk oxen are essentially at their northernmost limit in the Arctic Refuge and may be trapped from moving in response to rising temperatures by the ocean (Kerr and Packer 1998).
Sea level rise		Part of musk ox range in the Refuge exists in coastal areas, thus the species may be somewhat impacted by sea level rise along its northern edge.
Dispersal and movements		One factor possibly mitigating vulnerability is that the musk ox is capable of long-distance (>10km) movement or migration.
Sensitivity to temperature change		Musk ox range is restricted to extreme northern locations globally. There is also evidence to suggest that musk ox abundance decreased in the past due to climatic warming. Climate change has been implicated as the probable cause of decline in musk ox population numbers and restriction of the existing population to cooler habitats.
Sensitivity to moisture change		The musk ox, especially in winter, is highly dependent on shallow, windblown snow that allows the animal to forage on vegetation under the shallow snow. Climate change could melt these shallow snows from warming temperatures events, which would be beneficial to the species if cold temperatures didn't return after the initial thaw. But if freezing temperatures returned, those areas could produce a layer of ice that would prevent the musk oxen, particularly, calves, from being able to feed on the foliage.
Sensitivity to disturbance change		Warming temperatures in the Arctic have been linked to increased survival and faster development of a nematode that infects the lungs, reducing the animals' ability to run and making them more vulnerable to predation, potentially altering population structure.
Dietary versatility		Musk oxen eat a fairly narrow range of tundra vegetation species, and may therefore be sensitive to changes in tundra vegetation.
Genetic variability		Studies of both nuclear DNA and mitochondrial DNA show low levels of genetic diversity, and it has been hypothesized that the musk ox underwent a genetic bottleneck in the late Pleistocene (Campos et al. 2010).

Collared Lemming — Extremely Vulnerable

Dicrostonyx groenlandicus — Certainty: Very High

Collared lemmings (*Dicrostonyx groenlandicus*) are small rodents that live on the Arctic tundra, in Alaska, Canada, and Greenland, ranging to the northernmost reaches of the islands of the Canadian high Arctic. The lemming lives in the higher elevation areas of the tundra, feeding on a wide array of broad-leaved and grass-like plants in the summer, and the twigs of willow, aspen and birches in winter. It occupies runways beneath the snow and tunnel systems down to permafrost level. The collared lemming is the only rodent in Alaska that turns white in winter.

The collared lemming is **extremely vulnerable** to climate change in the Arctic Refuge due to climate change exposure, indirect climate factors such as natural barriers to species range shifts, and species-specific factors, including physiological thermal regime, occurrence in conditions of historically stable temperature and moisture regimes in the past, its dependence on snow cover, and its potentially low genetic variability (although there is disagreement in the peer reviewed literature about this). The lemming is restricted (>90% of occurrences or range) to tundra habitat that may be lost or reduced in the assessment area as a result of climate change. The species range is mainly limited to northern Canada and Alaska an area which has experienced only small shifts in temperature and precipitation in the past, which may predispose the lemming to higher sensitivity to future changes in these variables.

Collared lemmings may benefit from the insulating cover of snow in the winter months, use snow for tunneling, and turn white in the winter. The timing of molt is controlled by photoperiod, not the length of winter, which may make the species more vulnerable in the future as the timing of snowfall becomes more variable. Because their range in the Arctic Refuge is bordered by a large stretch of ocean, it is limited in its ability to shift northward. Kerr & Packer (1998) projected that a 3.6°F temperature increase would shrink the collared lemming's habitat by 38% and a 7.2°F change would cause 60% loss of habitat. Other research suggests that the population cycles for which the lemmings are famous are being "dampened" by climate change, and that the species is having fewer years where the population reaches high levels. This may be further bad news for the arctic fox and other predators that rely on lemmings (Gilg et al. 2009).

Critical Factors Affecting Collared Lemming Vulnerability to Climate Change

Natural barriers		Collared lemmings may be limited in keeping pace with habitat shifts due to climate change because of the ocean and sea ice very close to most of their range.
Dispersal and movements		Collared lemmings' vulnerability may somewhat mitigated by the fact that the species is capable of medium-distance (1 to 10 km) dispersal or movements (Brooks & Banks 1970).
Sensitivity to temperature change		Collared lemmings are found exclusively in Arctic tundra and are limited in distribution to northern Canada and Alaska. They tolerate very low temperatures, their fur turns white in winter, and they are active under and on the snow and ice (Hart 1962, Ferguson and Folk 1970).
Sensitivity to moisture change		(*)Collared lemmings prefer dryer ground in summer. If flooding or precipitation events increase this could be negative for the species, while drying may have an overall positive affect. However, the magnitude and direction of moisture change over the next 50 years is unclear. While the projections used in the index indicate little change in moisture in 50 years, other studies and projections in the region suggest that drying is likely to occur.
Dependence on ice or snow		The species may be dependent on snow in the winter for insulation of its tunnels and also some degree of protection from predators. The species turns white in winter, so snow provides camouflage. Results from a modeling study (Gilg et al. 2009) also suggest that a decrease in snow cover may lead to longer population cycles and decreased densities: increasing the length of the snow-free period increases the length of the population cycle and reduces peak density.
Genetic variability		(*)We found conflicting evidence regarding the level genetic variability in the species (Ehrich & Jorde 2005, Boonstra 1997, Prost et al. 2010), so this factor was weighted as neutral but with the caveat that it was difficult to score.
Phenology		Molt timing is controlled by photoperiod (Gower et al. 1992), and for this reason there is the potential for a phenologic mismatch to occur with the species turning white without snow cover. This would likely make the species highly visible and therefore vulnerable to predation. However, we did not find documentation of observed discontinuities have arisen to date between molt timing and snow cover.
Modeled future change in range or population size		The index only accepts population modeling information within the Arctic Refuge, and we did not find any studies that qualified. However, population models in other regions do project lemming declines (Kausrud et al. 2008, Gilg et al. 2009).

Brown Lemming
Lemmus trimucronatus

Extremely Vulnerable
Certainty: Very High

Brown lemmings (*Lemmus trimucronatus*) are another small tundra rodent, but they are not found as far north as the collared lemming and do not turn white in winter. Brown lemmings live in moister areas of the tundra than collared lemmings. They use well-drained tundra uplands in the spring, when the lowest areas are flooded with snowmelt, but move downslope as the wet meadows dry out over the course of the summer (Batzli et al. 1980). They mainly eat grasses and sedges, with mosses also forming an important part of the diet in summer and twigs of willow and birch in winter. Active all year, they make their nests underground in the summer, and above ground under insulating snow cover in winter.

Brown lemmings score as **extremely vulnerable** to climate change in the Arctic Refuge. The species' sensitivity to climate change results from its physiological thermal and hydrological regime, occurrence in conditions of historically stable temperature and moisture regimes, dependence on ice, ice-edge, or snow habitats, and reliance on one or a few species for its habitat. The lemming is highly dependent (>90% of occurrences or range) to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change (tundra and taiga). The species is found in northern Canada and Alaska, though not as far north the collared lemming, which reaches the High Arctic islands. Brown lemming habitat has experienced only small variations in temperature and precipitation in the past, which may predispose it to higher sensitivity to future changes in these variables. Brown lemmings may benefit from the insulating cover of snow in the winter months, as well as from decreased predation risk resulting from snow cover. Finally, the species is most often found in sphagnum bogs and sedge habitats, suggesting it may be dependent on one or a several species for habitat generation and these species (in this case sphagnum moss in particular) may be vulnerable to changes in climate.

Critical Factors Affecting Brown Lemming Vulnerability to Climate Change

Natural barriers		Brown lemmings may be limited from keeping pace with habitat shifts due to climate change because of the ocean and sea ice.
Sensitivity to temperature change		The brown lemming is almost completely restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change.
Sensitivity to moisture change		While brown lemmings preferentially utilize moist areas, they are not completely dependent on them. Furthermore, it is unclear from the climate data if there is going to be a loss of moisture in the next 50 years across the Arctic Refuge assessment area.
Dependence on ice or snow		The brown lemming may be somewhat dependent on snow in the winter for insulation of its tunnels and also for protection from predators
Habitat versatility		The brown lemming appears to use a limited number of species, particularly sphagnum moss and sedge, for much of its habitat.

Tundra Vole — Extremely Vulnerable

Microtus oeconomus — Certainty: Very High

Another small rodent confined to the northernmost reaches of North America, Europe and Asia, the tundra vole (*Microtus oeconomus*) typically inhabits damp, densely-vegetated areas along the edges of lakes, streams and marshes. It may be found in tundra, taiga, forest-steppe, and even semi-desert. Wet meadows, bogs, fens, riverbanks and flooded shores are all important habitats. It eats mainly green grasses and sedges in summer and stores rhizomes (especially knotweed and licorice root) and grass seeds for later use. Nests are in shallow burrows or under debris.

The tundra vole is **extremely vulnerable** to climate change in the Arctic Refuge. The species is limited in distribution mainly to moist tundra, which may shrink in extent over the next century. The species may also suffer from increasing fire or flooding disturbances and changes in hydrology or temperature. It is less clear how moisture conditions will change across the area assessed however. The species may also be squeezed out of its habitat as shrubs and trees encroach along the southern areas of the Refuge and the Beaufort Sea and coastal ice areas prevent northward expansion of the tundra.

