National Fish, Wildlife and Plants Climate Adaptation Strategy

Arctic Tundra Ecosystems

Photo: Arctic NWR

Disclaimer

The information in this Arctic Tundra Ecosystems Background Paper was developed by the Grassland, Shrubland, Desert, Tundra Technical Team of the National Fish, Wildlife and Plants Climate Adaptation Strategy (hereafter *Strategy*), and was used as source material for the full *Strategy* document. It was informally reviewed by a group of experts selected by the Team. While not an official report, this Arctic Tundra Ecosystems Background Paper is available as an additional resource that provides more detailed information regarding climate change impacts, adaptation strategies, and actions for U.S. tundra ecosystems and the species they support. These papers have been edited by the Management Team for length, style, and content, and the Management Team accepts responsibility for any omissions or errors.

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Introduction

Over the past decade, there have been increasing calls for action by government and non-governmental entities to better understand and address the impacts of climate change on natural resources and the communities that depend on them. These calls helped lay the foundation for development of the National Fish, Wildlife and Plants Climate Adaptation Strategy (hereafter *Strategy*).

In 2009, Congress asked the Council on Environmental Quality (CEQ) and the Department of the Interior (DOI) to develop a national, government-wide climate adaptation strategy for fish, wildlife, plants, and related ecological processes. This request was included in the Fiscal Year 2010 Department of the Interior, Environment and Related Agencies Appropriations Act Conference Report. The U.S. Fish and Wildlife Service (FWS) and CEQ then invited the National Oceanic and Atmospheric Administration (NOAA) and state wildlife agencies, with the New York State Division of Fish, Wildlife, and Marine Resources as their lead representative, to co-lead the development of the *Strategy*.

A Steering Committee was established to lead this effort and it includes representatives from 16 federal agencies with management authorities for fish, wildlife, plants, or habitat as well as representatives from five state fish and wildlife agencies and two tribal commissions. The Steering Committee charged a small Management Team including representatives of the FWS, NOAA, Association of Fish and Wildlife Agencies (representing the states) and Great Lakes Indian Fish and Wildlife Commission to oversee the day-to-day development of the *Strategy*.

In March of 2011, the Management Team invited more than 90 natural resource professionals (both researchers and managers) from federal, state, and tribal agencies to form five Technical Teams centered around a major ecosystem type. These teams, which were co-chaired by federal, state, and I most instances, tribal representatives, worked over the next eight months to provide technical information on climate change impacts and to collectively develop the strategies and actions for adapting to climate change. The five ecosystem technical teams are: Inland Waters, Coastal, Marine, Forests, and a fifth team comprising four ecosystems: Grasslands, Shrublands, Deserts, and Arctic Tundra.

This Background Paper focuses on tundra systems, including information about these systems, existing stressors, impacts from climate change, and several case studies highlighting particular impacts or adaptation efforts. Information from this Background Paper informed discussion of tundra impacts and adaptation measures in the full *Strategy*, and was used to develop the Goals, Strategies, and Actions presented in that document and repeated here. This Background Paper is intended to provide additional background information and technical details relevant to tundra systems, and to summarize those approaches most relevant to managers of these areas and the species they support. Some of the material presented herein overlaps with that for other ecosystem types, particularly regarding cross-cutting issues.

The ultimate goal of the *Strategy* is to inspire and enable natural resource professionals, legislators, and other decision makers to take action to adapt to a changing climate. Those actions are vital to preserving the nation's ecosystems and natural resources—as well as the human uses and values that the natural world provides. The *Strategy* explains the challenges ahead and offers a guide to sensible actions that can be taken now, in spite of uncertainties over the precise impacts of climate change on living resources. It further provides guidance on longer-term actions most likely to promote natural resource adaptation to climate change. The *Strategy* also describes mechanisms to foster collaboration among all levels of government, conservation organizations, and private landowners.

Federal, state, and tribal governments and conservation partners are encouraged to look for areas of overlap between this Background Paper, the *Strategy* itself, and other planning and implementation efforts. These groups are also encouraged to identify new efforts that are being planned by their respective agencies or organizations and to work collaboratively to reduce the impacts of climate change on tundra fish, wildlife, and plants.

Arctic Tundra Ecosystem Description

Arctic tundra ecosystems are present on the North Slope and west coast of Alaska. The North Slope is in the Arctic and is divided into three major ecological regions: Arctic Coastal Plain, Arctic Foothills, and Brooks Range. Tundra regions of western Alaska are in the Subarctic and include coastal plains, lowlands, and mountains (Gallant et al. 1995). Alpine tundra is not considered here, but is included as an element within the landscape in which it occurs (e.g., forest systems).

Alaskan tundra has much more vegetation than tundra in the high Arctic regions (Walker 2010). Vegetation is a nearly continuous carpet of plants less than 20 inches tall, mainly sedges, low shrubs, and mosses. Lichens, forbs, grasses, and horsetails are also common in some areas. Shrubs are taller along drainages and in western Alaska. Trees are absent, except for groves of small balsam poplar at warmer inland sites. Soil texture and moisture are important determinants of the different tundra vegetation types.

