Alaska Climate Change Strategy

Natural Systems Adaptation Technical Working Group

Catalog of Adaptations and Policy Options

For Presentation to Adaptation Advisory Group
December 17, 2008

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Introduction

The Natural Systems Technical Working Group (TWG) has developed a catalog of adaptation options related to the expected effects of climate change on Alaska's natural systems. This catalog will be presented to the Adaptation Advisory Group on December 17, 2008, and includes the results of balloting by TWG members using criteria listed in Attachment 1. There are three major sections to the Natural Systems Adaptation Catalog:

I. **<u>Changes to Habitats and Dependent Species</u> –** This section summarizes the expected effects of climate change on Alaska's habitats and the fish and wildlife that depend upon those habitats. It addresses potential changes in:
- Marine habitats and dependent species
- Terrestrial habitats and dependent species
- Freshwater habitats and dependent species
- Future Trends

This section sets the context for the adaptation analysis by evaluating what changes are likely to occur in Alaska's natural habitats and dependent fish and wildlife species in response to climate change. The section will (1) inform what types of human adaptation will be needed to these changes (presented in Section II, below), and (2) indicate what research and monitoring is needed related to natural systems (to be forwarded to the Research Working Group).

II. **<u>Adaptation of Human Uses of Alaska's Natural Systems</u> –** This section presents the recommendations of the Natural Systems TWG and the "catalog" of relevant actions that the State of Alaska could take to adapt to changes in Alaska's natural systems due to climate change (informed by the summary of natural system change provided in Section I, above). It addresses the following topics, for which adaptation options are recommended:

NS-1 Agriculture
NS-2 Forestry
NS-3 Wildfire
NS-4 Invasive Species and Disease
NS-5 Commercial Fishing
NS-6 Fish and Wildlife Management
NS-7 Water Conservation and Management

III. **<u>"Cross-Cutting" Recommendations</u> –** This section includes recommendations of the Natural Systems TWG regarding two areas that are beyond the scope of just natural systems, for the consideration of the AAG. These recommendations are regarding:
- Capacity-Building, Education & Outreach
- Support for Cap & Trade Emissions Trading

Section I. Changes to Alaska's Habitats and Dependent Species

OVERVIEW: Climate-Change Effects on Alaskan Ecosystems

In the last three decades Alaska has warmed substantially, approximately twice the global average. This has substantially affected marine, terrestrial, and freshwater ecosystems. The resilience and ecological integrity of these ecosystems depends on the sensitivity of the physical environment (e.g., permafrost and hydrology) to warming and the capacity of local species to adapt or move in response to the resulting environmental changes. In general, highly mobile species like salmon or songbirds adjust more readily than less mobile ones like blackfish and trees. In addition, warming brings the arrival of new species, including pests and diseases, which can modify the responses of local ecosystems in ways that challenge their resilience to environmental changes. These environmental and ecosystem changes are projected to continue in coming decades, although the rate and pattern are often difficult to predict because of complex ecosystem interactions. In the following sections, we outline the changes observed and projected in different Alaskan ecosystems as a basis for development of policies that will foster the resilience of these ecosystems and the benefits that they provide to Alaskans.

MARINE ENVIRONMENT: Anticipating Climate Change in Alaska's Seas: Prospects for the 21st Century

The seas around Alaska have responded dramatically to the warming trend of the last few decades, and are now on the brink of fundamental transitions that may substantially alter their productivity. The Bering Sea and the Arctic Ocean are strongly affected by changes in ice cover, which are amplified by multiple feedbacks in the associated ecosystems. Even in the Gulf of Alaska, where sea ice is not a crucial factor, the marine ecosystem will change considerably if current warming trends continue. Like predicting the weather, forecasts of how these seas will respond is necessarily imprecise, but consensus scientific projections provide the best guidance available for evaluating and prioritizing policy alternatives for adapting to these changes. These findings are summarized here, in the hope that the context they provide will constructively inform the difficult decisions that face Alaskans as we try to cope with the changes ahead.

The following summary begins with a basic account of how sub-polar and polar marine ecosystems function, how the three major marine ecosystems around Alaska (roughly associated with the Gulf of Alaska, the Bering Sea and the Arctic Ocean) are thought to interact with the physical environment and a description of the ecosystem changes that have occurred to date. The range of likely warming trajectories is presented next, along with a sense of the reliability of these projections. Forecasts of changes in the effective sizes of these ecosystems and their biological productivity follow, together with an indication of how these ecosystems may reorganize in response. The concluding section addresses the acidifying effects of rising carbon dioxide levels in the atmosphere, and how these interact with the effects from warming.

Marine Productivity around Alaska

As on land, marine productivity is fundamentally determined by the amount of plant growth over the course of the year. Microscopic plants called phytoplankton account for nearly all of this growth in the ocean, and require light and inorganic nutrients (especially nitrogen) to flourish. Processes that affect growth are important because phytoplankton productivity sets a limit on the productivity of everything else, including economically valued resources such as fish.

