
Sector 3: Natural Systems and Associated Economies

All of the impacts included in the Natural Systems and Associated Economies sector are described below and organized according to subsector. This sector examines the impacts of climate change on biodiversity, ecosystem health, and associated human economic activity.

AGRICULTURE

1. **Agricultural impacts:** Current impacts – increased growing degree days (gdd) (e.g., Fairbanks increased from 1,100 to over 1,250 since 1950); longer growing season for current crops (e.g., hay); introduction of new crops and fruit trees (e.g., apples, pears); changes in growing zones and hardiness zones; increase in invasive species, pests, and diseases in agriculture (e.g., potato late blight, Canada thistle, hawkweeds); less water available in certain areas of the state (e.g., interior) suitable for agriculture. *Future projections – continued increase in gdd (e.g., in Fairbanks, under high emissions scenario, gdd double by 2071); agriculture becomes possible in more northerly locations; greater increase in invasive species, pests, and diseases; more water deficits (in Fairbanks, under low emissions scenario, almost a doubling by 2071); potential for increased animal husbandry.*

Potential adaptation measures include:

- convene agricultural representatives, scientists, government officials and others to examine the impacts of current and projected climate change on agriculture in Alaska;
- examine what new opportunities exist for agriculture in Alaska, and disseminate this information;
- examine concerns about new or expanded insects, other pests, invasive species, and diseases on agriculture, and develop strategies addressing how best to address these issues;
- examine, as appropriate, insect and invasive species control measures, using least toxic options;
- expand pest and invasive species monitoring;
- conduct research on new crops, pest and disease control and other issues;

-
- consider the need for irrigation systems and containment measures to address potential water deficits, and where appropriate construct these systems;
 - examine, and if appropriate, provide programs and incentives to promote the rapid transfer of new knowledge and technologies to assist farmers in adapting to climate change; and
 - assist in the creation and expansion of markets for new agricultural products.

BOREAL AND TEMPERATE FORESTS AND DEPENDENT SPECIES

2. **Forest insects and diseases:** Current impacts – greater incidence of existing diseases such as spruce bark beetle, resulting in massive forest death (over 4 million acres); other forest diseases include larch saw fly (killed 90% of larch near Fairbanks), birch leaf roller, birch leaf miner, aspen leaf miner, and woolly saw fly; introduction of new diseases in forests such as spruce bud worm and aphids, resulting in tree injury and death. *Future projections – greater incidence of existing diseases, resulting in even greater forest death; more new diseases and greater expansion of recently introduced diseases resulting in further tree injury and death.*

Potential adaptation measures include:

- conduct a comprehensive assessment of the current impacts and future threats of forest insects and diseases on Alaska's forests;
 - convene experts to determine what intervention strategies (such as early detection, selected removal, biological control or quarantine), if any, can be effectively taken;
 - research whether there are more insect and disease tolerant trees; and
 - establish more extensive monitoring, capture and reporting systems, including public reporting.
3. **Forest fires:** Current impacts – more and earlier fires; record breaking acreage burned (over 11 million acres in 2004 and 2005); substantial impacts on forests and habitat for species (approximately 25% of all forests in 2004/2005 burned in NE Alaska); also expensive fire fighting (cost in 2004/2005 was \$108 million); less habitat available for some forest dependent species; potential increase in food availability for other species,

such as moose. *Future projections – greater fire impacts, including possibility of fires in southeast Alaska.*

Potential adaptation measures include:

- re-examine, as necessary, fire fighting goals and strategies in light of climate change;
 - conduct a statewide assessment of areas of high ecosystem or other values. and utilize fire fighting to protect these highly sensitive areas, as appropriate;
 - project future fire fighting needs using climate change assumptions and impacts on forest ecosystems;
 - consider examining and testing pilot programs for alternative fire hazard treatments;
 - assess whether some biologically significant natural areas need to be protected in other ways from fire for biodiversity or other reasons;
 - determine and implement increased prescribed burning, as appropriate;
 - obtain additional funding;
 - research impacts of 2004/2005 seasons on habitat;
 - research possible fire risks in Southeast Alaska; and
 - increase public education about fire prevention.
4. **Warming effects on trees:** Current impacts – tree growth decline, stress, and death due to warmer temperatures and less water availability (e.g., birch, white spruce, and yellow cedar); overall decrease in boreal forest productivity measured; loss of yellow cedar (over 1/2 million acres); some limited northern and western expansion of boreal forests and some expansion to higher altitudes and into drying wetlands, but a net loss overall. *Future projections – projected elimination of most of Alaska’s boreal forest if temperatures continue to increase and water availability continues to decline; loss of boreal forest habitat, turning into grasslands, impact on boreal forest species such as migratory songbirds; greater loss of yellow cedar and other tree species; potential northern and western forest expansion and expansion into drying wetlands.*

Potential adaptation measures include:

- conduct a comprehensive assessment of the current impacts and future threats from temperature increases and less water availability on Alaska's forests;
- research and assess impacts of reduction or elimination of certain trees on other plant and animal species; and
- test and then consider introducing new, more heat and drought tolerant trees, if they exist.