Arctic Alaska has low precipitation, very low winter temperatures, and short, cool summers. The mean annual air temperature is 10 °F, with mean temperatures below 50 °F in every month of the year (Shulski and Wendler 2007). Air temperature is strongly influenced by proximity to the coast, with inland areas experiencing warmer summers and colder winters in comparison to the coastal zone. Soils are underlain by permanently frozen ground, termed permafrost, and the thawed surface layer that supports plant growth is usually less than 25 inches deep in mid-summer. Precipitation is low and ranges from 6 inches per year near the coast at Barrow to 24 inches or more in portions of the Brooks Range. The ground surface remains frozen and snow-covered from approximately mid-September to early June. Winter snow cover is shallow due to low precipitation and variable because of redistribution by high winds, resulting in sparse cover on hillcrests and deep accumulations in water courses.

The west coast tundra has a warmer and moister climate than Arctic Alaska. The mean annual air temperature is 29 °F, though mean summer temperatures are still below 52 °F, because of the cool, cloudy maritime climate. Precipitation ranges from 17 inches in the northern areas to 45 inches in more southern areas. Permafrost is present in colder areas, but generally absent in the more southern areas.

Arctic Coastal Plain

The Arctic Coastal Plain is the northernmost ecoregion in the United States, and spans east to west across the entire North Slope of Alaska. The treeless plain rises very gradually from sea level to the adjacent foothills. The region has an arctic climate, with short cool summers and long cold winters. The region is underlain by permafrost up to 2100 feet deep. Permafrost-related topographic features are common, including, pingos, ice-wedge polygons, peat ridges, and frost boils. Lakes are often formed by permafrost-related processes and cover over 14 percent of the landscape. Streams in the west are interconnected with lakes and tend to be sluggish and meandering, while those in the east are braided and build deltas in the Arctic Ocean. Most of the smaller streams freeze completely during winter. Because of frozen soils and poor soil drainage, most plant communities are dominated by graminoids, often with abundant mosses and dwarf shrubs.

Arctic Foothills

The Arctic Foothills, a band of rolling hills and plateaus dissected by north-flowing rivers, grades from the Coastal Plain on the north to the Brooks Range on the south. The ecoregion is underlain by permafrost, and permafrost-related surface features are common on the landscape. The Foothills have better defined drainage networks than the Coastal Plain. Most streams tend to be swift, but portions may be braided and smaller streams dry or freeze during winter. Lakes of glacial origin and oxbow lakes along rivers are the predominant types in the region. Vegetation is mainly moist graminoid, most commonly sedge tussock tundra, with low shrubs and mosses.

Brooks Range

The Brooks Range ecoregion is the northern extension of the Rocky Mountains. The ecoregion covers most of the east-west extent of northern Alaska. In contrast to the Arctic Coastal Plain and Arctic Foothills, this ecoregion was extensively glaciated during the Pleistocene epoch, but the few remaining glaciers are limited to the eastern sector. The terrain is dominated by rugged mountains, and continuous permafrost underlies the region. The combination of harsh climate, shallow soils, and highly erodible slopes result in sparse vegetation cover that is generally limited to valleys and lower hill slopes. Vegetation is often dominated by dwarf shrubs. Streams in the Brooks Range often have braided drainage patterns and lakes are uncommon.

Subarctic Tundra Ecosystems of Western Alaska

While the southern coast and interior regions of Alaska are forested, the cold maritime climate and cloudy summers of the west coast of Alaska limit tree growth, resulting in tundra ecosystems in the subarctic zone. Terrain varies from coastal plains to volcanic mountain ranges (Gallant et al. 1995).

The Subarctic Coastal Plains ecoregion includes plains along the west coast of Alaska, mainly the coastal plains of the Yukon and Kuskokwim River delta area and the Kotzebue Sound area. Flat, lake-dotted coastal plains and river deltas are characteristic of the region. Streams have very wide and serpentine meanders. Soils are wet and the permafrost table is shallow, providing conditions for wet graminoid communities, the predominant vegetation type.

The Bristol Bay-Nushagak lowlands in southwest Alaska bordering Bristol Bay have rolling terrain formed from glacial moraine deposits. Soils are somewhat better drained than the soils of the subarctic coastal plains. Dwarf shrub communities are widespread, but large areas of wetlands occur. Lakes are scattered throughout the lowlands, but are not nearly as numerous as in the subarctic coastal plains.

The Seward Peninsula in western Alaska includes varied terrain types and is predominantly treeless. Graminoid and low shrub communities occupy extensive areas.

The Alaska Peninsula Mountains and Aleutian Islands ecoregions are composed of a chain of active volcanoes. A maritime climate prevails and both regions are generally free of permafrost. Vegetation cover commonly consists of dwarf shrub communities at higher elevations and on sites exposed to wind, and low shrub or graminoid communities at lower or more protected sites.