Little phytoplankton productivity occurs in the winter in sub-polar and polar seas because of low light levels and because of generally stormy weather that mixes the seawater column to depths of hundreds of meters, so the plants do not spend much time exposed to what little light is available at the surface. Calmer weather, increased light and addition of fresh water from rainfall, ice melt or terrestrial runoff create a buoyant layer of water on the sea surface during spring, and phytoplankton in this layer are continuously exposed to increasing light and to relatively high nutrient levels brought to the surface by the winter mixing. These conditions trigger a period of rapid plant growth that lasts until nutrients are exhausted or light levels diminish during fall. Strong storms during spring and summer may interrupt this growth, but if followed by calm weather may increase productivity by re-supplying nutrients.

The presence of sea ice usually affects marine productivity strongly. Because sea ice reflects ~80% of the sunlight reaching it, the productivity beneath continuous ice sheets is generally quite low. But near the margins during spring productivity can be quite high. This is because the underside of the ice provides a surface for algae to grow on that is irradiated by light scattered within nearby open water, and because the melting ice adds relatively fresh water to surrounding sea surface, lowering its buoyancy.

Warming climate affects Alaskan marine productivity processes in three fundamental ways. Shrinking the size and displacing the location of seasonal sea ice is the most important effect, and may have substantial impacts in the Bering Sea and the Arctic Ocean. By increasing the buoyancy and thickness of the sea surface during spring, increased warming suppresses re-supply of nutrients from the deeper waters beneath during summer and fall. And finally, the warmer temperatures increase the phytoplankton growing season, which tends to increase annual productivity. These warming effects have markedly different consequences in the Gulf of Alaska, the Bering Sea and the Arctic Ocean.

Response to Climate Warming in Alaskan Seas

Gulf of Alaska

The Gulf of Alaska is widely suspected of providing one of the first large-scale marine ecosystem transitions in response to climate warming. Following several unusually warm and wet winters, a major "regime shift" in the organization of the marine food web occurred beginning in 1977. Over the course of this transition, the shellfish fishery crashed but the productivity of salmonids and many other finfish soared[1]. Other biological responses include a general decline in abundances of oil-rich forage fish species that prefer cold waters, and a more than doubling of the zooplankton biomass, which are small animals that graze on phytoplankton[2]. These and associated changes in sea surface temperature and other physical factors strongly suggest that the warmer temperatures increased the growing season of the phytoplankton and especially the zooplankton, which reduced the supply of un-grazed phytoplankton falling to the seafloor where it supported a food web favorable for shellfish. The increased biomass of the zooplankton sustained a different food web in the water column that is more favorable for fish. Climate-ecosystem models suggest that these changes have if anything caused modest increases in the overall biological productivity of the Gulf of Alaska[3].

Other responses to warming surface waters in the Gulf of Alaska include northward range incursions of fish that prefer warmer waters such as hake and mackerel, of invasive species and of more widespread occurrences of warmer-water fish diseases and other pests such as paralytic shellfish poisoning.

Bering Sea

The conjunction of the seasonal sea ice edge during spring with the edge of the continental shelf makes the Bering Sea one of the most productive on earth. Tidally-driven currents induce nearly continuous upwelling of nutrients along the shelf edge, and the ice provides a substrate for algae and source of meltwater that stabilizes adjacent surface waters, both of which allow plants to be well-supplied with both nutrients and light. Unfortunately this very favorable production regime is at risk. In recent decades the Bering Sea has supported enormous shellfish and finfish (mainly pollock) fisheries, the relative productivity of each being modulated by the weather during spring[4]. During cold springs, the phytoplankton bloom is closely associated with the sea ice edge, and the cooler temperatures suppress zooplankton population growth that would otherwise graze on the phytoplankton. The result is that most of the un-grazed phytoplankton production eventually sinks to the bottom, supporting a food web favorable for shellfish. During warm springs, the ice melts before the phytoplankton bloom starts, delaying the onset of the bloom until zooplankton abundances are increasing more rapidly. More of the phytoplankton production is consumed by the zooplankton, that are consumed in turn by finfish.

As in the Gulf of Alaska, the surface waters of the Bering Sea have been steadily warming over the last few decades, resulting in marked ecosystem changes. Whereas finfish have flourished, shellfish and cold water adapted forage fish have moved steadily north seeking cooler waters[5]. The edge of maximum sea ice extent has tended to move northwards as well, decreasing the coupling between the ice-melt processes during spring with the nutrient upwelling associated with the continental shelf edge. These responses have likely caused a small reduction in the overall productivity of the Bering Sea.

Arctic Ocean

The most dramatic marine ecosystem changes are underway now in the Arctic Ocean, including Alaska's Arctic coast. In 2007 and again in 2008, the extent of seasonal ice retreat resulted in a minimum ice cap area some 40% smaller than the average from 1979 – 2000[6]. In addition, most of the ice now consists of 1-year ice (ice that is 1 year old or less), compared with predominantly multi-year ice just a decade ago, and nearly half the summertime Arctic ice cap volume has now melted[6]. These sea ice losses will likely increase the productivity of the Alaskan continental shelf in the Arctic substantially, although from such a low base it is unclear whether this will result in commercially viable fishing opportunities. Ice loss in spring and summer allows much more light to penetrate the water column. The shallow seawater depth of the continental shelf insures that phytoplankton are always illuminated, so phytoplankton growth can increase no matter how stormy the weather conditions are. However, except in the westernmost portion of Alaska's Arctic continental shelf, most of the shelf will still likely suffer from nutrient limitation. This is because the coastal waters of Alaska's Arctic are diluted by freshwater discharge from the Mackenzie River, which is nutrient poor. But just north of the Bering Strait lies the most productive patch of marine water anywhere on earth. This region is supplied by the nutrients upwelled from the continental shelf in the Bering Sea and carried northward by surface currents, and fuels a particularly rich benthic food web that supports walrus, gray whales and a variety of seabirds.