5. **Plant invasive species in forests:** Current impacts – increased number and distribution of invasive species in the forests, especially following major fires. *Future projections – likely increased invasive species in both the boreal and temperate rain forests; possibility of invasive species reducing biodiversity and food availability for species.*

Potential adaptation measures include:

- conduct a comprehensive assessment of the current impacts and future threats from plant invasive species on Alaska's forests;
- project most likely future invasive species;
- convene experts to determine what, if any actions, can be taken;
- prioritize threats and needs;
- develop an invasive species response plan;
- determine whether early detection and selected removal are effective options;
- determine whether complete removal from highly sensitive locations is appropriate;
- research most effective removal methodologies; and
- establish more extensive monitoring and reporting systems, including public reporting.

-
6. **Impacts on forest-dependent species:** Current impacts – few current ecosystem-wide impacts, some animals lost or displaced by loss of local habitat after massive fires. *Future projections – greater impacts on forest dependent species due to substantial loss of boreal forest habitat (e.g., forest dependent birds such as passerines).*

Potential adaptation measures include:

- convene forest, fish, wildlife, and other experts to assess current and projected impacts of climate change on forest dependent species;
- identify species and habitat at greatest risk;
- examine and, where appropriate, implement available strategies to protect species at greatest risk;
- review and, where appropriate, modify land management and fish and wildlife management plans to incorporate climate change projections;
- investigate the possibility of providing needed protected forest corridors to facilitate the movement of species so that animals can migrate as forests change, using land acquisition, exchanges, cooperative management or other means;
- examine the need for new protected areas for forest dependent species using land management plans, land acquisition, cooperative management, exchanges or other means;
- increase monitoring of key species; and
- review and, where appropriate, modify fish and wildlife seasons, take, and other regulations to reflect changes in wildlife and fish abundance, locations and timing, including providing opportunities for harvesting new species.

FORESTRY

7. **Impacts on forestry:** Current impacts – loss of some available trees due to fire, disease, and climate stress. *Future projections – likely substantial loss of yellow cedar trees (the most valuable tree economically) in the southeast; further loss of boreal forest trees due to fire, drought, and disease.*

Potential adaptation measures include:

- convene forest industry representatives, scientists, land managers (federal, state and Native corporation), conservationists, and others to examine the impacts of current and projected climate change on forestry in Alaska;
- assess the impacts of global warming on the most valuable trees for forestry, especially yellow cedar;
- examine what measures exist to address projected changes, including whether forestry practices are appropriately modified;
- research, test and then consider introducing new, more heat and drought tolerant trees, if they are available;
- develop and implement fire protection plans; and
- examine the development of markets for non-traditional products and services from commercial forests, including carbon storage.

TUNDRA AND ALPINE ECOSYSTEMS AND DEPENDENT SPECIES

8. **Loss of tundra and alpine habitat from bushification and tree-line expansion:** Current impacts – because of warmer temperatures, increased bushification and tree-line expansion (e.g., in the Kenai Mountains, tree-line has advanced 3 feet/year in last 50 years). *Future projections – greater loss of tundra and alpine habitat; potential elimination of alpine and tundra habitat in certain locations and extinction of dependent species (e.g., impacts on caribou due to reduction in lichens).*

Potential adaptation measures include:

- assess tundra and alpine ecosystems at greatest risk;
- conduct a species survey in areas at greatest risk;
- examine what if any strategies exist to protect areas at greatest risk, such as mechanical or other clearing; and
- evaluate, and as appropriate, protect key alpine and tundra habitats through regulation, legislation, cooperative agreements, or land acquisition.

-
9. **Tundra fires:** Current impacts – larger and more intense tundra fires (almost 250,000 acres in 2007); modification of tundra habitat from wildfires. *Future projections – more tundra fires and loss of habitat with impacts on dependent species.*

Potential adaptation measures include:

- assess tundra ecosystems at greatest risk from fire;
- identify tundra areas of highest value;
- consider using fire prevention and suppression, as appropriate, to protect highly valued tundra areas;
- research impacts of tundra fires on caribou and musk oxen forage; and
- research and monitor impacts of tundra fires on vegetation survival, growth and succession.