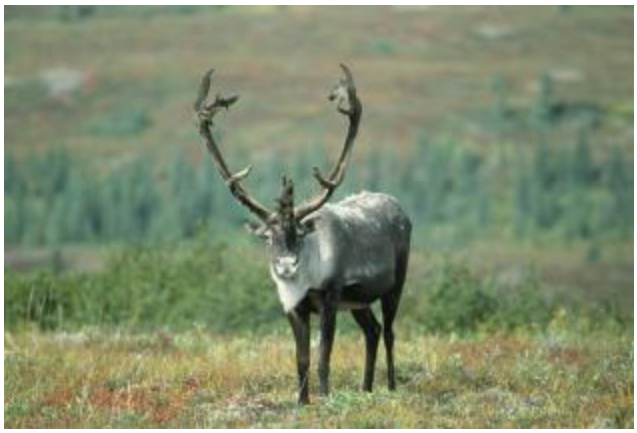
The tundra vole's high vulnerability to climate change is due in part to the fact that winter survivorship is inversely correlated with temperature. One study tracking vole survival through a series of winters found that the survival rate was highest during the coldest winter, which had only 1 day above freezing, and plummeted in the warmest winter, which had 20 days above freezing (Aars and Ims 2002). Survival is lowest during warmer winters, specifically those with a higher proportion of days above freezing, because that sets up a freeze/thaw cycle that covers vole habitat with ice. The authors noted, "In particular, mild weather that led to the formation of ice on the ground seemed to be detrimental for winter survival. We predict that if increased frequency of such events arose, due to climate change, normal cyclic dynamics of northern small rodent populations would be disrupted." Tundra habitat is also likely to see increasing forest encroachment as temperatures rise which would be detrimental to the species. Temperature increases could lead to encroachment by shrubs, displacing sedges and other plants used as food.

Critical Factors Affecting Tundra Vole Vulnerability to Climate Change

Natural barriers		The Beaufort Sea and ice to the north may form a significant natural barrier to species movement; however, since the vole's range extends through most of Alaska, this factor adds less to vulnerability as for species (like the arctic fox) whose range is entirely near the coast.
Sensitivity to temperature change		Tundra voles have lower rates of survival in warmer winters, due to the increased likelihood of freezing rain events (Aars and Ims 2002). Tundra habitat is also likely to experience increasing shrub and forest encroachment as temperatures rise which would be detrimental to the species, as these would displace sedges and other plants used as food.
Sensitivity to moisture change		(*)The species is particularly associated with wet tundra, due to their dependence on grasses and sedges for food. Roughly 70-80% of summer diet is sedges, and tundra vole density is highest in low, wet habitats dominated by these types of plants (Batzli and Henttonen 1990). The moisture balance the species prefers could shift under climate change, though it is not clear this will happen in the next 50 years under the climate projections; hence the species scored both under "somewhat increase" and "neutral" for this factor.
Sensitivity to disturbance change		Due to its small size and limited ability to move quickly in the event of disturbances like fire, the vole is somewhat sensitive to changes in disturbance regime from climate change.
Dependence on ice or snow		While not strictly a snow-dependent species, tundra voles' winter survival is enhanced by insulating snow cover (Aars & Ims 2002).

Caribou
Rangifer tarandus

Highly Vulnerable
Certainty: Very High



Caribou (*Rangifer tarandus)* are one of the most iconic species of the Arctic National Wildlife Refuge, and, like the polar bear, are already considered a sentinel of climate change. Circumpolar in distribution (referred to as "reindeer" in Europe), caribou live in scattered populations, or herds. The Refuge's Porcupine holds the world record for longest overland migration, averaging 2,700 miles (Berger 2004). The Porcupine herd arrives on the tundra in early summer to give birth to their calves and feed on the new growth of nutritious sedges. As summer progresses, they switch their diet to low-growing tundra shrubs, including dwarf birch, bog blueberry, arctic heather and arctic willow. In autumn, they move south into the boreal forest, where they feed on lichens throughout the fall and winter.

Caribou are **highly vulnerable** to climate change in the Arctic Refuge. The species is sensitive to climate change due to the following factors: Historical thermal and precipitation niche, its physiological thermal and hydrological niche, its reliance on a specific disturbance regime, its phenological response to climate change and documented results showing declines in abundance across its range. The species may also be restricted from moving in response to climate changes by the ocean and Arctic sea ice to the north and loss of tundra vegetation to the south.

Worldwide, caribou populations have declined 57 percent in recent decades, including in the Arctic Refuge. Climate changes in the Arctic are among the most important drivers of this decline: 1) increased frequency of ice storms are covering their winter food sources in a coating of ice that is difficult to paw through; 2) increases in fire frequency kill off the slow-growing lichens they prefer to eat; 3) changes in spring timing mean the best forage now peaks before the caribou herd arrive at their calving ground; and 4) warmer summer temperatures mean an increase in mosquitoes, which can get so bad that the caribou spend more time shaking off mosquitoes than they do eating.

Critical Factors Affecting Caribou Vulnerability to Climate Change

Natural barriers		The ocean and sea ice may represent barriers to caribou along its northern range in the Arctic Refuge, while encroachment of boreal forest could limit habitat for the species in the southern portion of the Refuge.
Dispersal and movements		The Porcupine Caribou herd undertakes the longest overland migration of any terrestrial mammal, averaging over 2,700 miles per year (Berger 2004). Their excellent dispersal ability may help to mitigate their vulnerability.
Sensitivity to temperature change		Caribou are restricted to tundra and boreal forest and adapted to cold temperatures. A notable example of the direct effect of warming temperatures is an increase in the level of insect harassment faced by caribou during the summer grazing season. Cold temperatures have historically limited the abundance and timing of emergence of mosquitoes and other insects. An increase in these pests in response to temperature increases has already had demonstrable negative effects on caribou (Vors and Boyce 2009).
Sensitivity to moisture change		Caribou may be particularly sensitive to changes in winter precipitation from dry snow to freezing rain and ice. One already documented impact of observed climate change on caribou is the increase in winter ice storms that form hard crust over lichens. Pawing through this crust substantially increases foraging effort (Vors & Boyce 2009).
Sensitivity to disturbance change		Because of the slow growth of lichen, caribou avoid boreal forests that have burned within the past 50 to 60 years. An increase in the frequency, severity or extent of fires, particularly if they create an overall shift to younger forests, would negatively impact winter habitat availability and quality (Rupp et al. 2006). Projections suggest that fires are likely to increase in Alaska under climate change.
Dietary versatility		The caribou diet is limited to certain species at various times of the year: fruticose and foliose lichens dominating in winter, sedges in early summer, and shrubs in later summer (Thomas & Hervieux 2010, White & Trudell 1980).
Phenology		Phenologic mismatches have been detected for caribou in Greenland, where spring plants are achieving maximum nutritional value earlier, but the timing of caribou arrival and birth of calves has not changed (Vors and Boyce 200, Post & Forchhammer, 2008).
Documented response to recent change		"Thirty-four of the 43 major herds that scientists have studied worldwide in the last decade are in decline, with caribou numbers plunging 57 percent from their historical peaks" (Struzik 2010). Climate change has been implicated as one major factor (along with mining, drilling and other disturbances) in the decline.

Wolverine
Gulo gulo

Highly Vulnerable
Certainty: Very High

The wolverine (*Gulo gulo*) is the largest terrestrial member of the mustelid family, and ranges mainly in mountain forests, where it hunts and feeds on carrion. Individuals have been known to disperse up to 500 miles.

The wolverine is **highly vulnerable** in the Arctic Refuge, due to a combination of climate change exposure, natural barriers to species range shifts, and species-specific factors including dependence on snow covered habitats. The species will not face significant anthropogenic barriers in its range around the Arctic Refuge, should it need to shift in response to climate change. However its northward expansion is limited by ocean directly to the North of the Refuge which will likely increase the vulnerability of the species in this area. Other portions of the species range that can move directly northward will likely be less vulnerable.

The species' sensitivity results from its physiological thermal regime, occurrence in conditions of more stable temperature and moisture regimes in the past across this range, dependence on snow, and low to average genetic variation. The wolverine is completely or almost completely restricted (>90% of occurrences or range) to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change. This is documented in literature results that suggest that the wolverine is limited in its range by summer temperatures. Whether this limitation is due to temperature itself of is a result of elevation, prey base, of other factors is not clear. Wolverines require persistent spring snowpack for denning and studies suggest that the distribution of spring-snow covered areas can be used to predict year round habitat use, dispersal pathways and historical and current distributions (reviewed in McKelvey et al. 2010). These factors significantly increase the wolverine's vulnerability to changes in climate and resulting changes in snow cover.

Finally, there have been several studies on the impacts of climate change on current and future distributions of wolverines. A study from 2010 (Brodie and Post 2010) examined snow cover in 6 Canadian Provinces and also looked at wolverine harvest numbers and found correlating declines over the period from 1970 to 2004. Declines ranged from about 50 to 70% -- though questions have been raised about whether harvest data is a good proxy for abundance (De Vink et al. 2011).

Critical Factors Affecting Wolverine Vulnerability to Climate Change

Natural barriers		If wolverines need to move to locations to the north to keep pace with warming temperatures populations in the Arctic Refuge, they will face a natural barrier in the form of the ocean to the north. Other locations in the range of the species will have unrestricted access further north, and Alaskan populations may be able to shift east and then north in response to changing temperatures.
Dispersal and movements		Wolverines are known for their large home ranges and excellent dispersal capabilities (Inman et al. 2004), and in one individual is known to have traveled from Grand Teton National Park to Rocky Mountain National Park.
Sensitivity to temperature change		The wolverine is completely or almost completely restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change. This is documented in literature results that suggest that the wolverine is limited in its range by summer temperatures. Whether this limitation is due to temperature itself of is a result of elevation of other factors is not clear.
Dependence on ice or snow		Wolverines depend on persistent spring snow cover for denning. A study of den locations in North America and Scandinavia found that 98% were in locations that were covered with snow until mid-May, and 90% of spring locations of wolverines were in snow-covered areas (Copeland et al. 2010, McKelvey et al. 2010).
Genetic factors		(*) Habitat fragmentation at the southern end of the wolverine's range has decreased genetic diversity there (Kyle and Strobeck 2001), which would warrant a "somewhat increase" scoring, but this appears to be less problematic in the area of the Refuge.
Documented response to recent change		One study in six Canadian Provinces compared snow cover and wolverine harvest numbers and found correlating declines over the period from 1970 to 2004. Declines ranged from about 50 to 70% (Brodie and Post 2010). However, by way of caveat, *harvest* may not necessarily be a good proxy for abundance, (DeVink et al. 2011).