Ocean Acidification

Ocean acidification refers to another consequence of adding carbon dioxide to the atmosphere that is independent of the effects on warming. Some of the carbon dioxide added from human emissions dissolves into the surface layer of the ocean where it reacts with water to form carbonic acid. Enough has dissolved since the advent of the industrial revolution to cause about a 30% increase in the acidity of the oceanic surface waters worldwide, and are projected to triple by the end of this century under "business as usual" emissions scenarios. Increases of this magnitude will likely eliminate important components of the food web in the Gulf of Alaska, threaten some cold water corals in the Bering Sea, and may adversely impact commercially and economically important shellfish such as euphausids, crabs and shrimp.

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2. Brodeur, R.D., Ware, D.M. 1992. Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. Fish. Oceanogr. 1:32-38.

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6. See: http://www.nsidc.org/news/press/20081002_seaice_pressrelease.html

7. See: http://www.aip.org/history/climate/index.html

TERRESTRIAL ENVIRONMENT

General

Potential human adaptations to the future conditions that may occur with climate change are of interest to many Alaskans. Climate is a principle influence on ecosystem services, which are the functions that support life and biological diversity (nutrient cycling, air and water purification, weather regulation, etc.) and provide resources for humans (food, fiber, energy, recreation, etc.). The supply of ecosystem services may become vulnerable to disruption if managed ecosystems become stressed from external factors (such as climate change) or unsustainable extraction of resources. The 2005 Millennium Ecosystem Assessment (http://www.millenniumassessment.org/en/Index.aspx) was commissioned by the United Nations to synthesize scientific information and knowledge held by the private sector, practitioners, local communities, and indigenous peoples on sustaining ecosystem services at the global scale. It included detailed reports on current state and trends in terrestrial ecosystem services and evaluation of policy responses to mitigate degradation and provide options for adaptation.

The Arctic Climate Impact Assessment in 2004 (http://www.acia.uaf.edu/) reviewed effects of climate change on and tundra (Chapter 7) and forest (Chapter 14) biomes and selected species. It included several authors and research case studies from Alaska. A more detailed account of the status of wildlife species status in Alaska including the context of climate change was given in the Comprehensive Wildlife Conservation Strategy in 2005 (http://www.sf.adfg.state.ak.us/statewide/ngplan/NG_outline.cfm). Recent trends in warmer and drier conditions in parts of mainland Alaska have influenced plant growth rate and the expansion of tree line and shrub line northward and to higher elevation. A continued decrease in growth rate of white spruce and Alaska paper birch coincident with warmer, drier conditions could eventually lead to possibly rapid change in species diversity (forest transition to grassland savanna) and the supply of fiber or biomass fuel. Changing bioclimate can also affect the supply of wild foods (e.g., berries) as species distributions change. Lower fitness or growth rate of trees could decrease reforestation success or prolong the harvest rotation period of wood supply.

For the short term (10-25 years), the recent trend toward warmer conditions may be moderated by a cooler phase of the Pacific Decadal Oscillation (http://kenai.fws.gov/overview/notebook/2008/august/29august2008.htm), which could moderate ecological changes or rates of change recently documented as coincident with warmer temperatures. Adaptation during this period should focus on convening scientists and resource managers to forecast changes in biomes, habitats, and species as the basis for recommending revision of resource management policy. Monitoring protocols should be established and implemented to calibrate ecological forecast models. As evidence for change becomes clearer in species distribution or the supply of food or commodities, revision of policy will become more informed. Experimentation in adaptive management (e.g., introduced trees from nearby ranges, such as lodgepole pine; conducting moose hunts during the rut to test effect on subsequent breeding success) should also begin to understand system performance under new bioclimatic conditions.

In 2008 agencies in the U.S. Department of Interior began several projects that use prediction from global climate models to forecast changes in biome distribution and potential effects on plants and animals over defined periods in Alaska (e.g., creation or disruption of migration corridors or range extension pathways). These efforts are being done in collaboration with the Scenarios Network for Alaska Planning (http://www.snap.uaf.edu/), and some are already available for specific national wildlife refuges with forecasted effects on moose and caribou habitat (http://www.snap.uaf.edu/downloads/reports-boreal-alfresco). Outcomes may be used to prioritize mitigation (e.g., transplanting of alpine-dependent species to remaining alpine areas to maintain genetic diversity) or suggest adaptive strategies (e.g., major changes in caribou migration routes may require focus on new transportation options or alternative game species by subsistence hunters). Continued warmer and drier conditions are predicted to increase the area or frequency of wildand fire, cause retreat of inland glaciers, and decrease the area of continuous and discontinuous permafrost and lakes.