Tundra Wildlife

Tundra mammals include caribou (*Rangifer tarandus*), polar bears (*Ursus maritimus*), grizzly bears (*Ursus arctos horribilis*), muskoxen (*Ovibos moschatus*), wolves (*Canis lupus*), foxes, ground squirrels, lemmings, voles, and wolverines. They are generally year-round residents and use a diversity of strategies for living in cold and severe weather. Some, such as bears and ground squirrels, are dormant in winter dens for 6-8 months. Others, such as wolves and foxes, are active all winter. Muskoxen reduce their activity in winter to conserve energy. Lemmings and voles live beneath the insulating snow. The caribou herds migrate to forested winter ranges. The diversity of habitats on the tundra and in the adjacent mountains and boreal forest provide seasonal ranges that accommodate the survival strategies used by mammals during the long winter and short summer season.

Alaska's coastal plain tundra contains one of the largest blocks of sedge wetlands in the circumpolar arctic (one quarter of global distribution) and provides breeding grounds for millions of birds (more than 100 species), including species that breed nowhere else in the United States. This area provides habitat for federally listed species (Steller's and spectacled eiders (*Polysticta stelleri*, *Somateria fischeri*), polar bear), and candidate species (yellow-billed loon (*Gavia adamsii*), Kittlitz's murrelet (*Brachyramphus brevirostris*), Pacific Walrus (*Odobenus rosmarus*), and other species of conservation concern such as black brant (*Branta bernicla nigricans*) (Martin et al. 2009).

Millions of birds migrate to Alaskan tundra each summer to breed, raise young, and feed. Birds include ducks, shorebirds, songbirds, raptors, and several species of geese, loons, and swans. Birds that use Alaskan tundra have ranges that include all 50 U.S. states and 6 continents. Birds that breed and are reared in northern Alaska likely migrate as far as Antarctica (Arctic terns (*Sterna paradisaea*)), New Zealand (bar-tailed godwits (*Limosa lapponica*)) and sub- Saharan Africa (northern wheatear (*Oenanthe oenanthe*)). Many species breed in wetland habitats on the coastal plains and on river deltas.

Fresh water fish that inhabit lakes and streams in Alaskan tundra include Arctic char (*Salvelinus alpinus*), Arctic grayling (*Thymallus arcticus*), broad whitefish (*Coregonus nasus*), burbot (*Lota lota*), lake trout (*Salvelinus namaycush*), longnose sucker (*Catostomus catostomus*), northern pike (*Esox lucius*), sheefish (*Stendous leucichthys nelma*), and slimy sculpin (*Cottus cognatus*). Anadromous fish of this region include Arctic cisco (*Coregonus autumnalis*), chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*Oncorhynchus keta*), Dolly Varden char (*Salvelinus malma*), least cisco (*Coregonus sardinella*), humpback whitefish (*Coregonus pidschian*), ninespine stickleback (*Pungitius pungitius*), pink salmon (*Oncorhynchus gorbuscha*), and round whitefish (*Prosopium cylindraceum*). Nearshore marine fish species include Arctic cod (*Arctogadus glacialis*), Arctic flounder (*Liopsetta glacialis*), fourhorn sculpin (*Myoxocephalus quadricornis*), and saffron cod (*Eleginus gracilis*).

ALASKA CLIMATE CHANGE WORKING GROUP

Indigenous communities possess local environmental knowledge and relationships with particular resources and homeland areas, built up through hundreds and even thousands of years of place-based history and tradition, which may make them highly sensitive to and aware of environmental change. Climate change, with its promise of unprecedented landscape-level environmental change, is a threat not only to particular resources or features, but also to the traditions, the culture, and ultimately, the very health of the community itself. Indigenous communities lend unique and important perspectives and knowledge about landscapes and climates to the overall effort to respond to climate change, and recognize that they must work together to nurture native environmental knowledge, enhance indigenous capacity to use modern scientific methods, and create indigenous climate-change leadership.

Due to climate warming impacts such as coastal erosion, increased storm effects, sea ice retreat, and permafrost melt, the village of Newtok, home to the Qaluyaarmiut people for at least 2,000 years, has begun relocation plans. The Qaluyaarmiut are avid fishermen and depend on the natural environment for subsistence. With an average erosion rate of 68 feet per year from 1953 to 2003 and the combination of all the climate warming impacts it is enduring, Newtok is no longer a sustainable long-term home for the Qaluyaarmiut people (Feifel and Gregg 2010).

Members of the American Indian Alaska Native Climate Change Working Group represent a broad alliance of indigenous communities, tribal colleges, scientists, and activists, who recognize the significance of situations like Newtok, working together to empower indigenous climate-change adaptation. They argue that indigenous educational institutions are critical vehicles for nurturing indigenous environmental knowledge and scientific capacity, and can be organizers and leaders of regional indigenous responses to climate change (Upham 2011). Indigenous working groups provide neutral ground in a relaxed setting that promotes broad participation, and often lead to consideration of a broader spectrum of resources and issues than externally driven approaches.

Existing Stressors:

Oil and gas development is the main industry in the region. The industrial footprint is spreading outward from the Prudhoe Bay oil fields, the origin of the Trans-Alaska Pipeline, which results in alteration or loss of tundra habitat (NRC 2003). In Western Alaska, mining of metal sulfide ores of lead, zinc, and iron has also resulted in some habitat loss, as well as contamination of surrounding habitat from the ore-crushing process (Hasselbach et al. 2005). Another ubiquitous source of contamination in this region is atmospheric deposition of mercury from Asia (Jaegle 2010). Pollutants can work their way up Arctic food chains to concentrate in top predators such as polar bears and humans.

