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.*

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 wooly 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.*

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*.

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.*

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.*

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).*

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.*

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).*

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.*

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.*

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.*

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*

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.*

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.*

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.*

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.*

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*.

18. **Impacts on marine mammal ice dependent species:** Current impacts – walruses (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).*

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.*

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 molluskan hosts.

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).*

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.*

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.

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).*

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).*

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).*

TOURISM AND WATCHABLE WILDLIFE

27. **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.*