Forest Environment

The forests of Alaska are represented by two broad categories, the boreal forests of Interior and the coastal forests of Southeast. Forests are generally treated as carbon (C) sinks in most models developed to assess climate change scenarios, but ongoing work is showing that under the influence of fire, the boreal forest under certain conditions may be a net emitter of carbon or a source. The boreal forest is a fire dependent ecosystem and frequent fires are a common occurrence on the landscape. Fire return intervals can range from 70 to 300+ years with a common interval range of 100-150 on upland sites. The 2004 and 2005 fire seasons were the first and third largest on record in terms of total acreage burned with a combined size of 11.2 million acres[1] (6.5 million and 4.6 million) however, the 2008 season was one of the lowest on record at 103.3 thousand acres[2]. These numbers exhibit a wide range of variability in such a short time span. Under the influence of a changing climate, an increase in fire frequency, size, location or burn intensity could change the carbon flux rate in a positive (net source) manner and affect long-term storage of C in above ground biomass and in the organic and mineral layers of the soil. Melting of permafrost and increased soil respiration in tundra independent of fire may also release methane (CH_4)[3], which has twenty-three times the capacity as CO_2 to absorb heat in the atmosphere[4].

A large component of the boreal forest C is stored in the soil and in permafrost. Recent work by Dr. Chien-Lu Ping at the University of Alaska has demonstrated the potential for permafrost soils to store large quantities of organic materials. His work on the North Slope in the tundra ecosystem has shown that previous estimates of stored C were underestimated by as much as 60 percent when compared to previous studies[5]. With the potential for increased fire activity in this relatively fire free ecosystem, a large sink of stored C may be vulnerable. In 2007 the Anaktuvuk fire burned 250 thousand acres and is the largest single fire to burn in this ecosystem to date. The previous record was in 1993 when 100 thousand acres burned[6]. In addition to C impacts, these fires have the potential for a wide range of social and biological impacts. For

[1] Alaska Department of Natural Resources, Division of Forestry (DOF) 2005 Annual Report, DOF, June, 2006
[2] 2008 Alaska Wildfires by Area and Protection Level, Alaska Interagency Coordination Center (AICC) Predictive Services, November 9, 2008 draft report.
[3] http://www.acia.uaf.edu/PDFs/ACIA_Science_Chapters_Final/ACIA_Ch06_Final.pdf
[4] http://www.epa.gov/outreach/qanda.html
[5] Ping, Chien-Lu
[6] Jandt, Randi, Presentation at the 2007 Interagency Fall Fire Review, Fairbanks, AK 2007

example, barren ground caribou *(Rangifer tarandus)* have annual migrations between summer and winter range. Lichens *(Peltigera sp)* are important for winter range, but take several decades to recover biomass levels adequate for caribou forage after disturbance by fire[7,8]. Changes to caribou migration patterns in relation to village locations and increased distances to hunt for subsistence foods are a valid concern for rural residents.

Warming trends in the Interior have increased the number of growing degree days and in some years have caused moisture stress due to drought like conditions[9]. In turn this has affected forest health with many tree species exhibiting stress and associated issues with susceptibility to insects and disease. Insect populations have dramatically increased in some portions of the state and in South-central Alaska the spruce bark beetle *(Dendroctonus rufipennis)* has caused widespread mortality of white spruce *(Picea glauca)* on 6 million acres in the 90's with a peak in 1997 when 1.1million acres of mortality occurred[10]. Defoliator insects such as the spruce budworm *(Choristoneura fumiferana)* and the aspen leaf miner *(Phyllocnistis populiella)* have also caused widespread damage and some mortality to trees in the Interior. The aspen leaf miner is in its sixth consecutive year of outbreak with approximately 755.4 thousand acres of activity, the most ever recorded in Alaska.[11] Many of the region's tree and shrub species have been impacted by defoliators and in turn this can affect wildlife species that utilize these species for food, cover or nesting. The willow leaf blotch miner is in its fifteenth consecutive year of outbreak and a nearly four fold increase in activity was observed in 2007 with over 91.9 thousand acres infested[12]. Consecutive years of heavy leaf mining activity can cause widespread willow mortality. This can have local, negative impacts on moose populations that depend on the species as a primary food source.

Forest health is a complex topic and in addition to insects and pathogens, there is also a term called "decline" which describes a condition of widespread tree mortality in situations where several interacting factors contribute. An example of a decline condition found in the coastal forests of Alaska is yellow-cedar *(Chamaecyparis nootkatensis)* decline. This condition is a form of freezing injury that occurs in the spring due to low snowfall or the early melting of protective snow cover in the spring. This decline has been ongoing since about 1900; it accelerated in mid-century and continues today.