10. **Impacts on tundra-dependent species:** Current impacts – some current impacts on caribou, muskoxen, and other species because of decreased food availability due to freezing rain (e.g., porcupine caribou herd has decreased 3.5%/year between 1989 and 2001); decreased food because of tundra fire events; decreased habitat because of bushification and tree-line advance for dall sheep, mountain goats, and other alpine and tundra species; increased tundra plain flooding events (e.g., deaths of muskoxen on North Slope); *Future projections – further impacts on tundra and alpine species due to loss of habitat, less available food, more flooding, and changing distributions and abundance of pathogens and diseases, resulting in substantial population level impacts; altered patterns of distribution for pathogens and parasites with emergence of disease are predicted for caribou, wild sheep, moose, and muskoxen; diseases interact with habitat perturbation and other stressors to influence reproductive success, survival, and sustainability of wildlife populations.*

Potential adaptation measures include:

- convene tundra, alpine, fish and wildlife, and other experts to assess current and projected impacts of climate change on alpine and tundra dependent species;
- assess, examine, and where appropriate, implement strategies to protect species at greatest risk;

-
- review, and where appropriate, modify land management and fish and wildlife management plans to incorporate climate change projections;
 - investigate the possibility of providing needed protected tundra or alpine corridors to facilitate the movement of species, through land acquisition, exchanges, or other means;
 - examine the need for new protected areas for tundra or alpine dependent species through land management plans, land acquisition, land exchanges or other means;
 - where appropriate, consider relocating species at risk, especially to new alpine locations;
 - increase monitoring of key species; and
 - review and, where appropriate, modify fish and wildlife seasons, take and other regulations to reflect changes in wildlife and fish abundance, locations and timing.

FRESHWATER ECOSYSTEMS AND DEPENDENT SPECIES

11. **Temperature increases:** Current impacts – river temperatures have increased throughout the state (e.g., Yukon River summer temperatures have increased more than 10 degrees Fahrenheit in last 25 years, and monitored Kenai Peninsula river temperatures now repeatedly exceed 55 degrees Fahrenheit and occasionally exceed 68 degrees Fahrenheit (above which is deemed “unhealthy for spawning areas”); increased lake temperatures. *Future projections – continued increase in water temperature throughout the state with more 55 degree and 68 degree exceedences; greater impacts on fish spawning, disease, egg development, etc.*

Potential adaptation measures include:

- increase stream, river and lake temperature monitoring and reporting;
- examine trends and provide best future projections; and
- increase research on impacts of increased temperatures on the life cycles and diseases of key fish species, including salmon, trout, and grayling.

-
12. **River water flows:** Current impacts – increased flooding events; less water in many non-glaciated rivers during warmer summers, disrupting spawning and other functions (e.g., low pink salmon catch in 2006 (11.6 v. 52 million); increased summer river flow for glaciated rivers; major landslides into rivers and retrogressive thaw slumps (e.g., Selawik River) resulting in sedimentation and other issues. *Future projections – even less water in many river systems especially those in Alaska’s interior and North Slope; increased summer flow in glaciated rivers until glaciers disappear; more major landslides and retrogressive thaw slumps*

Potential adaptation measures include:

- increase stream and river flow monitoring and reporting;
 - increase monitoring of landslides and retrogressive thaw slumps that effect rivers;
 - examine stream and river flow and obstruction trends and provide best future projections;
 - increase research on impacts of changed river and stream flows on the life cycles of key fish species, including salmon and trout; and
 - convene experts and others to discuss and evaluate potential impacts and responses to water flow changes.
13. **Loss and shrinkage of ponds and lakes:** Current impacts – ponds and lakes are shrinking and disappearing throughout Alaska through evaporation, permafrost loss, coastline erosion, and coastal storm surges; shrinkage of ponds and lakes (e.g., in a statewide study, closed pond areas decreased by 4 to 31% in last 50 years); in northeast Alaska, of 23 lakes studied, 21 decreased in size; salinization of coastal ponds and lakes from storm surges (storm surge in 2005 covered extensive areas on Y-K Delta under 9 feet of saltwater), erosion (loss of lakes on North Slope), and sea ice scouring. *Future projections – greater loss of ponds and lakes, including substantial loss from sea level rise (projected approximate 18-inch sea level rise by end of century); major impacts on many species including waterfowl and migratory birds (Note: see subsector below); increased storm surges causing salinization of coastal lakes, ponds, and wetlands; some possible expansion of wetlands on the North Slope from thawing permafrost.*

Potential adaptation measures include:

- increase monitoring of changes in size of lakes and ponds through analysis of aerial photography and other means;
- assess likely future loss and shrinkage of ponds and lakes;
- increase research on impacts of lake and pond loss, including impacts on waterfowl and species like muskrats; and
- where species are at risk, consider creating new lakes and ponds through river diversion or damming.