Small Inupiat and Yupik Eskimo villages and two cities, Barrow and Bethel, occur in the tundra region. None are connected to a road system, and most residents lead a hunting and fishing subsistence life style. Subsistence activities are generally conducted using motorized boats and off-road vehicles, which can impact habitats near the villages.

Invasive plant and animal species are currently less common than in many other ecosystems, but the prevalence of non-native plant and animal diseases and parasites is unknown. Current temperatures are warmer than the recent past and have probably already paved the way for less cold tolerant species to spread into portions of Alaska that were formerly inhospitable to them. Ballast water discharge may also be a source of invasive aquatic species in coastal Alaska.

Impacts of Climate Change on Tundra Systems

Climate is changing worldwide, but the Arctic has already warmed at a rate almost twice the global average (ACIA 2005). Global Circulation Models identify northern Alaska as one of the fastest-warming regions of the planet. The average annual temperature of Alaska's North Slope tundra is projected to rise approximately 13 °F by 2100 (SNAP 2008). Precipitation is also expected to increase in the future (SNAP 2008). Despite higher precipitation, models predict a generally drier summer environment due to higher air temperatures, increased evaporation, and increased water use by plants (SNAP 2008). Likely impacts are summarized in Table 1.

Table 1: Expected Climate Change Impacts on Tundra Ecosystems (USGCRP 2009 and IPCC AR4 2007)

Major Changes Associated With Increasing Levels of Greenhouse Gases	Major Impact on Tundra
Increased atmospheric CO_2:	Disproportionate increased productivity of some plant species will change plant community composition
Increased temperatures:	Moisture-stressed vegetation, changing plant communities, longer snow-free season, increased wildfire, invasion by plant and animal species from the south
Melting ice/snow	Thawing of permafrost and soil ice changes hydrology and leads to terrain instability and vegetation change
Rising sea levels	Salt water intrusion, loss of coastal habitat to erosion
Changing precipitation patterns:	More winter thaws and rain-on-snow events harden snowpack, hampering mammal movements and foraging
Drying conditions/drought:	Moisture stressed vegetation, reduction in coastal plain wetlands, fish passage issues in streams
More extreme rain/weather events:	More landslides/slumps, changes to surface drainage patterns, surface erosion

Changes already observed on tundra landscapes include early onset and increased length of growing season, melting of ground ice, increased encroachment of shrubs into sedge tundra, and increased biomass of tundra vegetation (Hinzman et al. 2005, Richter-Menge et al. 2011). In addition, summer sea ice has declined dramatically in both mass and areal extent off of northern and western Alaska in recent decades. The lack of near-shore ice in summer has made the shoreline more vulnerable to storm-induced erosion, impacting the value of these areas as habitat for a suite of arctic specialist species (Hinzman et al. 2005).

In the Arctic, climate affects habitat uniquely through the interdependence of permanently frozen ground (permafrost), hydrology, and vegetation (Jorgenson et al. 2010). Increasing seasonal melting of ground ice and frozen soils are already measurably altering habitats and water distribution on the landscape, allowing new hydrologic patterns to form (Jorgenson et al. 2006). Even slight changes in moisture regime are expected to have a notable effect on tundra vegetation. In addition, thawing of frozen organic material stored in tundra soils will release huge amounts of the greenhouse gasses carbon dioxide and methane to the atmosphere, contributing markedly to global warming (Schaefer et al. 2011).

Spring snow melt is occurring earlier as the climate warms. Records show that the snow melt on the North Slope has become increasingly variable and has advanced an average of 10 days since 1941 (Hinzman et al. 2005). A longer snow-free season increases absorption of heat from solar radiation, which provides a positive feedback to local landscape warming, and ultimately exacerbates climate change (Hinzman et al. 2005).

Analysis of satellite images has shown an increase in greenness in arctic Alaska over the last three decades, indicating increased plant cover and biomass (Hinzman et al. 2005). Other studies have documented recent advancement of trees and tall shrubs onto tundra in western Alaska (Lloyd et al. 2003). Increased shrub cover has been documented in the northern foothills of the Brooks Range and is expected to continue (Tape et al. 2006). Shrubs can have dramatic effects on local microclimates by trapping snow, which provides an insulating blanket that increases winter soil temperatures and winter soil microbial activity (Tape et al. 2006).

Historically, fires have been rare on Alaskan tundra, but fire frequency will likely increase as the climate warms. A positive feedback relationship can result, as soils tend toward warmer and drier conditions after fire, promoting shrub growth and a more fire-prone landscape (Racine et al. 2004).

Some tundra plant species in Alaska are living at the edges of their ranges and the limits of their physiological tolerances. Other species occur in the adjacent boreal forest and are prevented from moving into the tundra regions only by climate. A changing climate will therefore alter species ranges and assemblages, and affect fish and wildlife in ways that are difficult to foresee (Martin et al. 2009).