Dall Sheep
Ovis dalli

Highly Vulnerable
Certainty: Very High

Dall sheep (*Ovis dalli)* live in the high mountains of the Brooks Range. In summer, they graze in alpine meadows on grasses, sedges, forbs and shrubs, and they winter on alpine ridges where strong winds keep the ground clear of snow. Nearly half of their winter foraging is in areas with no snow, and they spend very little time in places where the snow is more than a few inches deep. Dall sheep is **highly vulnerable** to climate change in the Arctic Refuge. The species is sensitive to climate change due to the following factors: Historical thermal and precipitation niche, physiological thermal and hydrological niche, and low genetic variation. For instance, an increase in temperature could increase the parasite load on Dall sheep, as these conditions lengthen the growing season and enhance winter survivorship of parasites. Climate-mediated range expansion of a parasitic muscleworm to Brooks Range Dall sheep populations has been predicted (Jenkins et al. 2005). Warming temperatures are also altering patterns of precipitation, and given the sheep's strong avoidance of deep snow, any changes that bring deeper or icier snows to its winter range could impede foraging.

Natural barriers to species movement will also be important for *Ovis dalli.* Because the species is restricted to the rain/snow-shadowed sides of mountain ranges and because the species uses these areas to escape from predators, the species faces natural barriers in the form of intervening valleys. Moving through this unsuitable habitat in response to climate change could pose a significant risk both in terms of snow-cover and predator avoidance. Additionally, the ocean provides a barrier to further northward migration.

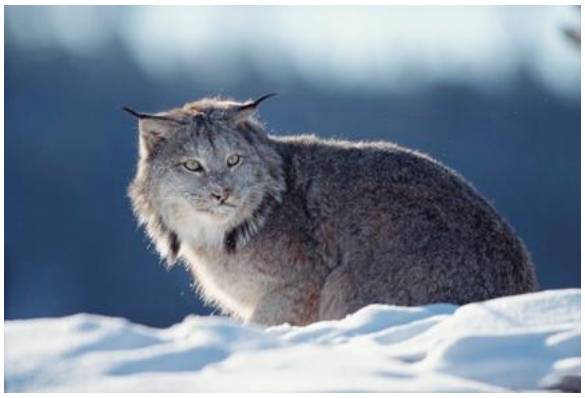
The USGS is currently studying the effects of climate change on Dall sheep habitat and populations in Alaska; results should be available in coming years to inform future management of this species (Pfiefer et al. 2010).

Critical Factors Affecting Dall Sheep Vulnerability to Climate Change

Natural barriers		Dall sheep is limited to mountainous environments. Females with lambs rely on steep slopes utilize steep mountain slopes for protection from predators. Summer foraging occurs in high alpine meadows, and winter foraging on wind-swept ridges. Areas of lower elevation may represent barriers to species movement.
Dispersal and movements		One factor possibly mitigating vulnerability is the fact that the species is characterized by excellent dispersal and movement abilities, with migration distances averaging 5 to 30 miles (Bowyer & Leslie 1992).
Sensitivity to temperature change		Dall sheep is restricted to cool and cold environments, namely, mountain ranges in Alaska, Northwest Territories Another important factor for this species is the potential for warming temperatures to enhance survivorship and expand the range of parasites, including a muscleworm that could lead to disease outbreaks (Jenkins et al. 2005).
Sensitivity to moisture change		Dall sheep may be particularly sensitive to changes in winter precipitation from dry snow to ice or heavy wet snow. Winter foraging occurs almost exclusively in areas of little or no winter snow, so precipitation patterns that bring deeper snow or thick icy ground cover could be detrimental to the species. Biologists with the Alaska Fish and are studying the impact of icing on Dall sheep mortality elsewhere in the state, but it could be a vulnerability factor in the Arctic Refuge as well.
Genetic variability		Reported genetic variation in Dall sheep is "low" compared to related taxa (Sage and Wolff 1986).

Lynx
Lynx canadensis

Highly Vulnerable
Certainty: Low



The Canada lynx (*Lynx canadensis*) is a highly specialized cat of the boreal forest, adapted to travel and hunt in areas of deep snow that deter their competitors, particularly coyotes and mountain lions. Lynx are known for the close coupling of their populations to those of the snowshoe hare, their most important prey item. They need a mix of young and old forests in close proximity to each other. Young forests with lots of underbrush are where snowshoe hares live, but lynx need older forests with a lot of downed trees to den in.

Due to these sensitivities, scientists and conservationists have already raised concern regarding the possible effects of climate change on the species, particularly at the southern edge of its range. For instance a Spatially Explicit Population Model was conducted for eastern Canada out to 2055. It predicted lynx decline of 59% because of climate change, 36% because of trapping, and 20% in scenarios evaluating the effects of population cycles (Carroll 2007). While results of this particular model are not translatable to future conditions and lynx vulnerability in the Arctic Refuge, our own exercise found similar results. Lynx scores as **highly vulnerable** to climate change in the Arctic Refuge.

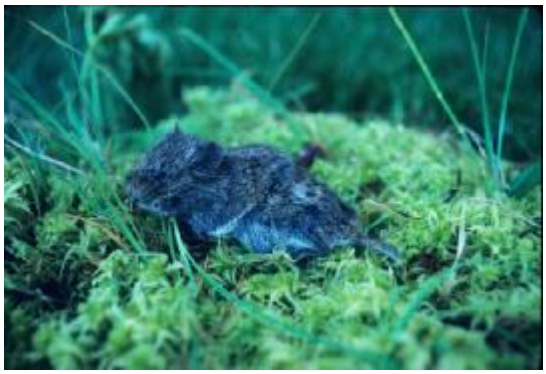
The species' sensitivity to climate change results from its occurrence in conditions of historically stable temperature and moisture regimes in the past, sensitivity to changes in disturbance regime, dependence on snow, and limited dietary diversity. Because the lynx needs a matrix of older growth and younger growth forests, changes in disturbance frequency that would reduce the availability of this matrix, particularly an alteration in fire regime, will be problematic. A reduction in the depth or increase in the density of snow will allow predators with higher foot load, like coyotes, to access areas where the lynx currently holds a competitive advantage due to its small weight to foot area ratio (Krohn et al. 1995; Mowat et al. 2000). Finally, snowshoe hare can account for over 90% of the lynx diet during winter, making the species more sensitive to climate changes that affect their prey base than more flexible carnivores.
However, because of uncertainties in the effect of changes to snow cover and forest response, the model simulations in our analysis split between "highly" and "moderately" vulnerable, resulting in "low" confidence for the lynx's vulnerability score.

Critical Factors Affecting Lynx Vulnerability to Climate Change

Natural barriers		The species is unlikely to need to shift further north in its range in Alaska in the next 50 years; however, if it does, significant natural barriers in the form of the ocean exist near the current northern range of the species in the Arctic Refuge.
Dispersal and movements		Excellent dispersal ability may help mitigate the lynx's vulnerability. Average dispersal distance for young animals is nearly 10 miles, and individual animals have been known to travel hundreds of miles (Schwartz et al. 2002).
Sensitivity to temperature change		While the lynx is primarily found in cold areas and is likely to be vulnerable at the southern end of its range, the climate changes in the Arctic Refuge are not likely to exceed the physiological tolerances for this species or to pose problems like expansion of parasite load.
Sensitivity to disturbance change		The lynx depends on a matrix of older growth and younger growth forests, so changes in disturbance frequency that reduce the availability of this matrix will be problematic. Changes in disturbance regime in the form of increased fire activity through the end of this century are very likely in response to projected temperature increased and lower available moisture. Increase in fire activity is projected to be greatest in the next 20-30 years (Rupp 2008). It is likely that large regions of mature spruce will be replaced by a more patchy distribution of deciduous forest and younger stages of spruce without the older growth; the loss of older growth trees could be detrimental to the lynx.
Dependence on ice or snow		(*)In Maine and Quebec, lynx populations are unlikely to occur in areas with less than 106 inches of snow per year. Lynx have large feet and relatively light body mass, allowing them to be more effective predators in deep, fluffy snow, compared to larger coyotes and mountain lions (Krohn et al. 1995; Mowat et al. 2000). Reduced snowfall or wetter, denser snow, could erase the lynx's competitive advantage against other predators.
Habitat versatility		Lynx have a fairly specific set of habitat needs, and are found preferentially in spruce-fir forests (RMRS, undated).
Dietary versatility		Lynx depend almost exclusively (up to 96%) on snowshoe hares as prey in winter (RMRS, undated).

Northern Bog Lemming — Highly Vulnerable

Synaptomys borealis — Certainty: Very High



The northern bog lemming *(Synaptomys borealis)* is a small, short-tailed lemming that lives primarily in and near sphagnum bogs. It is found in Labrador, Canada, west to central Alaska in the United States, and south to Washington, Montana, southeastern Manitoba and northern New England. Records from the southern end of its range indicate that it also inhabits alpine sedge meadows, krummholz spruce-fir forest with dense herbaceous and mossy understory, mossy streamsides. Northern bog lemmings make runways and tunnels within sphagnum mats, and eat mainly mosses, grasses and sedges.

Despite being one of the lesser-studied animals we analyzed, is **highly vulnerable** to climate change in the Arctic Refuge due to climate change exposure, indirect climate factors such as natural barriers to species range shifts, and species-specific factors. The species is at its northern range limit in the southern portion of the Arctic Refuge, and thus does have room to expand northward if its habitat moves in this direction. However, due to the patchiness of its habitat, it may encounter natural barriers in the form of unsuitable habitat areas.

The species' sensitivity to climate change results from its physiological thermal regime, occurrence in conditions of historically stable temperature and moisture regimes in the past, possible dependence on ice, ice-edge, or snow habitats, and reliance on one or a few species for its habitat. The lemming is moderately restricted (>50% of occurrences or range) to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change. The species is considered critically vulnerable in the southern extent of its range, though it is unclear if climate plays a role in this. The species has experienced only small shifts in temperature and precipitation in the past, which may predispose it to higher sensitivity to future changes in these variables. Northern bog lemmings may benefit from the insulating cover of snow in the winter months, as well as from decreased predation risk resulting from snow cover. Finally, the species is most often found in sphagnum bogs, though it also is found in sedge and moist upland habitats suggesting it may be dependent on one or a several species for habitat generation and these species (in this case sphagnum moss in particular) may be vulnerable to changes in climate.