14. **Invasive species in freshwater systems:** Current impacts – there are new invasive plant species that have the potential to adversely impact rivers and streams such as purple loosestrife. *Future projections – greater threat in numbers, types, and abundance of injurious invasive species, seriously impacting freshwater ecosystems.*

Potential adaptation measures include:

- conduct an assessment of the scope of the current and projected extent of invasive species in Alaska’s freshwater ecosystems;
- prioritize threats and needs;
- develop an invasive species response plan;
- predict most likely future invasive species;
- convene experts to determine what actions can be taken;
- determine whether early detection and selected removal are effective options;
- determine whether complete removal from highly sensitive locations is appropriate;
- research most effective removal methodologies; and
- establish more extensive monitoring and reporting systems, including public monitoring and reporting (such as Stream Watch).

-
15. **Impacts on freshwater dependent fish:** Current impacts – increase in warmer water diseases such as *Ichthyophonus* (up to 45% of Yukon chinook now infected, none prior to 1985); migration of salmon to more northern rivers and streams; decrease in salmon fry size in glacial-fed rivers and lakes (Skilak river fry 60% smaller when glacier melted extensively in 2005); greater spring flooding disturbing eggs; increase in warmer water predatory fish; impacts from expanding beaver populations on fish habitat; major landslide and slumping events (e.g., the Selawik slump affecting sheefish). *Future projections – more northerly migration of salmon and other species; threat to and potential elimination of grayling, steelhead, and some salmon from warmer streams and rivers; more predatory fish; more habitat disruption from major slumping events.*

Potential adaptation measures include:

- convene fish, management, and other experts to assess current and projected impacts of climate change on freshwater dependent fish, and complete an assessment;
- identify species at greatest risk;
- increase research on impacts of climate change on cold water fish like grayling;
- examine and, where appropriate, implement available strategies to protect species at greatest risk;
- consider relocation of selected species to colder water systems;
- review and, where appropriate, modify river, stream and lake management and fish management plans to incorporate climate change projections and to minimize other stream and river warming factors;
- investigate the possibility of providing needed protected river or stream corridors to facilitate the movement of species using designation, cooperative management or acquisition;
- examine the need for new protected streams, rivers, and lakes using land management plans, land acquisition, exchanges or other means;
- increase monitoring of key species at all levels of the life cycle, including size, abundance and condition;

-
- monitor impacts on fish of specific impacts such as slumping events and beaver pond expansion; and
 - review and, where appropriate, modify fish seasons, take and other regulations to reflect changes in fish abundance, locations and timing, including providing opportunities for harvesting new species.

16. **Impacts on birds and other non-fish freshwater dependent species:** Current impacts – loss of animals due to flooding events, such as muskoxen and caribou calves; impact on muskrats, waterfowl, migratory birds, and other species from smaller or eliminated ponds and lakes (e.g., scaup declines from over 7 million to 3.2 million). *Future projections – further reductions in waterfowl and other pond and lake dependent species.*

Potential adaptation measures include:

- convene bird and other non-fish freshwater dependent species experts, together with management and other experts, to assess current and projected impacts of climate change on these species, and complete an assessment;
- identify species at greatest risk;
- examine and, where appropriate, implement available strategies to protect species at greatest risk;
- review and, where appropriate, modify management plans to incorporate climate change projections;
- investigate the possibility of providing needed protected corridors to facilitate the movement of species;
- examine the need for new protected areas using land management plans, land acquisition, exchanges or other means;
- increase monitoring of key species, including size, abundance and condition;
- increase research on impacts of climate change on waterfowl;
- examine the desirability of habitat modification to create or expand lakes and ponds, as necessary; and

-
- review and, where appropriate, modify seasons, take and other regulations to reflect changes in abundance, locations and timing, including providing opportunities for harvesting new species.