Large mammals such as caribou and muskoxen suffer when access to forage is hampered by deep snow pack or a hard snow crust, caused by winter thawing or rain-on-snow events. These types of conditions are expected to increase in a warmer climate. In summer, changes in plant species composition and seasonality, along with changing quantity and quality of forage, are also expected to have profound effects on mammal populations. Small rodents may thrive under increased snow-cover, which will benefit both avian and mammalian predators. However, the arctic fox (*Vulpes lagopus*) may be negatively impacted if red fox (*Vulpes vulpes*), more common in the boreal forest, increase in abundance and continue to out-compete it where the two co-occur. Sea ice on the Arctic Ocean is rapidly decreasing in extent and thickness. Sea ice over the continental shelf is especially important to polar bears for foraging and maternal denning (Federal Register 2008), and it is the loss of this ice that could most impact polar bear productivity and survival. Wildlife pests and diseases are also expected to increase their northern range limits as the arctic climate warms (Martin et al. 2009).

Warmer summers, a longer open water season, and delayed freeze-up will likely improve reproductive success for some bird species, by increasing chick survival and food availability. However, warmer summers could cause drying of the wetland habitats and aquatic food sources that many birds rely on. While the timing of aquatic insect hatches are based on water temperature, birds time breeding primarily to the solar calendar. Thus, increased temperatures could result in a mismatch in timing between insect hatches and the stages of the avian reproductive cycle during which an abundant insect supply is most crucial, resulting in a trophic mismatch (Martin et al. 2009). In addition, arctic specialists may face increased competition as less cold-tolerant bird species expand their range northward (Martin et al. 2009).

Fish will likely be affected by higher water temperatures and changes in precipitation patterns, soil moisture, soil and water chemistry, and drainage pathways related to permafrost degradation. Similarly, changes in water flow, water chemistry, turbidity, and temperature could cause physiological stress to less adaptable species. More southerly species may establish themselves in this region and some may compete with endemic species. Some Arctic fish species migrate between marine and freshwaters, and will suffer if stream changes prevent fish passage. Fish populations that occur in glacial fed rivers of the North Slope may be especially hard hit, as they rely on late summer meltwater-generated flow to reach spawning and overwintering areas. If the glaciers disappear, as expected, in the next 100-200 years, this seasonal flow facilitating fish passage may end (Martin et al. 2009).

Climate-related habitat changes can be complex. For example, insect production in shallow wetlands may drop off as these areas dry out during the summer, affecting bird species that are dependent on them for food. Invertebrate production in persistent wetlands may increase with warming temperatures, or may decrease if the wetlands become more acidic due to establishment of sphagnum mosses (*Sphagnum* spp.), which are common in wetlands of warmer tundra areas (Szumigalski and Bayley 1997). If drying wetlands impede fish passage into certain lakes, invertebrate populations may increase—helping species dependent upon those invertebrates for food, but hurting those who prey on the fish themselves. Similarly, potential summer habitat improvements for browsing species, such as moose (*Alces alces*), could be offset by habitat quality reductions that result from increased freeze/thaw cycles and icing, which will make food harder to reach during winter (Martin et al. 2009).

Climate change is expected to increase availability and uptake of contaminants by fish, wildlife, and tundra. Contaminants such as mercury and persistent organic pollutants are contained within glacial ice and frozen tundra soils. These substances will almost certainly be released to aquatic systems as temperatures increase. Tundra fires will exacerbate the release of these compounds from peat dominated soils (Martin et al. 2009).

CONNECTING ALASKA LANDSCAPES INTO THE FUTURE

The landscapes of Alaska can be divided into biomes, defined as broadly categorized species assemblages based on climate and habitats. More than 60 percent of Alaska is anticipated to experience a geographic shift of present biomes by the end of this century. This forecast is based on *Connecting Alaska Landscapes into the Future* (Murphy et al. 2010), a collaborative project that showed how critical areas in Alaska could be linked through time and space to maintain landscape connectivity for biomes and selected species in a rapidly changing climate.

Arctic, Western Tundra, Alaska Boreal, Boreal Transition, North Pacific Maritime, and Aleutian Islands biomes were adapted from the unified eco-regions of Alaska (Nowacki et al. 2001). The climatic envelope of each biome was modeled based on downscaled climate forecasts for 2000–09, 2030–39, 2060–69 and 2090–99. Refugia were then defined as areas which sustained the same biome over all four time steps.

This predictive modeling project showed that some biomes are more vulnerable to climate change than others. In this forecast, the Arctic and Alaska Boreal eco-regions each diminished by 69 percent, and Western Tundra by 54 percent, all but disappearing from their current distribution in favor of Montane Cordillera (which currently only exists in Canada) and Boreal Transition. Similarly, much of southeast Alaska was invaded by flora currently in British Columbia, transitioning from North Pacific Maritime to Canadian Pacific Maritime. Western Tundra may be the most vulnerable biome, with the least resilience for conservation purposes, even without considering the significant losses expected from sea level rise.