Over 500 thousand acres of cedar decline mortality have been mapped and this decline is often cited as a leading example of an impact from climate change[13]. This tree species has important cultural and economic uses associated with its occurrence in this ecosystem and its further

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[7] Joly, Kyle, Dale W. Burce, Collins, B. William, and Adams, G. Layne, Winter Habitat Use by Female Caribou in Relation to Wildland Fires in Interior Alaska, Can. J. Zool. 81:1192-1201 (2003)
[8] Jandt, Randi, Joly, Kyle, Meyers, C. Randy and Racine, Charles, Slow Recovery of Lichen on Burned Caribou Winter Range in Alaska Tundra: Potential Influences of Climate Warming and Other Disturbance Factors, Arctic, Antarctic, and Alpine Research, Vol. 40, No. 1, 2008, pp. 89-95
[9] Juday, Glenn, Presentation to the Board of Forestry, November 12, 2008, UAF Alaska Climate Research Center http://climate.gi.alaska.edu
[10] Forest Ecology and Management, Special Issue, Spruce beetles and forest ecosystems of south-central Alaska, Volume 227, Issue 3, 2006
[11,12,13,14] Forest Health Conditions in Alaska - 2007, USDA Forest Service, Alaska Region. R10-PR-18, 2008

decline is a concern. Additional research in regeneration techniques for yellow-cedar and into the causal effects of the condition is warranted.

Invasive plants are another aspect of climate change that can have detrimental impacts on a region's economy and natural resources. Alaska is geographically isolated and past climate factors have contributed to a delay in invasive plant problems, but in recent years numerous problematic and invasive plant species have become established including spotted knapweed *(Centaurea biebersteinii)* and purple loosestrife *(Lythrum salicaria).*[14]
Strategies for dealing with this issue are centered on early detection and rapid response. A comprehensive summary of organizations and plant survey data can be found in a section of the *Forest Health Conditions in Alaska-2007* report entitled, *Non-native Invasive Plant Prevention and Management Efforts in 2007* authored by Melinda Lamb and Jamie Nielsen. A copy of this publication and other related information is available at http://www.fs.fed.us/r10/spf/fhp/.

Perhaps the best resource for additional reading is a recently published paper in the April/May 2008 Journal of Forestry entitled, *Forest Management Solutions for Mitigating Climate Change in the United States*. (http://www.safnet.org/jof_cctf.pdf) This document provides an excellent summary of current thinking on this topic with an executive summary that is well worth reviewing. It provides the context for the larger discussion of climate change and discusses strategies for preventing green house gas (GHG) emissions, reducing atmospheric GHGs with forest mitigation and adaptation approaches, and discusses forest carbon offset projects. Subsequent sections of the paper go into more detail on specific items in each category; however in summary, it is useful to quote directly from a section discussing adaptation.

> "Adaptive strategies include increasing resistance to insects, diseases and wildfires; increasing resilience for recovering after a disturbance; and assisting migration-facilitating the transition to new conditions by introducing better – adapted species, expanding genetic diversity, encouraging species mixtures, and providing refugia."

It is difficult to predict the short and long-term changes that will occur with climate change, but it is clear to many in the profession that innovation, adaptive management and hard work will be required to ensure the forests of Alaska will be part of the solution to climate change and its challenges.

FRESHWATER ENVIRONMENT

Climate models presently lack the detail to project changes in specific freshwater environments throughout Alaska. Also, because of Alaska vast size, effects will differ significantly regionally across the state. Because of this, it is difficult to project with certainty specific impacts that may occur.

That said, it is possible to anticipate some general impacts. It is expected that freshwater systems will experience increased winter flooding, reduced summer and fall streamflows, and warmer summer stream temperatures. Also, earlier snowmelt and peak spring streamflow are likely to occur.

These impacts will likely result in changes to both in-channel and out of channel freshwater habitat. In-channel changes will likely result from shifts in ice, runoff, physical limnology regimes and human land use. In turn, these ecosystem shifts will likely affect biological structure and function including biogeochemical processes, trophic structure, food web interactions, and primary and secondary productivity. This in turn will have diverse effects on population structures within the supported ecosystems.

In general, impacts are speculated to be harmful for existing populations of fish adapted to the current conditions, resulting in the elimination of some species and increases in others. In general, species adapted to cold water systems will become more stressed whereas species more adapted to warmer water temperatures will benefit. In addition, new species will be introduced as environmental conditions allow for expanded ranges. For example, salmon may become established in tributaries to the Arctic Ocean. Also, invasive species may spread as well as pathogens whose frequency of occurrence increase as temperatures increase.

These impacts will have major effects on people who currently utilize fish and wildlife dependent upon freshwater habitats as well as industries seeking to utilize other resources. Managers will need to adopt novel management strategies to address increased uncertainty associated with changing environmental conditions. Users may need to travel further distances to meet current needs or shift preferences onto available species.

Finally, increased research and monitoring will need to be conducted to learn how environmental conditions are changing at local levels and to assess how these changes may be influencing both species and communities of users. Increased education and outreach will need to be designed collaboratively with users to communicate observed and expected changes at relevant scales.

See also:

Wrona, F.J., Prowse, T.D., Reist, J.D., Hobbie, J.E., Levesque, L.M.J., and Vincent, M.F., 2006. Climate Change Impacts on Arctic Freshwater Ecosystems and Fisheries: Key Findings, Science Gapes and Policy Recommendations. Ambio 35:411-415.