MARINE, SEA ICE, COASTAL ENVIRONMENT, AND DEPENDENT SPECIES

17. **Sea ice loss:** Current impacts – decline of summer Arctic Ocean sea ice (39% smaller in 2007 than recent average, and even greater loss off the coast of Alaska); decline in winter extent of Bering Sea ice; substantial thinning of ice so average is now only approximately 3 feet thick. *Future projections – greater loss and projected elimination of summer sea ice in Arctic Ocean by as early as 2013;; 40% loss of Bering Sea ice predicted by 2050; continued thinning.*

Potential adaptation measures include:

- insure comprehensive monitoring of sea ice thickness and sea ice extent in the Bering Sea and Arctic Ocean;
 - research impacts of sea ice loss on key variables such as nutrient cycles;
 - asses costs and benefits to Alaska from sea ice loss; and
 - consider supporting local, state, and national actions and legislation that will reduce greenhouse gas emissions and associated sea ice loss.
18. **Impacts on marine mammal ice dependent species:** Current impacts – walrus (abandoning calves, coming on land, stamping); polar bears (drownings, cannibalism, less cub survival, smaller skull size, more on-land denning), ice seals (collapse of some ice dens, less habitat), grey whales (weight decline, population impacts), humpback whales (first appearance in Arctic Ocean); decline of benthic habitat in Bering Sea because of less ice affecting walrus and grey whales. *Future projections – with the elimination of sea ice, many marine mammal species face dramatic reductions in numbers and possible extinction; some new marine mammal species from the south may appear; patterns of distribution for pathogens in marine mammals, including some zoonoses such as Trichinella, will influence exposure in humans (Note: see the Health and Culture sector for a full discussion of impacts on human health).*

Potential adaptation measures include:

- convene ice dependent species experts, together with other experts to assess current and projected impacts of climate change on these ice dependent species;
- examine and, where appropriate, implement available strategies to protect species at greatest risk;
- review and, where appropriate, modify management plans to incorporate climate change projections;
- investigate the possibility of providing needed protected corridors to facilitate the movement of species;
- examine the need for creating new protected areas (for such needs as walrus haul outs) through land management plans, land acquisition, exchanges or other means;
- examine the regulatory, management, and biological implications of new species, such as humpback whales, in the Arctic Ocean;
- consider promulgating new regulations regarding human behavior that will provide greater protection to avoid stampeding and other problems in walrus haul outs and other sensitive areas;
- consider providing greater protections for polar bear denning sites;
- increase monitoring of key species, including size, abundance and condition;
- examine the possibility of “out of the box” strategies such as constructing walrus platforms; and
- review and, where appropriate, modify seasons, take and other regulations to reflect changes in abundance, locations and timing, including providing opportunities for harvesting new species, such as new seal species.

19. **Impacts on fish, birds, and other species from reduction in sea ice and marine terminus glaciers:** Current impacts – loss of marine terminating glaciers with impacts on species such as Kittlitz’s murrelets (97% decline in Prince William Sound between 1989 and 2001; 89% decline in Glacier Bay between 1991 and 2000) and other species; in

Arctic Ocean declines in species like black guillemot; in Bering Sea declines in fishery species that are benthic residing and/or feeding, such as snow crab (harvest down 85% in last 6 years), other crab, halibut, yellowfin sole, Greenland turbot, as well as certain species of birds (e.g., spectacled eiders); increase in some pelagic species (e.g., pollock, cod); some changes in species distribution; introduction of new species not ice dependent. *Future projections – greater declines in ice dependent species; more introduction and distribution of non-ice dependent species; greater loss of glaciers, potential extinction of Kittlitz’s murrelets.*

Potential adaptation measures include:

- convene experts, fishermen and others to assess current and projected impacts of climate change on these non-marine mammal ice dependent species;
- examine and, where appropriate, implement available strategies to protect species at greatest risk;
- review and, where appropriate, modify management plans to incorporate climate change projections;
- examine the need for creating new protected areas through land management plans, land acquisition, exchanges or other means;
- increase monitoring of key species, including size, abundance and condition;
- assess most likely changes to existing commercial fisheries, especially in the Bering Sea;
- assess potential commercial fishing opportunities in the Arctic Ocean;
- reduce other stressors on rapidly declining species like Kittlitz’s Murrelets; and
- review and, where appropriate, modify seasons, take and other regulations to reflect changes in abundance, locations and timing, including providing opportunities for harvesting new species.

20. **Increase in marine water temperatures:** Current impacts – in 2007, Arctic Ocean 5 degrees Celsius above normal; in 2005, Gulf of Alaska 2-3 degrees Fahrenheit above normal; shifts in species distribution (e.g., pollock moving northward); introduction of new species such as tuna, anchovies, sardines, pomfret, and opah; new diseases such as