To conserve flora and fauna, biome refugia must remain connected to transitional areas of Alaska in which the climate is expected to become favorable for these biomes over the remainder of this century. This project ranked areas in Alaska that are likely to remain refugia during climate change, while sustaining high biodiversity or species endemism. Finally, possible corridors for conservation were sketched between neighboring areas that ranked highest. This modeling approach demonstrates that stepping stones, which may be ephemeral because they are ecologically transitional due to climate change, can be important links in a rapidly shifting landscape.

Climate Adaptation Strategies and Actions for Tundra Systems

The *Strategy* identifies seven primary Goals to help fish, wildlife, plants, and ecosystems cope with the impacts of climate change. As discussed in the Introduction, these Goals were developed collectively by diverse teams of federal, state, and tribal technical experts, based on existing research and understanding regarding the needs of fish, wildlife, and plants in the face of climate change. Each Goal identifies a set of initial Strategies and Actions that should be taken or initiated over the next five to ten years.

Actions listed here were derived from those Technical Team submissions determined to be most applicable to tundra systems. Numbers that correspond to the full *Strategy* document are designated by *Strategy* (S) and the Action number (e.g., 1.1.1).

GOAL 1: Conserve habitat to support healthy fish, wildlife and plant populations and ecosystem functions in a changing climate.

Strategy 1.1: Identify areas for an ecologically-connected network of terrestrial, freshwater, coastal, and marine conservation areas that are likely to be resilient to climate change and to support a broad range of fish, wildlife, and plants under changed conditions.

Actions:

— A: Identify and map high priority tundra areas for conservation using information on species distributions (current and projected), habitat classification, land cover, and geophysical settings (including areas of rapid change and slow change). (**S 1.1.1**)

— B: Identify and prioritize for consideration tundra areas currently experiencing rapid climate impacts (such as the coastline of Alaska). (**S 1.1.2**)

— C: Produce a detailed land cover map of the Alaskan tundra, using satellite imagery, Digital Elevation Models, and ancillary spatial data such as surface geology.

Strategy 1.2: Secure appropriate conservation status on areas identified in Action 1.1.1 to complete an ecologically-connected network of public and private conservation areas that will be resilient to climate change and support a broad range of species under changed conditions.

Actions:

— A: Conserve tundra areas identified in Action 1.1.1 that provide high-priority habitats under current climate conditions and are likely to be resilient to climate change and/or support a broad array of species in the future. (**S 1.2.1**)

— B: Identify and pursue opportunities to increase conservation of priority tundra lands by working with managers of existing public lands such as state lands managed for purposes other than conservation. (**S 1.2.5**)

Strategy 1.3: Restore habitat features where necessary and practicable to maintain ecosystem function and processes and resiliency to climate change.

Actions:

— A: Restore degraded habitats as appropriate to support diversity of species assemblages and ecosystem structure and function. (**S 1.3.2**)

Strategy 1.4: Conserve, restore, and as appropriate and practicable, establish new ecological connections among conservation areas to facilitate fish, wildlife, and plant migration, range shifts, and other transitions caused by climate change.

Actions:

— A: Assess and prioritize critical connectivity gaps and needs across current tundra conservation areas. (**S 1.4.2**)

— B: Conserve corridors and transitional habitats between ecosystem types through both traditional and non-traditional (e.g., land exchanges, rolling easements) approaches. (**S 1.4.3**)

— C: Assess existing barriers or structures that impede movement and dispersal within and among habitats to increase natural tundra ecosystem resilience to climate change, and where necessary, consider the redesign or mitigation of these structures. (**S 1.4.5**)

GOAL 2: Manage species and habitats to protect ecosystem functions and provide sustainable cultural, subsistence, recreational, and commercial use in a changing climate.

Strategy 2.1: Update current or develop new species, habitat, and land and water management plans, programs and practices to consider climate change and support adaptation.

Actions:

— A: Incorporate climate change considerations into existing and new tundra management plans and practices using the best available science regarding projected climate changes and trends, vulnerability and risk assessments, and scenario planning. (**S 2.1.1**)

— B: Review and revise as necessary techniques to maintain or mimic natural disturbance regimes and to protect vulnerable habitats. (**S 2.1.5**)

— C: Develop standards for off-site mitigation for projects that impact migratory species habitat, but the species is subject to critical limiting factors in other portions of its range.

Strategy 2.2: Develop and apply species-specific management approaches to address critical climate change impacts where necessary.

Actions:

— A: Use vulnerability and risk assessments to design and implement management actions at species to ecosystem scales. (**S 2.2.1**)

— B: Develop criteria and guidelines for the use of translocation, assisted migration, and captive breeding as climate adaptation strategies. (**S 2.2.2**)

— C: Where appropriate, actively manage populations (e.g., using harvest limits, seasons, translocation, captive breeding, and supplementation) of vulnerable species to ensure sustainability and maintain biodiversity, human use, and other ecological functions. (**S 2.2.3**)

— D: Develop criteria and guidelines for determining when assisted colonization is inappropriate, and allowing species to rearrange themselves into new assemblages is a more appropriate strategy.

Strategy 2.3: Conserve genetic diversity by protecting diverse populations and genetic material across the full range of species occurrences.