Critical Factors Affecting Northern Bog Lemming Vulnerability to Climate Change

Natural barriers		The northern bog lemming may be limited by keeping pace with habitat shifts due to climate change because the patchy nature of its habitat.
Dispersal and movements		Dispersal and movements are not well known in the northern bog lemming, but they seem to be able to move between bog patches up to a mile apart (Reichel and Beckstrom 1992).
Sensitivity to temperature change		The northern bog lemming is moderately restricted (>50% of occurrences or range) to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change.
Sensitivity to moisture change		Because the species is found most often in or near sphagnum mats or wet sedge meadows, it may be particularly sensitive to changes in moisture.
Dependence on ice or snow		The lemming may be somewhat dependent on snow in the winter for insulation of its tunnels and also some degree of protection from predators.
Habitat versatility		A single group of species, sphagnum mosses, is the primary component of the lemming's habitat; however, it is also found in sedge areas and other upland sites with moist soil.

Tundra Shrew
Sorex tundrensis

Highly Vulnerable
Certainty: Very High

Tundra shrews (*Sorex tundrensis*) live in tundra and boreal forests, particularly thinned forests with dense understory cover, from Russia and Mongolia to Alaska, Yukon, and the Northwest Territories. They feed on insects, small invertebrates and grasses in grassy and shrubby tundra on hillsides and other well-drained sites.

Although the species has high genetic variability and is able to tolerate and utilize a range of habitats, the tundra shrew may be **highly vulnerable** to climate change in the Arctic Refuge. Vulnerability in the tundra shrew is caused by a combination of climate change exposure, indirect climate factors such as natural barriers to species range shifts, and species-specific factors including dependence on snow covered habitats and physiological thermal regime. While the species will not face significant anthropogenic barriers should it need to shift in response to climate change, its location in the Arctic Refuge with ocean directly to the north of the Refuge will likely increase the vulnerability of the species in this area. Other portions of the species range that can move directly northward will likely be less vulnerable.

The species' sensitivity to climate change results from: its physiological thermal regime, occurrence in conditions of historically stable temperature and moisture regimes in the past, and its possible dependence on snow for insulating cover in the winter months. The shrew is completely or almost completely restricted (>90% of occurrences or range) to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change (e.g., the tundra). The species distribution is in boreal forest and tundra habitat in Alaska and Northwest Canada. It reaches its southern extent in British Columbia where it is considered critically imperiled. It is not clear if the species' distribution is limited by temperature or by competition with more southern species. The range of the tundra shrew in the Arctic Refuge has historically experienced by low temperature and moisture shifts which increase the sensitivity of the species to future climatic changes. Finally, the species may rely on snow cover to provide insulation in the cold winter months. These factors significantly increase the shrews' vulnerability to changes in climate.

Critical Factors Affecting Tundra Shrew Vulnerability to Climate Change

Natural barriers		If the shrew needs to move to locations to the north to keep pace with warming temperatures populations in the Arctic Refuge, it will face a natural barrier in the form of the ocean to the north. Other locations in the range of the species will have unrestricted access further north, and Alaskan populations may be able to shift east and then north in response to changing temperatures.
Sensitivity to temperature change		The shrew is completely or almost completely restricted (>90% of occurrences or range) to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change.
Sensitivity to moisture change		The species has some association with damp habitats but is found in drier areas as well (Vinogradov 2008), so moisture changes may have less impact on this species than others.
Sensitivity to disturbance change		(*)One study found relatively high numbers in recently logged or cleared areas (Vinogradov 2008), so a moderate increase in disturbance might create additional habitat for the species.
Dependence on ice or snow		The shrew may be somewhat dependent on snow in the winter for insulation of its tunnels and also some degree of protection from predators.

Barren Ground Shrew — Highly Vulnerable

Sorex ugyunak — Certainty: Low

The barren ground shrew (*Sorex ugynak*) uses wetter areas of the tundra than the tundra shrew, and eats a similar diet of insects, small invertebrates and seeds. It is distributed across a narrow band of Alaska north of the Brooks range, stretching east across most of Nunavut Territory to the northwest Hudson Bay. It was once considered to be a subspecies of *S. cinereus*.

Confidence in information was low on this species due to paucity of species-specific information; however, *Sorex ugyunak* may be **highly vulnerable** to climate change in the Arctic Refuge due to climate change exposure, natural barriers to species range shifts, and species-specific factors including its physiological thermal regime. While the species will not face significant anthropogenic barriers should it need to shift in response to climate change, its location in the Arctic Refuge with ocean directly to the north of the Refuge will likely increase the vulnerability of the species in this area. Other portions of the species range that can move directly northward in response to changing temperatures will likely be less vulnerable.

The species' sensitivity to climate change results from its physiological thermal regime, occurrence in conditions of historically stable temperature and moisture regimes in the past, possible dependence on snow and ice habitat, and moderate dependence on disturbance regimes. The shrew is significantly restricted (>90% of occurrences or range) to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change (montane areas and boreal forests). The species distribution follows a very narrow range across northern Alaska and Canada bounded to the east by Hudson Bay. While the shrew does prefer moist habitats of the wet tundra, but there is no indication that these areas will be lost in the Arctic Refuge based on the ClimateWizard moisture analysis. Therefore this factor is neutral for the species. For snow cover dependence we scored the species as slightly increase/neutral because while the species does forage under snow in winter there is no data to suggest that snow is important for insulation.

Critical Factors Affecting Barren Ground Shrew Vulnerability to Climate Change

Natural barriers		If the shrew needs to move to locations to the north to keep pace with warming temperatures populations in the Arctic Refuge, it will face a natural barrier in the form of the ocean to the north. Other locations in the range of the species will have unrestricted access further north, and Alaskan populations may be able to shift east and then north in response to changing temperatures.
Sensitivity to temperature change		The barren ground shrew is completely or almost completely restricted (>90% of occurrences or range) to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change.
Sensitivity to moisture change		The barren ground shrew is moderately dependent on wet areas but the predicted moisture changes do not indicate that these will be drastically reduced.
Dependence on ice or snow		(*)The shrew does forage under snow cover in winter and may depend on snow cover for insulation; however, species information was unclear on the level of dependence.

Arctic Ground Squirrel — Highly Vulnerable

Spermophilus parryii — Certainty: Low

The arctic ground squirrel (*Spermophilus parryii*) inhabits well-drained soils on open tundra, in areas where permafrost is not close to the surface. They preferentially utilize upland ridges and dunes with well-drained soils appropriate for burrowing and with views of the surrounding landscape. Arctic ground squirrels hibernate at the lowest body temperature of any mammal; they can "supercool" their body temp to 27 degrees F. Of the species analyzed here, they have the most distinctive associations certain geological feature, rather than hydrology or plant composition.

The arctic ground squirrel is **highly vulnerable** to climate change in the Arctic Refuge. The species is limited in distribution and is likely sensitive to changes in temperature, hydrologic regimes and vegetation. The species is also dependent on more rare geologic features and snow for winter hibernacula. Changes that bring more freezing rain and ice events could also decrease winter survivorship. The species may be limited in range expansion in the future by the ocean on its northern boundary.

Simulations of the vulnerability models split between "highly" and "extremely" vulnerable, resulting in "low confidence for this species.

Critical Factors Affecting Arctic Ground Squirrel Vulnerability to Climate Change

Natural barriers		If the ground squirrel needs to move to locations to the north to keep pace with warming temperatures populations in the Arctic Refuge, it will face a natural barrier in the form of the ocean to the north. Other locations in the range of the species will have unrestricted access further north, and Alaskan populations may be able to shift east and then north in response to changing temperatures.
Dispersal and movements		Arctic ground squirrels have moderate dispersal ability. In the Yukon, females dispersed a mean 400 feet and males a mean 1700 feet (Byrom & Krebs 1999).
Sensitivity to temperature change		Arctic ground squirrels are limited in distribution to a small swath of northwest Canada and Alaska and preferentially utilize tundra habitat. They are found less frequently in boreal forest. Increased extent of boreal forest in the Arctic Refuge as a result of climate warming could be detrimental to the species that prefers open ground. Also, they appear to preferentially avoid eating shrubs (Batzli & Sobasky 1980), so a change in conditions or disturbance regime that allowed encroachment of trees or shrubs could be detrimental to the species.
Sensitivity to moisture change		Increased precipitation could increase the vulnerability of the species, particularly if rain increases during hibernation. Winter rain events may affect hibernating ground squirrels in two important ways; reducing snowpack and by directly flooding burrows (Donker 2010). Flooding is a major problem for the species, so in the short-term melting of permafrost and pooling of meltwater would represent a challenge as would increases in winter precipitation falling as rain.
Sensitivity to disturbance change		Increasing fire activity projected during this century (Rupp 2008) will likely benefit the species by increasing forest openings which provide preferable habitat to the species (Donker 2010). Because it is somewhat uncertain, the species was scored in two categories.
Dependence on ice or snow		The species burrows under snow in the winter during hibernation. Snow thus provides both important insulation and predator protection.
Restriction to uncommon geologic features		The arctic ground squirrel has one of the clearest geological associations of any of the Refuge mammals analyzed. They preferentially utilize upland ridges and dunes with well-drained soils appropriate for burrowing and with views of the surrounding landscape.

Alaska Marmot
Marmota broweri

Highly Vulnerable
Certainty: Very High

The Alaska marmot (*Marmota broweri*) is endemic to northern Alaska, found mainly in the Brooks Range and environs. They inhabit talus slopes and feed on a variety of alpine tundra vegetation: leaves, seeds, grains, and also eat insects. They are active for a short period, hibernating from early September through April or May. Hibernacula tend to be on exposed ridges where the snow melts earlier (Rausch & Rausch 1971); however, from the limited hibernation data available (Lee et al. 2009), they need to maintain an above freezing body temp, and overwinter is a significant source of mortality, so insulating cover is probably important in deep winter.