Vibrio; increase in predatory fish such as barracudas and sharks; changes in food availability and size; decreased food availability for marine birds and other species because food is lower in the water column; changes in marine productivity; harmful algal blooms adversely affecting crabs, fish, marine mammals, seabirds, and mollusks. *Future projections – greater shifts of many species north, with impacts on other species, human communities, and fishery economics (Note: fishing economics has a separate subsector below); more predatory fish with potential impacts on indigenous fish population levels; further decreases in food availability and algal blooms may result in massive die-offs; decrease in size of plankton in Bering Sea with warmer temperatures leading to problems throughout the marine food chain; potentially significant declines or elimination of sockeye salmon; shifting patterns of distribution and abundance of pathogens and parasites in marine birds, mammals, and fishes are predicted; altered seasonal patterns of abundance for parasites circulating in mollusks and birds can lead to near collapse of intertidal ecosystems through mortality of molluscan hosts.*

Potential adaptation measures include:

- increase ocean temperature monitoring and reporting;
- examine trends and provide best future projections;
- conduct additional research on impacts of warmer ocean temperatures on physical oceanic factors;
- increase research on impacts of increased temperatures on the life cycles of key species, including salmon, trout, and grayling; and on species like plankton;
- increase monitoring of key species, including size, abundance and condition;
- assess most likely changes to existing commercial fisheries, especially in the Bering Sea and Gulf of Alaska, including the introduction of new commercial species;
- assess potential commercial fishing opportunities in the Arctic Ocean;
- review and, where appropriate, modify seasons, take and other regulations to reflect changes in abundance, locations and timing, including providing opportunities for new species, such as new seal species; and
- provide state loans for fishery fleet modifications to accommodate new species and opportunities.

-
21. **Ocean acidification:** Current impacts – ocean acidity has increased by 30%. *Future projections – increased ocean acidity, potentially increasing to pH 7.9 by end of century; adverse impacts on calcium carbonate dependent species, from plankton such as pteropods to shellfish such as crabs, especially at larval stages; adverse impacts on deep sea coral and the coral dependent communities; adverse impacts on other species such as squid; adverse impacts on species that consume these species (such as salmon and pteropods).*

Potential adaptation measures include:

- research impacts of ocean acidification on key species;
- analyze risks to Alaska’s marine ecosystems and fishing industry from current and projected ocean acidification;
- convene experts to expand the analysis and understanding of the current and projected impacts from ocean acidification;
- increase monitoring especially of pH, deep sea coral, shell fish larvae, and vulnerable plankton;
- consider reducing additive threats to species most at risk, such as deep sea coral; and
- support actions that will reduce carbon dioxide emissions at the federal, state, organizational, and individual level.

OTHER WARM TEMPERATURE IMPACTS ON ANIMALS

22. **Non-fish animal impacts in addition to habitat-based changes:** Current impacts – loss of animals due to new or increased viral, bacterial, and parasitic diseases, such as lungworm in muskoxen (a tipping point changing transmission from a 2 year to a 1 year cycle was reached in the 1990s); muscleworms in caribou where responses to extreme warm weather events can drive emergence of disease and mortality; increasing abundance of biting fly vectors linked to the emergence of parasitic diseases in reindeer; new distributions for viral pathogens in rodents (potentially transmissible to humans) through range expansion; earlier arrival and birthing of migratory species including birds, whales, etc. (e.g., hatch dates for geese in Yukon Delta 5-10 days earlier since 1982); new species both to the state as a whole and to specific areas; greater predation threats to

eggs after storm surges reduce vole populations. *Future projections – more new or increased emergence of pathogens, diseases, and vectors (e.g., injury or death to moose from excessive ticks and deer-borne pathogens, including winter tick); potential new diseases affecting caribou; more damage to muskoxen and wild sheep from lungworm; other potential disease damage to caribou, muskoxen, and dall sheep; increase in biting flies both as direct nuisance and as vectors.*

Potential adaptation measures include:

- increase monitoring of species numbers, diseases, distribution, and condition;
- establish or expand disease registries and reporting;
- convene experts to examine the impact of climate change on current and new animal diseases, and to review possible controls;
- develop and implement specific strategies for species at greatest risk;
- research, consider, and where appropriate, implement vaccination or other disease control strategies;
- research impacts of early migratory arrivals and hatching dates on key species;
- research impacts of major storm surges on fish and wildlife populations and response strategies; and
- review and, where appropriate, modify seasons, take and other regulations to reflect changes in abundance, locations and timing, including providing opportunities for new species and earlier arrivals.

FISHING: COMMERCIAL AND SPORT

23. **Commercial fishing:** Current impacts – changes in fish distribution and catch composition; northern migration of species such as pollock (in some cases outside of U.S. waters); some fish farther away from on-shore processors, harbors, and communities, requiring further travel; introduction of new species such as tuna; declines in catch of benthic species in Bering Sea and elsewhere such as most species of crab, shrimp, and in some locations, halibut; increase in some pelagic species (e.g., cod). *Future projections – opening up of the northern Bering Sea and Arctic Ocean to the possibility of commercial fishing; greater introduction of new species; need for new gear;*

continued declines in benthic species; decline of sockeye salmon; potentially more dangerous fishing conditions due to greater storms, less weather predictability, and the need to travel farther distances.