Actions:

— A: Protect and maintain high quality native seed sources including identifying areas for seed collection across elevational and latitudinal ranges of target species. (**S 2.3.2**)

— B: Develop protocols for use of propagation techniques to rebuild abundance and genetic diversity for particularly at-risk species. (**S 2.3.3**)

GOAL 3: Enhance capacity for effective management in a changing climate.

Strategy 3.1: Increase the climate change awareness and capacity of natural resource managers and enhance their professional capacity to design, implement, and evaluate fish, wildlife, and plant adaptation programs.

Actions:

— A: Build on existing training courses and work with professional societies, academicians, technical experts, and natural resource agency training professionals to address key needs, augment adaptation training opportunities, and develop curricula and delivery systems for natural resource professionals and decision makers. (**S 3.1.2**)

— B: Develop training on the use of existing and emerging tools for managing under uncertainty (e.g., vulnerability and risk assessments, scenario planning, decision support tools, and adaptive management). (**S 3.1.3**)

— C: Encourage use of interagency personnel agreements and interagency (state, federal, and tribal) joint training programs as a way to disperse knowledge, share experience and develop interagency communities of practice about climate change adaptation. (**S 3.1.5**)

— D: Increase scientific and management capacity (e.g., botanical expertise) to develop management strategies to address impacts and changes to tundra species. (**S 3.1.7**)

Strategy 3.2: Facilitate a coordinated response to climate change at landscape, regional, national, and international scales across state, federal, and tribal natural resource agencies and private conservation organizations.

Actions:

— A: Identify and address conflicting management objectives within and among federal, state, and Alaska native conservation agencies and private landowners, and seek to align policies and approaches wherever possible. (**S 3.2.2**)

— B: Collaborate with Alaskan native governments and native peoples to integrate traditional ecological knowledge and principles into climate adaptation plans and decision-making. (**S 3.2.4**)

— C: Engage with international neighbors, including Canada, Russia, and others to help adapt to and mitigate climate change impacts in shared trans-boundary areas and for common migratory species. (**S 3.2.5**)

Strategy 3.3: Review existing federal, state and tribal legal, regulatory and policy frameworks that provide the jurisdictional framework for conservation of fish, wildlife, and plants to identify opportunities to improve, where appropriate, their utility to address climate change impacts.

Actions:

— A: Review existing legal, regulatory and policy frameworks that govern protection and restoration of habitats and ecosystem services and identify opportunities to improve, where appropriate, their utility to address climate change impacts. (**S 3.3.1**)

Strategy 3.4: Optimize use of existing fish, wildlife, and plant conservation funding sources to design, deliver, and evaluate climate adaptation programs.

Actions:

— A: Prioritize funding for land and water protection programs that incorporate climate change considerations. (**S 3.4.1**)

— B: Review existing federal, state, and Alaska native grant programs and revise as necessary to support funding of climate change adaptation and include climate change considerations in the evaluation and ranking process of grant selection and awards. (**S 3.4.2**)

— A: Review existing conservation related federal grants to Alaska native agencies and revise as necessary to provide apportioned funding for Alaska native climate adaptation activities. (**S 3.4.5**)

GOAL 4: Support adaptive management in a changing climate through integrated observation and monitoring and use of decision support tools.

Strategy 4.1: Support, coordinate, and where necessary develop distributed but integrated inventory, monitoring, observation, and information systems to detect and describe climate impacts on fish, wildlife, plants, and ecosystems.

Actions:

— A: Develop consensus standards and protocols that enable multi-partner use and data discovery, as well as interoperability of databases and analysis tools related to fish, wildlife, and plant observation, inventory, and monitoring. (**S 4.1.2**)

— B: Work through existing distributed efforts (e.g., NCA, National Estuarine Research Reserve System -wide monitoring program, State Natural Heritage Programs, National Wildlife Refuge System, National Park Service) to support integrated national observation and information systems that inform climate adaptation. (**S 4.1.4**)

— C: Conform to accepted international monitoring procedures of circumpolar Arctic Council.

— D: Expand and develop as necessary networks of places for integrated climate change inventory, monitoring, research, and education. (**S 4.1.5**)

— E: Promote a collaborative approach to acquire, process, archive, and disseminate essential geospatial and satellite-based remote sensing data products (e.g., snow cover, green-up, surface water, etc.) needed for regional-scale monitoring and land management. (**S 4.1.8**)

Strategy 4.2: Identify, develop, and employ decision support tools for managing under uncertainty (e.g., vulnerability and risk assessments, scenario planning, strategic habitat conservation approaches, and adaptive management evaluation systems) via dialogue with scientists, managers (of natural resources and other sectors), and stakeholders.

Actions:

— A: Conduct risk assessments to identify key climate change hazards and assess potential consequences for tundra fish, wildlife and plants.

— B: Engage scientists, resource managers, and stakeholders in climate change scenario planning processes, including identification of a set of plausible future scenarios associated with climate phenomena likely to significantly impact tundra species. (**S 4.2.2**)

— C: Conduct vulnerability and risk assessments for priority species (threatened and endangered species, species of greatest conservation need, species of socioeconomic and cultural significance). (**S 4.2.4**)

— D: Ensure the availability of and provide guidance for decision support tools (e.g., NOAA's Digital Coast, etc.) that assist federal, state, local, and Alaska native resource managers and planners in effectively managing fish, wildlife, and plants in a changing climate. (**S 4.2.7**)

— E: Establish long-term observatories in Arctic Alaska to collect integrated hydrological, climate, and geophysical data regarding the response of permafrost, hydrologic, and ecological systems to changes in thermal and precipitation regimes.