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FUTURE TRENDS

Forecasts of the effects of warming trends on Alaska are based on models that couple atmospheric and oceanic processes and are driven by changes in the atmospheric concentrations of carbon dioxide and other greenhouse gases[1]. Although some members of the general public are skeptical of such models, they have found widespread acceptance within the scientific community for at least three reasons. First, no alternative explanation for all the myriad physical details associated with the warming trend of the last half century has been proposed that does not have serious defects, whereas the carbon dioxide hypothesis provides a physically-based explanation, and has predicted specific effects that have turned out to be true[2]. Second, the models based on the carbon dioxide hypothesis perform reasonably well in their ability to replicate the record of past climate observations, including the results from the geological record that extend well past the instrumental record from which the models are derived[2]. Third and perhaps most compellingly, these models have correctly forecast general climate trends with increasing precision over the last two decades, but have shown an enduring tendency to underestimate the magnitude of these trends, especially in the Arctic. Hence, to the extent skepticism is warranted, most should be in the direction of allowing for more drastic effects than these models predict.

The short-term accuracy of model-based forecasts is limited by uncertainties from natural factors that have transient effects on climate. Foremost among these are El Niño-La Niña, the Pacific Decadal Oscillation (PDO) and the Arctic Oscillation (AO), sunspot activity and volcanic eruptions. For example, the last three years have been slightly cooler than the long-term warming trend because the current La Niña phase brings cold water to the surface of the tropical Pacific causing a slight cooling effect on the whole planet, and because the sun is in a quiescent period of sunspot activity that temporarily diminishes its output. Of particular relevance to Alaskan climate is the PDO, which can remain for a decade or two in one of its two phases. These two phases correspond to warm and cold conditions in Alaska during the winter half of the year. This Oscillation shifted to the "Alaska warm" phase in the late 1970s, and was associated with a substantial increase in Alaskan winter temperatures[3]. Over the past few years, there are indications that this oscillation may be returning to its "Alaska cold" phase, which would have the effect of at least partially offsetting the warming arising from increasing greenhouse gas concentrations.

The AO refers to variations in the intensity of atmospheric pressure in the Arctic basin, and operates on a time scale of several years to over a decade. During periods of low pressure, such as have prevailed during the 1980s and 1990s, more warm Atlantic seawater is drawn in to the Arctic and ice export through Fram Strait accelerates, exacerbating ice loss. During high pressure periods, ice loss in the Arctic decelerates. There is also a weak tendency for a colder pattern of winds over Alaska during the low-pressure phase. A re-emergence of the high-pressure phase will tend to warm Alaska, much as the return of the next El Niño event will tend to warm the whole planet above the long-term trend. When the quiescent period of sunspot activity abates, solar output will increase, accelerating these warming trends. As for volcanoes, the particulates injected into the upper atmosphere may lead to planet wide cooling for a couple of years, but the carbon dioxide added is usually negligible in comparison with human emissions (as, for example, the 1992 Mt. Pinatubo eruption that was barely discernable in records of atmospheric carbon dioxide monitoring stations). While these natural perturbations may cause significant discrepancies from climate forecasts on time scales of a few years or even a decade (PDO), they will not likely do so on time scales longer than a decade or two.

Another factor contributing to uncertainty in climate projections is uncertainty in the rate of increasing greenhouse gas concentrations. The future rate of greenhouse gas increases depends on unknown future rates of fossil fuel burning, uncertain rates of uptake by the oceans and terrestrial vegetation, and possibly new approaches to carbon sequestration. Recognizing these uncertainties, the Intergovernmental Panel on Climate Change[4] (IPCC) has provided a set of scenarios of greenhouse gas and aerosol concentrations, ranging from "business as usual" to significant reductions of greenhouse gas release. Since the release of the IPCC report, actual emissions have tracked the high end of the IPCC range. The choice of the scenario has little effect on the projected warming through about mid-century (2050)[4]. However, after 2050, the uncertainty arising from the greenhouse gas scenario becomes larger. By 2100, the projected Arctic (and Alaskan) warming varies by about a factor of two between the low-emission scenario and the high-emission scenario.

Finally, different climate models project different rates and geographical patterns of climate change, adding to the uncertainty in future projections. Some of the differences among models arise from different responses to natural variability (El Nino, PDO and AO). Even when models capture these oscillations, the timing of specific events cannot be expected to correspond across models with natural variations in the actual climate system. A strategy that is being used with increasing success is the compositing (averaging) of model projections for any future time period. The compositing has the effect of reducing the natural variations that are essentially randomly distributed over time in each model, thereby reducing the forecast variability of the composite model.

Marine Impacts

Applied to Alaskan seas, forecasting models[1] based on "business as usual" emissions scenarios[4] indicate that the ecological functioning characteristic of the Gulf of Alaska will expand, whereas that of the Bering Sea will shrink. By about 2050, the subpolar ecosystem of the Gulf of Alaska and southern Bering Sea is forecast to increase modestly by ~14% in area, whereas the highly productive marginal sea ice ecosystem of the rest of the Bering Sea will shrink by ~45%. The productivity per unit sea surface area of these two regions is forecast to increase by 21% and 15% respectively, for an overall increase of total productivity of 31 – 37% in the subpolar ecosystem, but a decrease of 36 – 41% in the marginal sea ice ecosystem. Because the marginal sea ice ecosystem of the Bering Sea is so much more productive than the subpolar ecosystem of the Gulf of Alaska, these changes imply a net loss of productivity overall.

Forecasts for the Arctic Ocean are not available owing to scant data for the region, exacerbated by the unforeseen large sea ice losses over the last two years, but it seems likely that most of the Alaskan Arctic shelf will shift from a light- to a nutrient-limited system during spring and summer, with modest increases in productivity except north of the Bering Strait, where increases may be substantial.