The marmot is **highly vulnerable** to climate change in the Arctic Refuge in the next 50 years primarily because of its limited range in the tundra environment of Alaska. The species may face a natural barrier (in the form of the ocean) to northward movement in the future which may increase its future vulnerability. The species is endemic to the northern mountains in Alaska and depends on tundra vegetation for its food supply. The species has also existed under conditions of stable temperature and precipitation across its range in the Arctic Refuge, which may make it slightly more sensitive to climatic changes.

Critical Factors Affecting Alaska Marmot Vulnerability to Climate Change

Natural barriers		If the marmot needs to move to locations to the north to keep pace with warming temperatures populations in the Arctic Refuge, it will face a natural barrier due to the absence of mountainous habitat north of the Brooks Range.
Dispersal and movements		Marmots exhibit good dispersal and movement ability, generally in the range of 2 to 9 miles.
Sensitivity to temperature change		The Alaska marmot is endemic to the northern mountains of Alaska and makes its home in talus fields above productive tundra vegetation which is the coldest climate in our assessment area. It is dependent on tundra vegetation for its food supply and encroachment from woody vegetation and boreal forest as warming occurs is likely to be detrimental to the species.
Dependence on ice or snow		Alaska marmots hibernate from early September through April or May. There is some indication that their hibernacula tend to be on exposed ridges where the snow melts earlier (Rausch & Rausch 1971). However, from the limited hibernation data available (Lee et al. 2009), they need to maintain an above freezing body temp, and overwinter is a significant source of mortality, so insulating cover may be an important factor in deep winter.

Singing Vole
Microtus miurus

Highly Vulnerable
Certainty: Very High

The singing vole (*Microtus miurus)* lives in arctic and alpine tundra in mountainous areas of Alaska and northwestern Canada. It is found most often in mesic microhabitats: low, moist slopes with mosses, sedges, and broad-leaved plants, better drained slopes covered with shrubs, and rocky flats near streams. They feed on horsetails, shoots of grasses and sedges, and leaves of broadleaved plants and shrubs. Singing voles are active year round, and store food in aboveground haypiles and underground caches.

The singing vole is **highly vulnerable** to climate change in the Arctic Refuge. The species is limited in distribution mainly to tundra and mountainous habitats and has specific hydrological requirements. The species may suffer from increasing flooding disturbances and changes in hydrology or temperature. It is less clear how moisture conditions will change across the area assessed however and therefore difficult to predict the impact on the species. The species may also be squeezed out of a habitat as shrubs and trees encroach along the southern areas of the Refuge and the Beaufort Sea and coastal ice areas prevent northward expansion of the tundra.

Critical Factors Affecting Singing Vole Vulnerability to Climate Change

Natural barriers		Encroachment by shrubs (which the species does not live in) and the Beaufort Sea and ice to the north may form a natural barrier to species movement.
Sensitivity to temperature change		The singing vole is found entirely in cold areas; namely arctic and alpine tundra.
Sensitivity to moisture change		(*)The species has a preference for areas that are of mesic, or intermediate, moisture. The delicate balance the species prefers could shift under climate change, though it is not clear this will happen in the next 50 years under the climate projections used in this analysis.
Sensitivity to disturbance change		(*)Increases in flood frequency or severity could cause mortality for riparian-dwelling animals. Increases in drought or fire frequency could impact food availability, though the likelihood of these is unclear.
Dependence on ice or snow		Much singing vole habitat is snow-covered up to eight months of the year. The link between survivorship and snow cover has not been illustrated as clearly as with tundra vole, but is probably in line with other small mammals that use snow for insulation and protection for predators.

Brown Bear
Ursus arctos

Moderately Vulnerable
Certainty: Low

Ursus arctos, the brown bear, scores as moderately vulnerable to climate change in the Arctic Refuge. Once widespread, the species has been extirpated from much of its original range, and Alaska is the only place where North American brown bear populations are considered likely to be secure, making the Refuge a critical sanctuary for the species. The species is omnivorous, adaptable and uses a wide variety of unforested habitats, though it is highly sensitive to human disturbances. It does not have specific thermal and hydrological requirements, though it does utilize areas of stable snowcover for denning.

The species has excellent dispersal abilities. The bear is mostly threatened in more southern portions of its range by human encroachment on its habitat; it requires undisturbed habitat and interactions with humans and roads decrease its fitness. Because its range in the Refuge is on the coastal tundra, the brown bear scores more vulnerable on the sea level rise and range shift categories than many other species.

Simulations of brown bear vulnerability in our model split between "moderately" vulnerable and "presumed stable," resulting in low overall confidence in vulnerability score.

Important Factors Affecting Brown Bear Vulnerability to Climate Change

Natural barriers		Brown bears may not to need to shift further north in its range in Alaska in the next 50 years, but if they do they will encounter the Beaufort Sea.
Sea level rise		Brown bears use coastal areas of the Refuge, so they may be somewhat impacted by sea level rise along its northern edge.
Dispersal and movements		Brown bears have excellent dispersal and movement abilities and can range hundreds of miles (Pasitschniak-Arts 1993, LeFranc et al, 1987).
Sensitivity to temperature change		The brown bear's current distribution is mostly northern, but it once ranged as far as south as Mexico. Available information suggests that human development and habitat loss, rather than climate factors, drove distribution changes.
Dependence on ice or snow		Grizzly bears select den sites with stable snow conditions for the duration of time required. Stable snow conditions are most often present at middle elevations where slope and aspect offer protection from prevailing wind and sun exposure (Linnell at al. 2000).
Phenology		The bear has a dormant period in winter following a period of gluttony in the fall. No information was found regarding possible impacts of climate change effects on the hibernation cycle in the Refuge, but this may be a topic requiring further investigation.

Marten
Martes americana

Moderately Vulnerable
Certainty: Very High

The American marten (*Martes americana*), is a small forest carnivore that is strongly associated with mature stands of conifers, generally spruce-fir, fir-white birch, or black spruce- jack pine forests. They feed on a wide variety of small rodents, birds and bird eggs, amphibians, and will eat berries and seeds seasonally. The marten scores as moderately vulnerable to climate change in the Arctic Refuge. The species has been extirpated from portions of the southern part of its range, but this more likely due to logging and other forms of habitat destruction than to climate changes. Marten habitat is sensitive to habitat disturbance, but they have a much broader dietary versatility, compared to lynx. Like lynx, martens are positively associated with snow cover, due to a light foot-load and thus a competitive advantage against larger predators in snowy conditions. However, unlike the lynx, the marten's closest competitor, the fisher, is not found in the Refuge, or near enough to be likely to move in within the next 50 years. This, with their broader dietary versatility, reduces their overall vulnerability to "moderate" in this analysis.

Important Factors Affecting Marten Vulnerability to Climate Change

Sensitivity to disturbance change

Martens are strongly associated with older coniferous forests, and negatively associated with disturbances like fire and logging (Drew 1995). Changes in disturbance regime in the form of increased fire activity through the end of this century are very likely in response to projected temperature increased and lower available moisture. Increase in fire activity is projected to be greatest in the next 20-30 years. (Rupp 2008). It is likely that large regions of mature spruce will be replaced by a more patchy distribution of deciduous forest and younger stages of spruce without the older growth which could be detrimental to the marten.

Dependence on ice or snow

Like lynx, martens are positively associated with snow cover and appear to gain an advantage over larger competitors, in the snow Krohn et al. 1995, Carroll 2007). However, their most important competitor is unlikely to expand its range into the Refuge over the near term.

Habitat versatility

The marten is fairly restricted by forest type associations and prefers spruce-fir, fir-white birch, black spruce-jack pine. However, age structure is likely important, which is reflected in the "disturbance" score.

Taiga Vole (Yellow-cheeked Vole) — Moderately Vulnerable

Microtus xanthognathus — Certainty: Very High

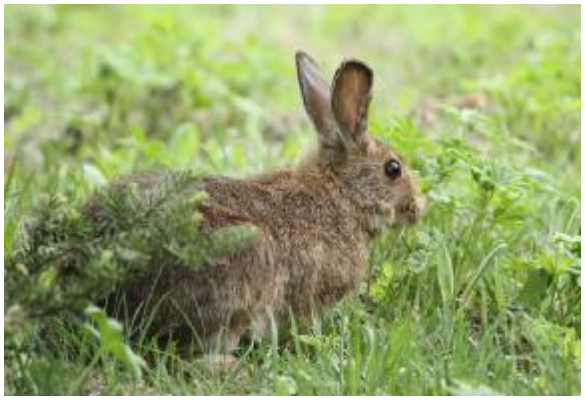
Microtus xanthognathus, the taiga vole, is also known as the yellow-cheeked vole. This vole is found primarily in early successional bottomland forests (Swanson 1996, Wolff 1980) or recently burned stands regenerating with densely growing black spruce forest. They feed primarily on sedges and rhizomes of horsetail and fireweed, which they also cache for overwintering. During winter, they huddle in groups in underground burrows, but do not enter a true hibernation. The taiga vole is moderately vulnerable to climate change in the Arctic Refuge. The species is limited in distribution to boreal forests and has specific hydrological requirements. While these factors may make it more sensitive to climate change across some parts of its range, within this particular assessment area, the vole is unlikely to be significantly affected by changes in these variables in the next 50 years. For example, the boreal forest is expected to increase northward into tundra area, so the taiga vole habitat may actually expand initially. The species may also benefit from increasing disturbances (e.g., increasing fire activity projected under climate change) that open up clearings and edge habitats in forests. However, at some point the boreal forest may not be able to maintain the level of increased fire activity and may instead convert to a different species mix (Rupp 2008) which may be detrimental to the taiga vole. The species may also be sensitive to any loss of snow cover, due to the insulating benefit it provides for wintering voles. The species will not be affected by barriers to movement since it is not located near the Beaufort Sea.