Potential adaptation measures include:

- convene a statewide conference to examine current and projected impacts of climate change, including ocean acidification, on commercial fishing and prepare a report with specific recommended actions;
- complete a comprehensive assessment of the statewide impacts of current and projected climate change on commercial fishing opportunities;
- increase monitoring, observing and reporting of species numbers, composition and condition;
- provide state loans for boat, gear and other adaptation;
- help develop new markets as new species enter Alaskan waters;
- resolve boundary disputes with Russia in the Northern Bering Sea and Arctic Ocean to reduce fishing conflict possibilities;
- increase Coast Guard presence in northern Bering Sea and Arctic Ocean;
- reduce other stressors to key species;
- assess what infrastructure requirements exist for more northern fisheries, and provide that infrastructure, as needed; and
- review and, where appropriate, modify seasons, limits, areas, gear types and other variables to reflect changes in abundance, locations and timing, including providing opportunities for harvesting new species and earlier arrivals.

24. **Sports fishing business:** *Future projections – likely decline in cold water sports fish such as grayling, steelhead, some salmon in warmer streams, and rainbow trout; longer open water season with potentially higher harvest rates on recreational fish; greater requests to stock non-native warmer water fish; changed access to water bodies for fishing; more dangerous fishing conditions due to greater intensity and/or frequency of*

storms, less weather predictability, and the need to travel farther distances (e.g., for halibut).

Potential adaptation measures include:

- complete a comprehensive assessment of the statewide impacts of current and projected climate change on sports fishing opportunities and the sports fishing industry;
- consider requests for stocking non-native species and the need to have criteria for that decision;
- increase monitoring, observing and reporting of species numbers, composition and condition;
- provide the public an opportunity to report changes they are observing associated with sports fishing regarding fishery composition, abundance, location and condition;
- provide public education regarding the impacts of climate change on sports fishing, including new fishing opportunities; and
- review and, where appropriate, modify seasons, limits, areas, gear types and other variables to reflect changes in abundance, locations and timing, including providing opportunities for harvesting new species and earlier arrivals.

SUBSISTENCE FISHING, HUNTING, TRAPPING AND GATHERING

25. **Decline in traditional subsistence food availability:** Current impacts – decline and disease in traditional subsistence foods (e.g., *Ichthyophonus* in Y-K salmon); changed animal migratory routes, seasons, and patterns affecting hunting; hunting more dangerous if associated with ice; other adverse hunting and fishing access issues; decline in some animals traditionally trapped (e.g., muskrats); changes in berry distribution and availability; increased abundance of pathogens and parasites with emergence of diseases in muskoxen, caribou, moose, and wild sheep can influence availability and sustainability of these and other terrestrial, aquatic, and marine animals for exploitation in the subsistence food chain. *Future projections – additional decline and disease in traditional subsistence foods; decrease in hunting opportunities for dall sheep because of loss of alpine habitat, for caribou because of food availability issues and other impacts, for*

muskoxen because of disease and flooding events, for polar bears, walruses, and ice seals because of decrease in sea ice, and for waterfowl because of loss of ponds and lakes; ice-based and ocean-based hunting increasingly more dangerous because of thinning ice and unpredictable ice behavior; some new subsistence food possibilities (e.g., salmon in northern Alaska).

Potential adaptation measures include:

- complete a comprehensive assessment of the statewide impacts of current and projected climate change on subsistence hunting, fishing, and gathering opportunities;
- convene a statewide conference of regional subsistence representatives to examine current and projected impacts of climate change on subsistence hunting, fishing and gathering, including exploring new opportunities, and prepare a report with specific recommended actions;
- increase monitoring, observing and reporting of species numbers, composition and condition;
- provide subsistence fishers, hunters and gatherers an opportunity to report changes they are observing associated with their hunting, fishing and gathering activities, including species composition, timing, abundance, location, and condition;
- provide public education regarding the impacts of climate change on subsistence opportunities; and
- provide increased disease testing to create greater consumption confidence.