These ecosystem changes will continue to put pressure on organisms such as shellfish dependent on food webs associated with the seafloor, and favor mid-water fishes such as pollock in the Gulf of Alaska and the Bering Sea, and Arctic cod in the Arctic Ocean. They will also put pressure on cold-adapted species such as lipid-rich forage fish, because their habitat will continue to contract both in extent and in productivity. Such declines would in turn limit populations of several species of marine mammals and birds that rely on energy-rich prey to provision their young. Ice-dependent marine mammals, including polar bears, walrus and several seal species, face substantial habitat loss as the ice disappears, making them especially vulnerable to the effects of continued warming.

The pace of these anticipated changes in Alaskan seas over the next few decades will be modulated mainly by the PDO and the AO. The previous warm phase made the Gulf of Alaska stormier, warmer and wetter than usual, conditions that are conducive to high marine survival of salmon in the region. It now appears to be reverting to a cold phase, which will tend to obscure the effects of global warming in the Gulf of Alaska and the Bering Sea. Hence, sea ice loss in the Bering Sea will decelerate and winter ice cover may even increase for a few years until overwhelmed by continued global warming, but when the PDO changes again to its warm phase ice loss will be rapid. The AO could change from the warm phase to the cold phase sometime during the next few years, which will temporarily suppress the effects of global warming in Alaska even more. But this respite will quickly disappear when the AO reverts to the warm phase again after another few years.

Ocean acidification refers to another consequence of adding carbon dioxide to the atmosphere that is independent of the effects on warming. Some of the carbon dioxide added from human emissions dissolves into the surface layer of the ocean where it reacts with water to form carbonic acid. Enough has dissolved since the advent of the industrial revolution to cause about a 30% increase in the acidity of the oceanic surface waters worldwide, and are projected to triple by the end of this century under “business as usual” emissions scenarios. Increases of this magnitude will likely eliminate important components of the food web in the Gulf of Alaska, threaten some cold water corals in the Bering Sea, and may adversely impact commercially and economically important shellfish such as euphausids, crabs and shrimp. In addition, so little is known about how marine ecosystems may respond to acidification that serious unforeseen disruptions would not be surprising.

Terrestrial Impacts

The broadest impacts of climate changes in the terrestrial portions of Alaska will result through consequent effects of thawing permafrost and melting ice[5]. As the climate differentially warms in summer and winter, the permafrost will become warmer, and the active layer (the layer of soil above the permafrost that annually experiences freeze and thaw) will become thicker. These simple structural changes will affect every aspect of the surface water and energy balances. As the active layer thickens, there is greater storage capacity for soil moisture, and greater lags and decays are introduced into the hydrologic response times to summer precipitation events. When the frozen ground is very close to the surface, the stream and river discharge peaks are higher and the baseflow (low discharge rates that occur in rivers between storms or in winter) is lower. As the active layer thickens and the moisture storage capacity increases, the lag time of runoff also increases. This has significant impacts on large and small scales. The timing of stream runoff will change, reducing the percentage of continental runoff released during the summer and increasing the proportion of winter runoff. As permafrost becomes thinner and is reduced in spatial extent, the proportions of groundwater in stream runoff will increase as the proportion of surface runoff decreases, increasing river alkalinity and dissolved solids.

Other important impacts will occur due to changing basin geomorphology. Currently the drainage networks in Alaskan watersheds are quite immature as compared to the more well-developed stream networks of temperate regions. These stream channels are essentially frozen in place because the major flood events (predominantly snowmelt) occur when the soils and streambeds are frozen solid. As the active layer becomes thicker, there will be significantly increased sediment loads delivered to the ocean. Presently, the winter ice cover on the smaller rivers and streams ($<\sim 10{,}000\ km^2$) are completely frozen from the bed to the surface when spring melt is initiated. However, in lower sections of the rivers there are places where the channel is deep enough to prevent complete winter freezing. Break-up of the rivers differs dramatically in these places where the ice is not frozen fast to the bottom. Huge ice chunks are lifted by the flowing water, chewing up channels bottoms and sides and introducing massive sediments to the spring runoff. Such increased sediment loads may affect coastal water properties, estuary productivity, contaminant transport, and a host of other marine processes.

As the air temperatures become higher, the active layer becomes thicker. Even if precipitation increases, surface soils will likely become drier. The Arctic is described in many basic geography textbooks as a desert due to the low precipitation rates; however, it is a desert that frequently looks like a bog as the ice-rich permafrost near the surface prevents infiltration of surface soil moisture to deeper groundwater. If the active layer thickens to the point where a talik (an unfrozen layer above the permafrost, but below the seasonally frozen soil) forms, then soils may drain internally throughout the winter leaving the surface significantly drier. As the surface soils dry, the feedbacks to local and regional climate will change dramatically, with particular emphasis upon sensible and latent heat flux. Drier soils will also influence the rate and intensity of tundra fires, providing more positive feedback mechanisms by creating darker surfaces that absorb more solar radiation and by releasing large quantities of carbon from peat soils. This may impact recycling of precipitation, our capabilities to predict weather and may indeed increase variability of many processes and variables, including convective storms.