Important Factors Affecting Taiga Vole Vulnerability to Climate Change

Sensitivity to moisture change	●	(*)The species has a preference for wet, early successional boreal forest habitats. It is unclear from the climate data whether there will be any major change in moisture in the next 50 years. An increase in moisture would likely benefit the species, while a decrease in moisture would have a negative impact on the species.
Sensitivity to disturbance change	○	(*)Taiga voles may actually benefit from projected increases in fire disturbance over the next several decades, because that they are found most frequently in areas that have burned recently and have a dense stand of young trees. On the other hand, it is unclear whether taiga forest can sustain the increased fire regime over the long term.
Dependence on ice or snow	●	Taiga voles benefit from snow cover for overwintering insulation.
Dietary versatility	●	Taiga voles' seasonal diet is relies heavily on a limited number of species, particularly sedges in summer and caches of horsetail and fireweed in winter "(Conway and Cook 1999).

Snowshoe Hare — Not Vulnerable/Presumed Stable

Lepus americanus — Certainty: Very High



The snowshoe hare *(Lepus americanus)* lives in coniferous and mixed forests with large amounts of understory cover. It has a fairly flexible diet, eating a wide variety of plant species. The snowshoe hare is **not vulnerable/ presumed stable** to climate change in the Arctic Refuge. The species is likely to be less vulnerable than some of the other species assessed because it is not at its northern range limit and is not dependent on shrinking tundra habitat.

While the hare is dependent on cold habitats and is considered vulnerable in the southern edge of its range, it is not clear that climate changes in the Arctic Refuge over the next 50 years would alter the boreal forest habitat the species depends on; in fact, the species may be able to expand its range further north from its current limit in the southern portion of the Arctic Refuge as boreal forest moves into the tundra habitat further north in the Refuge.

Compared to the other species that ranked "Not vulnerable/ presumed stable," snowshoe hare exhibits stronger associations with snow and ice, and a greater degree of vulnerability associated with changes to snowpack. For instance, the species changes color in the winter to blend in with the snow and better avoid predators. Given the snowshoe hare's unique adaptations to snow (light build and huge back feet), loss of snowpack in winter or increased density of the snow would reduce the hare's ability to outrun predators. Additionally, the hare molts to white in winter, and this change is cued by photoperiod not temperature or snowfall itself. Over the last few years researchers in Montana have detected mismatches between hare seasonal coloration and their environment (white hares on brown ground). This could potentially be a problem for the species in the future across a wider portion of its range.

Moose
Alces alces

Not Vulnerable/Presumed Stable
Certainty: Very high

Moose *(Alces alces)*, which are the largest members of the deer family, live in northern areas. They eat willow, birch and aquatic plants, foraging in wet shrub thickets in summer and at forest edges in winter. The moose scores **not vulnerable/ presumed stable** to climate change in the Arctic Refuge, though it is likely to be vulnerable to climate change in more southern portions of its range. The moose does have some characteristics that may make it more sensitive to climate change, especially in areas further south of the Refuge including a reliance on lower temperatures, possible preference for snow-covered areas, and low genetic variability. Moose do not live in places where the temperature exceeds80°F for long periods of time, or where shade and access to water are lacking. In the summer it uses shaded areas or stands in water to prevent overheating, a practice which can limit foraging (Post et al. 1999). At the southern end of their range, there is also evidence that spring warming is associated with higher parasite loads, particularly ticks (DelGiudice et al. 1997). However, within the assessment period over the next 50 years, the species is not likely to encounter widespread loss of its thermal niche, so this factor was scored as "somewhat increase." Furthermore, while there is a barrier of ocean and Arctic sea ice to the north, it is unlikely that the temperature will change enough in the next 50 years to require the moose to need to move northwards to keep pace with climate change. Sensitivity to changes in snow cover reflected uncertainty as to the effect of snow cover changes on the species. Due to their long legs, moose have no trouble moving in snow depths up to 50 cm, and may use areas with this snow depth preferentially, for avoidance of wolves, but progressively impeded at depths greater than 60 cm. Harder, crustier snow supports them better, but also supports wolves better (Mech et al. 1987). The species' potential vulnerability is also moderated by their extensive use of early successional habitats, which may increase in the Refuge over the course of the assessment period.

Northern Red-backed Vole — Not Vulnerable/Presumed Stable

Myodes rutilus — Certainty: Very High

The northern red-backed vole *(Myodes rutilus)* is **not vulnerable/ presumed stable** to climate change in the Arctic Refuge. The species is limited in distribution mainly to tundra and boreal forest but appears to be flexible among these habitats, so its score for temperature sensitivity was "moderate increase in vulnerability." They utilize virtually every major forest type in Alaska, and will return to burned areas as soon as berry-producing shrubs, fungi and ground cover plants recolonize. The taiga and northern forest are unlikely to be altered significantly in our assessment area and may expand, while the tundra may shrink. The vole does not have specific hydrological requirements, has an extremely varied diet, and does not rely on a few species for habitat creation. Projected increases in fire activity over the next century may benefit the species, due to their extensive use of early successional habitats. While there is a barrier of ocean to the north, it is unlikely that the temperature will change enough in the next 50 years to require the vole to move northwards to keep pace with climate change. The only other factors that rated "yellow" for the northern red-backed vole were its use of snow for insulation, and low genetic variation, but these factors were not big enough problems to affect its overall score.

Meadow Vole — Not Vulnerable/Presumed Stable

Microtus pennsylvanicus — Certainty: Very High

Meadow voles (*Microtus pennsylvanicus)* are found in early successional habitats, such as old fields, pastures and forest clearings as far south as Georgia. They are strictly herbivorous but eat roots, shoots and seeds of a wide array of species. The meadow vole is **not vulnerable/ presumed stable** to climate change in the Arctic Refuge. The species is widely distributed and has broad temperature and hydrological requirements. The species may also benefit from increasing disturbances (e.g., increasing fire activity projected under climate change) that open up clearings in forests. The species will not be affected by barriers to movement since its current range is not located near the Beaufort Sea. Like the red-backed vole, the meadow may be somewhat sensitive to changes in snow cover and has low genetic variation, these factors were not sufficiently problematic to affect its overall score.

River Otter — Not Vulnerable/Presumed Stable

Lontra canadensis — Certainty: Very High

The river otter (*Lontra candensis)* is **not vulnerable/ presumed stable** to climate change in the Arctic Refuge, and may even expand its range further north into the Refuge. The species is wide ranging from Alaska in the North to Florida in the south and is not limited by a particular thermal regime or cold habitat. The species, though associated with rivers and streams, is not dependent on rare aquatic features such as ephemeral pools or seeps, and moisture is not likely to change enough in the Arctic Refuge in the next 50 years to affect flowing stream systems. The river otter does prefer certain geologic conditions, specifically steeply banked shorelines, and they avoid areas where the shoreline is more gradually sloped or has sand or gravel beds. However, these features are sufficiently dominant across the otter's range, that their availability is unlikely to be a climate change vulnerability factor. The only "yellow" factors that might make river otters slightly sensitive to climate change are potential changes in disturbance regimes and because it has low genetic variation. While there is a barrier of ocean to the north, it is unlikely that the temperature will change enough in the next 50 years to require the otter to move northwards to keep pace with climate change.

Mink — Not Vulnerable/Presumed Stable

Neovison vison — Certainty: Very High

The mink *(Neovison vision)* is found in a variety of wetland habitats throughout the U.S. except for southwestern deserts. They are strictly carnivorous but opportunistic, taking fish, bird eggs and nestlings, small mammals, frogs, and invertebrates. They do not dig burrows themselves, but will utilize abandoned burrows of muskrat, beaver, ground squirrel or rabbit. They will also use brush piles, cavities in trees, or rock piles. Given their dependence on proximity to water, they could be sensitive to extreme changes in hydrology, particularly flooding or severe drought. Nonetheless, our analysis found mink to be **not vulnerable/ presumed stable** to climate change in the Arctic Refuge. The species is wide ranging and does not have specific thermal or hydrological requirements that are likely to change in the Arctic Refuge over the assessment period. While there is a barrier of ocean to the north, it is unlikely that the temperature will change enough in the next 50 years to require the mink to need to move northwards to keep pace with climate change.

Dusky Shrew
Sorex monticolus

Not Vulnerable/Presumed Stable
Certainty: Very High

Sorex monticolus (dusky shrew), another small insectivore of the boreal forest, is most frequently found in riparian areas or within 100 meters of streams or wet areas. They prefer areas with a substantial amount of ground cover and woody debris, so are generally found in medium-aged forests, rather than deeply shaded mature forests or very young stands with little woody debris. The dusky shrew is **not vulnerable/ presumed stable** to climate change in the Arctic Refuge over the next 50 years. The shrew ranges from in Alaska through British Columbia and as far south as the Sierra Madres of Mexico. While it is restricted to relatively cool or cold environments that include montane areas and boreal forests, it is unlikely that these habitats will be lost in the assessment area, or that the species will need to move north to the point where it would encounter the ocean as a barrier. Similarly, the shrew does prefer moist habitats such as wet meadows and riparian zones, but there is no indication that these areas will be lost in the Arctic Refuge based on our moisture analysis. High genetic variation in the shrew also increases its resilience to climate change.

The only factors raising the dusky shrew's sensitivity to climate change were change in disturbance regime and reliance on ice and snow. The shrew requires a moderately open forest habitat (not deep forest, but not clear cuts either) and may be sensitive to increasing fire frequency, duration and extent in the future. For snow cover dependence, the species rated as slightly increase/neutral because while it does forage under snow in winter, we found no data to suggest that snow is important for insulation or that the species suffers in its absence.