SPORT HUNTING

26. Current impacts – changes in seasons and location of some species in some locations (e.g., caribou and moose). *Future projections – decrease in hunting opportunities for dall sheep because of loss of alpine habitat, for caribou because of food availability issues and other impacts, for muskoxen because of disease and flooding events, for waterfowl because of loss of ponds and lakes, etc.; new hunting opportunities as new species arrive or are introduced (e.g., possible expanded hunting for Sitka deer, bison).*

Although the individual sports hunting businesses and individuals will undertake many adaptations on their own, a moderate amount of government intervention is necessary. Possible actions include, modifying seasons and harvests to accommodate changes; public education; increased local reporting and data gathering; increased information exchange

Potential adaptation measures include:

- complete a comprehensive assessment of the statewide impacts of current and projected climate change on sports hunting;
- convene a statewide conference of sports hunting representatives to examine current and projected impacts of climate change, including exploring new opportunities, and prepare a report with specific recommended actions;
- increase monitoring, observing and reporting of species numbers, composition and condition;
- provide sports hunters an opportunity to report changes they are observing associated with their hunting activities, including species composition, abundance, timing, location, and condition; and
- provide public education regarding the impacts of climate change on sports hunting opportunities.

TOURISM AND WATCHABLE WILDLIFE

27. **Summer and shoulder seasons:** Current impacts – longer summer and shoulder tourism season; expansion of cruise season; expansion of other summer and shoulder tourism opportunities throughout the state; some adverse impacts on summer tourism, including melting of glaciers, reducing tourism attractions (e.g., Portage), damaged roads, and diseased and dying forests; summer smoke from large wildland fires causes disruption in tourism (e.g., visibility diminished of Denali and other sites, highway closures); health issue for tourists (e.g., smoke and Vibrio); hotter temperatures without air-conditioning. *Future projections – even greater expansion of summer season; increased melting, decline, and/or elimination of glaciers; more dead and dying trees; greater disruption from smoke over a longer season; hotter, especially in interior Alaska.*

Potential adaptation measures include:

-
- provide proper road, airport, and bridge maintenance that is responsive to climate change to support the needs of the tourism economy;
 - help market Alaska's longer summer season;
 - work with communities to extend services in response to longer seasons;
 - examine and respond to cooling needs associated with warmer summers;
 - adjust permits and other requirements to address changed itineraries due to impacts from climate change;
 - insure adequate health system responses for tourists in case of smoke, fire, flooding or disease emergencies;
 - locate visitor centers with an awareness of future climate changes;
 - study expansion of tourism into the Arctic Ocean and assess infrastructure and other needs; and
 - modify interpretive signage to reflect changed species composition or other impacts from climate change.

28. **Winter tourism season:** Current impacts – shorter season; some adverse impacts include canceling of dog sled racing events (cancellation of Fur Rendezvous races 3 times in the last 9 years), changing start of Iditarod, shorter downhill skiing season, less cross-country skiing; positive impacts include warmer temperatures in previously very cold locations such as Chena Hot Springs and Bettles. *Future projections – increased reduction in winter season, dog sled races, downhill skiing, and lower elevation cross-country skiing; continued more comfortable temperatures for previously very cold locations.*

Potential adaptation measures include:

- study and prepare a report that examines the likely impacts of climate change on winter tourism, given an appropriate range of winter temperature increase assumptions;
- explore benefits of warmer, but still below freezing, winter temperatures for winter tourism in locations like Bettles;

-
- examine the possibility of making additional higher altitude lands available for activities like downhill skiing;
 - examine alternative winter activities for tourism; and
 - explore establishing earlier dates for major winter events.

29. **Watchable wildlife:** Current impacts – less watchable wildlife for such species as Kittlitz’s murrelets that have already declined significantly; changes in watchable wildlife distribution and timing (e.g., arrival dates of migratory birds). *Future projections – fewer watchable wildlife opportunities if populations of dall sheep, mountain goats, muskoxen, caribous, certain birds, etc., decline; potentially more watchable wildlife opportunities in the near term for polar bears and walruses on land; new watchable wildlife opportunities as new species arrive.*

Some potential adaptation measures include:

- study and prepare a report that examines the likely impacts of climate change on watchable wildlife;
- modify or create interpretive signage to reflect changed species composition or other impacts from climate change;
- consider the need to promulgate new watchable wildlife regulations, especially with respect to polar bears and walruses as they become more prevalent on land to avoid disturbances and hazardous situations;
- provide wildlife observers an opportunity to report changes they are seeing associated with watchable wildlife activities, including species composition, abundance, timing, location, and condition; and
- provide other public education about the impacts of climate change on watchable wildlife, including new watchable wildlife opportunities.

OTHER ADAPTATION ISSUES

The following potential adaptation measures could also be considered:

- research, document and potentially pursue the claim that Alaska should receive compensation as a carbon sink for temperate rainforests, oceans and other natural areas; and
- develop a comprehensive research and practitioner training program in climate change adaptive management.