GOAL 5: Increase knowledge and information on impacts and responses of fish, wildlife and plants to a changing climate.

Strategy 5.1: Identify knowledge gaps and define research priorities via a collaborative process among federal, state, and tribal resource managers and research scientists working with the

National Science Foundation (NSF), USGCRP, NCA, USDA Extension, Cooperative Ecosystem Study Units (CESUs), Climate Science Centers (CSCs), LCCs, JVs, and Regional Integrated Sciences and Assessments (RISAs).

Actions:

— A: Increase coordination and communication between resource managers and researchers through existing forums (e.g., NSF, USGCRP, NCA, USDA, CESUs, CSCs, LCCs, JVs, RISAs, and others) to ensure research is connected to management needs. (**S 5.1.1**)

— B: Bring managers and scientists together to prioritize research needs that address resource management objectives under climate change. (**S 5.1.2**)

— C: Participate in research planning for relevant programs of agencies such as the NSF, NOAA, National Air and Space Administration, and the Department of Energy, and intergovernmental forums such as the Conservation of Arctic Flora and Fauna working group of the Arctic Council to ensure inclusion of research relevant to missions of agencies and resource managers. (**S 5.1.4**)

— D: Prioritize research on questions relevant to managers of near-term risk environments (e.g., coastal Alaska) or highly vulnerable species. (**S 5.1.6**)

Strategy 5.2: Conduct research into ecological aspects of climate change, including likely impacts and the adaptive capacity of species, communities and ecosystems, working through existing partnerships or new collaborations as needed (e.g., USGCRP, NCA, CSCs, RISAs, and others).

Actions:

— A: Support basic research on life histories and food web dynamics of fish, wildlife, and plants to increase understanding of how species are likely to respond to changing climate conditions and identify survival thresholds. (**S 5.2.2**)

— B: Accelerate research on establishing the value of ecosystem services and potential impacts from climate change such as loss of pollution abatement or flood attenuation, etc. (**S 5.2.4**)

— C: Increase understanding of the adaptive capacity of tundra communities and species under climate change.

— D: Conduct research into how ground ice influences a landscape's susceptibility to warming to predict the extent and magnitude of habitat change and sedimentation rates into fluvial systems.

Strategy 5.3: Advance understanding of climate change impacts and species and ecosystem responses through modeling.

Actions:

— A: Develop and use models of climate-impacted physical and biological variables and ecological processes at temporal and spatial scales relevant to conservation.

— B: Improve modeling of climate change impacts on vulnerable species, including projected future distributions and the probability of persistence. (**S 5.3.2**)

GOAL 6: Increase awareness and motivate action to safeguard fish, wildlife and plants in a changing climate.

Strategy 6.1: Increase public awareness and understanding of climate impacts to natural resources and ecosystem services and the principles of climate adaptation at regionally- and culturally-appropriate scales.

Strategy 6.2: Engage the public through targeted education and outreach efforts and stewardship opportunities.

Strategy 6.3: Coordinate climate change communication efforts across jurisdictions.

GOAL 7: Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate.

Strategy 7.1: Slow and reverse habitat loss and fragmentation.

Actions:

— A: Consider application of offsite habitat banking linked to climate change habitat priorities as a tool to compensate for unavoidable onsite impacts to tundra and to promote habitat conservation or restoration in desirable locations. (**S 7.1.5**)

— B: Minimize impacts from alternative energy development by focusing siting options on already disturbed or degraded areas. (**S 7.1.7**)

— C: Reduce the footprint of energy development and mining activities in tundra systems.

Strategy 7.2: Slow, mitigate, and reverse where feasible ecosystem degradation from anthropogenic sources through land/ocean-use planning, water resource planning, pollution abatement, and the implementation of best management practices.

Actions

— A: Work with local and regional land-use, water resource, and coastal and marine spatial planners to identify potentially conflicting needs and opportunities to minimize tundra ecosystem degradation resulting from development and land and water use. (**S 7.2.1**)

— B: Reduce existing pollution and contaminants and increase monitoring of air and water pollution. (**S 7.2.3**)

— C: Address and improve best management practices for freshwater withdrawals used for ice road construction.

Strategy 7.3: Use, evaluate, and as necessary, improve existing programs to prevent, control, and eradicate invasive species and manage pathogens.

Actions:

— A: Employ a multiple barriers approach to detect and contain incoming and established invasive species, including monitoring at points of origin and points of entry for shipments of goods and materials into the United States and for trans-shipment within the country. Utilize education, regulation, and risk management tools (e.g., the Hazard Analysis and Critical Control Point process) to address. (**S 7.3.1**)

— B: Apply risk assessment and scenario planning to identify actions and prioritize responses to invasive species that pose the greatest threats to tundra ecosystems. (**S 7.3.3**)

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