Masked Shrew
Sorex cinereus

Not Vulnerable/Presumed Stable
Certainty: Moderate

Sorex cinereus, the masked shrew, is an insectivore that lives in damp leaf litter on the forest floor of many wooded areas of the northern U.S. and Canada, and extending further south in mountainous areas. The masked shrew is **not vulnerable/ presumed stable** to climate change in the Arctic Refuge over the next 50 years. The species rated "somewhat" vulnerable on the basis of sensitivity to moisture change, due to indications that environmental moisture is important for the species, and it is found more commonly on northern, mesic slopes, than on southern, xeric slopes (Brannon 2002). On the other hand, factors such habitat, disturbance, diet and genetic factors are not projected to be problematic for the shrew in the Arctic Refuge over the next 50 years. Nor is the species expected to need to move north to the point where it would encounter the ocean as a barrier.

Red Squirrel — Not Vulnerable/Presumed Stable

Tamiasciurus hudsonicus — Certainty: Very High

The red squirrel (*Tamiasciurus hudsonicus)* ranges as far south as New Mexico and Virginia, and reaches its northern extent in Alaska. It requires mature, seed-bearing conifers for its food supply, and large trees, with either cavities for nesting or branches that will support a leaf nest, and this requirement for mature forest makes it potentially sensitive to changes in fire frequency that could alter the age structure of forests. Overall, however, the red squirrel is **not vulnerable / presumed stable** to climate change in the Arctic Refuge. The species is somewhat restricted to relatively cool or cold environments such as montane areas and boreal forests, but these are unlikely to be lost in the assessment area, or to shift sufficiently to the point where the squirrel encounters the ocean as a barrier. Other factors that reduce its vulnerability include high levels of genetic variation and phenologic plasticity. Interestingly the species is one of the first mammals that has shown phenotypic plasticity and micro-evolution in response to climate change, namely by altering its reproductive timing (Reale et al. 2003). This may decrease its sensitivity to climate change exposure and allow it to successfully adapt to certain changes.

Porcupine — Not Vulnerable/Presumed Stable

Erethizon dorsatum — Certainty: Very High

Porcupines *(Erethizon dorsatum)* are found as far south as Texas, although they are more prevalent in northerly areas. They primarily are found in forested areas, but will also utilize wooded riparian corridors in otherwise unforested landscapes. They den in large hollow trees or logs and eat a variety of plant species, with strongly seasonal variation: mainly evergreen needles and inner tree bark in winter, and virtually any plant material in summer.

Porcupines are not **vulnerable / presumed stable** to climate change in the Arctic Refuge in the next 50 years. It does not have particular affinity with cold areas, specialized aquatic features, or dependence on snow and ice that make many other Refuge species vulnerable to climate change. Furthermore, while there is a barrier of ocean to the north, it is unlikely that the temperature will change enough in the next 50 years to require the porcupine to move northwards to keep pace with climate change. The factors that porcupine did rate somewhat sensitive to were changes in disturbance and dietary versatility. Changes in disturbance regime (such as an increase in fire) could be potentially detrimental to the species since it requires standing trees for perching and feeding. Finally, in winter porcupine's diet becomes somewhat more specialized than summer months, resulting in a "yellow" rank for this sensitivity factor.

Pygmy Shrew — Not Vulnerable/Presumed Stable

Sorex hoyi — Certainty: Very High

The pygmy shrew (*Sorex hoyi*) is the smallest mammal in North America. Its range extends through much of Canada and into the northern 48 States. Ants account for nearly half of its diet, but it also eats bees, beetles, moth larvae, and spiders. It is often found in association with rotting logs, and appears to select habitats where wet and upland areas occur in close proximity to each other. The pygmy shrew is **not vulnerable / presumed stable** to climate change in the Arctic Refuge and may increase its range across the assessment area. The species may be sensitive to changes in snow cover, as an assessment of shrews in Nova Scotia found winter factors to be a larger component of vulnerability for *S. hoyi* than summer factors (Herman and Scott 1994). That study found the pygmy shrew to be one of the less vulnerable species, and our assessment reaches a similar conclusion, that changes temperature or precipitation will not adversely affect its habitat or diet in this portion of its range.

Least Weasel — Not Vulnerable/Presumed Stable

Mustela nivalis — Certainty: Very High

The least weasel (*Mustela nivalis)* ranges across much of the northern half of the continent and through the Appalachians to as far south as Georgia. They are found in fields, forests, hedgerows, shrub-steppe, and semi-deserts.The most important habitat factor for this species is the presence of sufficient prey, which is dominated by mice and voles, but can also include other small mammals, bird eggs and nestlings, frogs, lizards, fish and invertebrates. The least weasel is **not vulnerable / presumed stable** to climate change in the Arctic Refuge and may instead expand its range in Alaska. The species is wide ranging and does not have specific thermal or hydrological requirements that are likely to change in the Arctic Refuge.

The least weasel does have some traits that may make it somewhat sensitive to climate changes, though these are more likely to be problematic in other portions of its range. The species may benefit from hunting in the subnivian zone during the winter so loss of snowpack or changes in snowpack (e.g., more ice instead of snow leading to crushed tunnels in the subnivian zone) could potentially be detrimental. On the other hand, the species seems to have significant phenological plasticity. Weasels in the northern portion of the range turn white in winter and weasels in the southern portion of the range don't. Breeding time and number of breeding cycles per year varies with prey density rather than with temperature or light variables. These characteristics indicate significant flexibility, which may help the species adapt to climate changes.

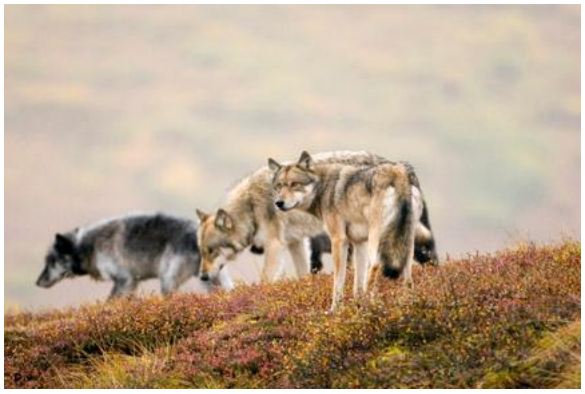
Muskrat — Not Vulnerable/Presumed Stable

Ondatra zibethicus — Certainty: Very High

Muskrats (*Ondatra zibethicus)* are found in a wide array of aquatic habitats. They eat aquatic vegetation and live either in constructed lodges or in burrows dug in banks. The muskrat is ranked as **not vulnerable/ presumed stable** to climate change in the Arctic Refuge. The species showed low sensitivity to climate change overall. Muskrats are found as far south as Texas and Alabama, and the species is at its northern border in Alaska; therefore, they are not restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change, and they are unlikely over the next 50 years to need to move northward to the point they will encounter the ocean as a barrier. While the muskrat is dependent on specific wetland environments, the direction of change in moisture (no significant change in the next 50 years or slight increase) is unlikely to affect these habitats. The muskrat's only "yellow" sensitivity factor was to changes in disturbance regime, particularly increases in floods or extremes in water levels. Tidal surges are associated with juvenile mortality (Kinler et al. 1990) and spring ice jam flood cycles are correlated with muskrat population cycles (Timoney et al. 1997). Similarly, changes in water level that affect emergent vegetation could also be detrimental because they reduce the food supply (Clark and Kroeker 1993).

Gray Wolf — Not Vulnerable/Presumed Stable

Canus lupis — Certainty: Very High



The gray wolf (*Canis lupis)* is not **vulnerable/ presumed stable** to climate change in the Arctic Refuge in the next 50 years. The species is widespread, generalized in its habitat and dietary needs, tolerates a variety of disturbance regimes, has excellent dispersal characteristics (Adama et al. 2008), and high genetic variability (Leonard et al. 2005). Its lack of sensitivity makes it one of the species likely to continue to remain widespread under climate change. Within the assessment period, the species is not likely to require northward movement that would cause it to encounter the natural barrier of the ocean. The only factor potentially increasing vulnerability for this species is changes in snow cover, because snowy conditions confer wolves an advantage over many prey species.

Ermine — Not Vulnerable/Presumed Stable

Mustela erminea — Certainty: Moderate

The ermine (*Mustela ermine)* ranges into the Great Lakes and mid-Atlantic region, and as far south as California and New Mexico in the mountains. Its preferred habitats are riparian areas, forest edges and hedgerows, avoiding deep forests and desert areas. Ermines feed exclusively on small mammals, and their elongate shape helps them track prey into burrows and under snow, but hinders thermoregulation at extremely cold temperatures. The ermine is **not vulnerable/ presumed stable** to climate change in the Arctic Refuge. The species is widespread, generalized in its habitat and dietary needs, has high genetic variability, and excellent dispersal characteristics. While the species' distribution is mainly limited to boreal forest habitat, boreal forest is not likely to decrease in the Arctic Refuge in the next 50 years and instead may increase as temperatures warm enough for this habitat to shift northward. For this species, the disturbance factor was scored with some uncertainty because disturbance has both positive and negative effects: fires reduce ermine numbers, but the species does seem to prefer early successional habitats. So an increase in fire frequency might actually create habitat, while also temporarily suppressing numbers. However, they have a fairly high reproductive rate, so disturbance ultimately may be a positive factor as long as it is not so frequent or severe that it suppresses the prey base.

Ermines may also be sensitive to changes in snow cover because they track prey under the snow and may utilize it for insulation as well. It is not clear whether snow cover changes will pose issues for the ermine with respect to molt timing. Seasonal molt appears to be controlled by both photoperiod and temperature: according to one study, white ermines placed at 18 hour daylight period molted to brown, but onset was faster for individuals held at 70°F than those at 20°F (Rust 1962). Furthermore, individuals on south end of range don't necessarily molt, so the species may have sufficient plasticity to avoid phonologic mismatches.

Coyote — Not Vulnerable/Presumed Stable

Canis latrans — Certainty: Very High

The coyote *(Canis latrans)*, which is well known as a widespread and adaptable carnivore, is **not vulnerable/ presumed stable** to climate change in the Arctic Refuge in the next 50 years. The species is widespread, generalized in its habitat and dietary needs, tolerates a variety of disturbance regimes, and has excellent dispersal characteristics. The coyote's lack of sensitivity makes it one of the species likely to continue to remain widespread under climate change. While there is a barrier of ocean to the north, it is unlikely that the temperature will change enough in the next 50 years to require the coyote to need to move northwards to keep pace with climate change.

Beaver — Not Vulnerable/Presumed Stable

Castor canadensis — Certainty: Very High

The beaver *(Castor candensis)* is **not vulnerable/ presumed stable** to climate change in the Arctic Refuge. They live in a wide range of aquatic habitats, and these environments are neither rare, nor likely to diminish as a result of climate change in the next 50 years. While the species will be exposed to climate change across its range, it lacks many of the sensitivity factors that make other species vulnerable to climate change. It is likely the species may expand north, further into the Arctic Refuge under climate change. While there is a barrier of ocean to the north, it is unlikely that the temperature will change enough in the next 50 years to require the beaver to need to move northwards to keep pace with climate change.

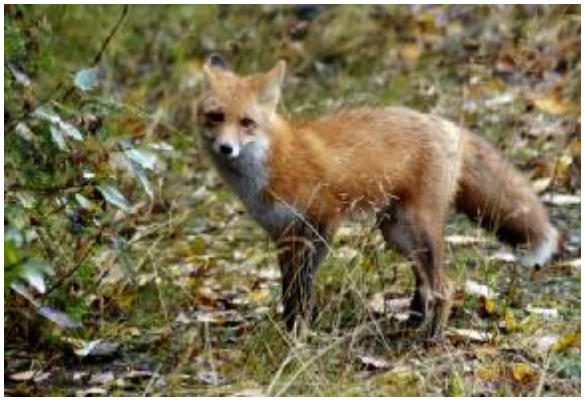
Black Bear — Not Vulnerable/Presumed Stable

Ursus americanus — Certainty: Very High

The black bear (*Ursus americanus*) is **not vulnerable/ presumed stable** to climate change in the Arctic Refuge. The species is ranges across much of the continent and does not have specific thermal or hydrological requirements that are likely to change in the Arctic Refuge. Black bears have few traits that will make them sensitive to climate change: they have a flexible diet, excellent dispersal ability, do not rely on interspecific associations with other species, tolerate a wide range of temperatures and hydrologic regimes, and may benefit from disturbances that are likely to increase in the future. While there is a barrier of ocean to the north, it is unlikely that the temperature will change enough in the next 50 years to require the black bear to need to move northwards to keep pace with climate change.

Red Fox
Vulpes vulpes

Not Vulnerable/Increase Likely
Certainty: Very High



The red fox *(Vulpes vulpes)* is **not vulnerable** to climate change and is **likely to increase** in the Arctic Refuge in response to climate change over the next 50 years. The species is the most widespread carnivore in the world, generalized in its habitat and dietary needs, not dependent on snow or ice, and with excellent dispersal characteristics. The species may benefit from projected increases in fire in the region (Rupp 2008), as fire will likely result in an increase in forest edge and early successional habitat that red foxes use preferentially (USFS FEIS 2007). Red foxes historically did not occupy the tundra partly because it was too cold; with their longer ears and limbs, they lose heat faster than the related arctic fox. But the temperature in the Arctic has risen over 2 degrees F in the past 50 years, making the region more hospitable to the red fox. The species may also benefit from encroaching forest habitat into the tundra. Large expenses of tundra habitat are expected to be replaced by forest. The red fox in adjacent boreal forest will be able to expand into the tundra as the climate warms and the forest moves towards the poles. This may result in negative consequences for the arctic fox as red foxes are superior hunters and may have been responsible for the decline of the arctic fox during the last interglacial (Dalen et al. 2005; see arctic fox notes above for more).

CONCLUSIONS AND RECOMMENDATIONS

Relationship of This Assessment to Other Listing and Management Plans

Vulnerability to climate change is an important and dynamic factor in assessing overall threat to species, and to formulating and prioritizing conservation actions. We believe that this assessment for the mammals of the Arctic National Wildlife Refuge provides a valuable and timely addition to the science of wildlife conservation in the face of climate change. However, climate change vulnerability is only one part of any species' or ecosystem's overall conservation status, and should be considered within the context of other parameters, including population size, population trends, isolation, and other threats.

Federally Listed Species

Only one mammal species in the Arctic National Wildlife Refuge is federally listed under the Endangered Species Act (ESA): the **polar bear**. The polar bear was listed as threatened under the ESA on May 14, 2008. This move officially recognized climate change as a driver of polar bear imperilment, but was accompanied by an unprecedented exemption stipulating that greenhouse gas emitting activities were outside of the purview of the ESA. In fact, the polar bear's extensively documented response to climate change, and its dependence on habitat factors that are particularly at risk from warming, argue strongly for it to be considered the Refuge's top conservation priority.

Alaska Listed Species and State Wildlife Action Plan

The Alaska Department of Fish and Game also maintains lists of Endangered Species and Species of Special Concern, but neither list contains any of the Refuge mammals analyzed here. Alaska's Comprehensive Wildlife Conservation Strategy (ADFG 2006), a state wildlife action plan, lists the **polar bear** and **Alaska marmot** as conservation priorities.

State and Global Conservation Rank

NatureServe and the International Union for the Conservation of Nature (IUCN) have established rankings that provide a quick snapshot of species population status and vulnerability to extinction. These rankings provide a quantitative assessment of species rarity and further highlight the urgent plight of the **polar bear**: of Refuge species, it is the only species considered "Vulnerable."

Management Recommendations for the Arctic National Wildlife Refuge

Conservation planning and actions to preserve the Refuge's species should take several factors into account.

The species most vulnerable to climate change in the Arctic National Wildlife Refuge are the ones specially adapted to the cold, snow and ice. Arguably the most vulnerable species in the Refuge are the polar bear and the arctic fox, because their distribution within the Refuge is limited almost entirely to the narrow North Slope. Other species whose Refuge habitats are limited to this narrow strip of tundra bordered by the Beaufort Sea, also face serious challenges from climate change. Species with broader distributions will most likely be less vulnerable.

The Refuge's tundra-dependent animals are particularly at risk from changes that bring icier conditions to the tundra or that encourage the expansion of boreal forest into areas that are currently open tundra. Icy conditions are on the increase as winters warm: warmer air can hold more moisture, and as the number of days where the temperature reaches above freezing expands, the likelihood increases that some precipitation will fall as freezing rain or sleet, or as thicker, crusty snow. Species like caribou and musk oxen have already been documented to have a more difficult time feeding when the vegetation is encrusted in ice, and they have to expend more energy to do so. This is undoubtedly also the case for smaller, less studied animals, like the voles and lemmings that form the basis of the food chain for many larger predators.

Expansion of boreal forest into areas that are currently tundra vegetation is also a significant problem for species that are specialized to the tundra. While our assessment did not itself predict vegetation changes, other work, including the Arctic Climate Impact Assessment (2005) and Feng and colleagues (2011), clearly project tundra vegetation to be replaced by shrubs and boreal forest.

The particular geography of the Arctic National Wildlife Refuge may be a contributing factor to vulnerability. North of the Brooks Range, the strip of coastal plain tundra is narrower in the Refuge than it is elsewhere in the North Slope of Alaska and adjacent areas of Canada. Therefore, changes in the region may more quickly push those habitats northward to the sea. To the west of the Refuge lies Prudhoe Bay, which has already experienced significant disturbance and modification due to oil exploration. To the east, just over the Canadian border, lies the Mackenzie River Delta, a large area of fairly low elevation, which is vulnerable to sea level rise (see Figure 4 in the web appendix). While there are large expanses of tundra to the west of the Refuge, and to the east in Canada, and islands to the north of Nunavut, it is unclear how easily species will be able to move around these barriers.

Considering these factors, land and wildlife managers should focus their efforts on four crucial objectives:

1. **Protect the North Slope from disturbance.**
   One way to help preserve the Refuge's most vulnerable species is to limit oil and gas exploration and development, and other activities that disturb wildlife and destroy habitat on the coastal plain tundra. Drilling in the 1002 area, as the Refuge's

coastal plain is known, with its attendant noise, spills, transportation and industrial development, should be permanently prohibited. The effects of shipping, visitation and other potentially disturbing activities should also be carefully monitored.

2. **Maintain linkages to areas of tundra adjacent to the Refuge.**
   While climate change projections indicate that the Arctic will warm more than much of the rest of the country, the region does have the advantage that its habitats are relatively pristine and more connected than in many other areas. Some of the more threatened species in the Refuge may need to move to broader expanses of tundra to the east and west that may persist longer into the future. It is important to maintain connectivity between the Refuge and these other areas, particularly on the Canadian side where islands stretch the northern extent of terrestrial habitats.

3. **Invest in research and monitoring of vulnerable species and habitats.**
   While our climate change vulnerability assessment has value in helping tease out factors and focus attention on potentially vulnerable species, real on-the-ground data and better modeling are needed to understand exactly how these and other species are being affected. Research and monitoring efforts focused on the suite of extremely and highly vulnerable species we have identified will be invaluable in helping conserve these animals. The Refuge should use research and monitoring information to educate the nation about the impacts of climate change on the Refuge's wildlife. Data needed may include:
   - Baseline data sets of variables including vegetation cover, soil type, permafrost extent, species distributions, snow and ice cover, and hydrology.
   - Modeling of climate change impacts to sensitive systems, particularly tundra vegetation.
   - Monitoring of climate and weather conditions, vegetation changes, hydrologic changes, fire frequency and extent, invasive species and forest pest outbreaks, and population trends of vulnerable species.

4. **Adopt as a fundamental management goal enhancing the adaptive capacity of vulnerable species and habitats.**
   This vulnerability assessment focused on Refuge mammals' exposure and sensitivity to climate changes over the next 50 years. The species' overall vulnerability may be reduced by actions to enhance their adaptive capacity. We recommend that the Service develop scenario planning and adaptive management as tools to identify and implement adaptation responses.

For references and an extended description of the methodologies and bibliography please see the Supplementary Material document:

http://www.defenders.org/resources/publications/programs_and_policy/gw/no_refuge_from_warming_supplementary_materials.pdf

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