Additional impacts of climate changes in the terrestrial portions of Alaska will result through climate-vegetation-disturbance interactions – particularly within the boreal biome. The potential importance of the boreal forest in the global climate system has been stressed repeatedly. Strong feedbacks to the climate system associated with changing land-surface energy exchange and carbon dynamics are likely to reveal themselves as the boreal forest responds to future warming. The boreal forest biome covers 15% of the land surface of our planet and contains around 40% of the Earth's terrestrial carbon, an amount equivalent to about half of the carbon currently in the atmosphere. This forest occupies the region of the Earth predicted to experience the earliest and most radical effects of anthropogenic warming. [6] As tree line moves poleward, the advancing boreal forest vegetation will change surface energy budgets and carbon budgets of the Arctic land surface.[7,8] Changes in the boreal forest will feedback to global climate.

On a more local scale, changes in the functioning of the boreal forest have the potential to alter its ability to deliver key ecosystem services to residents of the Arctic.[9] Boreal forest ecosystems provide habitat and subsistence resources to a diversity of indigenous cultures, members of whom stand to be significantly affected by major changes in the composition, distribution, and functioning of the boreal forest. Changes in the fire season, in particular, are likely to have large socio-economic impacts within the Arctic.[10]

Climate, fire, and vegetation in the boreal forest of Alaska interact on multiple spatial and temporal scales. Duffy et al. (2005)[11] found evidence linking the PDO to several weather variables that are directly related to the annual area burned in Interior Alaska – the region of Alaska where approximately 97% of cumulative area burned since 1950 has occurred. The most likely, ultimate mechanisms for these linkages are shifts in atmospheric circulation. One mechanism that can explain these short-term weather anomalies is impacts of the PDO on the location and intensity of the Aleutian Low.[12,13] A shift from cool to warm phase of the PDO typically results in the Aleutian Low intensifying and moving southeast of its former position. This shift causes a more easterly (less southerly) flow component across Interior Alaska and is associated with regional summer droughts.

Preliminary results from statewide simulations of future fire regimes and associated vegetation dynamics identify consistent trends in projected future fire activity and vegetation response. The simulation results strongly suggest that boreal forest vegetation will change dramatically from the spruce dominated landscapes of the last century. While simulation results identify a range of potential responses between the different climate scenarios, all model results show a shift in landscape dominance from conifer to deciduous vegetation within the next 50 years.

The model simulations suggest a general increase in fire activity through the end of this century (2099) in response to projected warming temperatures and less available moisture. Changes in the projected cumulative area burned suggest the next 20-30 years will experience the most rapid change in fire activity and the associated changes in vegetation dynamics. Future fire activity suggests more frequent large fire seasons and a decrease in magnitude and periodicity of small fire seasons. Large differences do exist among climate scenarios providing multiple possible futures that must be considered within the context of land and natural resource management.

Increased deciduous dominance on the landscape will contribute to a probable change in the patch dynamics between vegetation types and age. The large regions of mature unburned spruce will likely be replaced by a more patchy distribution of deciduous forests and younger stages of spruce. The simulation results suggest that this change will occur over the next few decades, in response to simulated increases in fire activity, and will then reach an equilibrium stage where the patch dynamics may self-perpetuate for many decades if not centuries. In spite of the shift towards less flammable age classes and towards deciduous species, the simulation results indicate that there will be more frequent fires burning; resulting in an overall increase in acres burned annually. These two results appear to drive the simulated change in landscape dynamics where increased landscape flammability, driven by climate change, modifies landscape-level vegetation (i.e., fuels) distribution and pattern, which in turn feeds back to future fire activity by reducing vegetation patch size (i.e., fuel continuity).

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Section II. Adaptations in Human Uses of Alaska's Natural Systems

The Natural Systems Technical Working Group is recommending the following nine adaptations in human uses of Alaska's natural systems to address expected effects of climate change. The average ballot score is provided, reflecting the results of balloting using the criteria listed in Attachment 1. The following catalog provides additional information regarding each of these adaptation options.

Option No. (see Catalog)	**Adaptation Option**	**Average Ballot Score** (of 30)

NS 5.2 Comm Fish	Incorporate possible climate change impacts on fishery resources into commercial fisheries policy development and management plans.	24.9
NS 3.1 Wildland Fire	Modify wildland fire policies in the context of climate change (appropriate responses to wildfires in forests and tundra in a warmer climate). Provide information, technical assistance and funding to enable communities to develop and implement wildland fire protection plans appropriate to a warmer climate.	24.4
NS 7.1 Water Cons.	Establish policies and take actions to identify and protect watersheds needed to meet the estimated future water needs, under conditions of climate change, of Alaskan communities, and to reserve water in streams to ensure that instream flows are adequate for productive fish habitat.	23.6
NS 4.1 Invasives	Support establishment of an all-taxa Alaska Invasive Species Council and invest in the staffing, policy and program development needed to implement a statewide strategic plan of action to address invasive and erupted plants, insects, pathogens, and marine invasives.	22.9
NS 6.1 Fish & Wildlife	Revise the State's fish and wildlife management laws, policies and practices to allow for the *timely, coordinated and effective* adjustment of state and federal fishing and hunting regulations to adapt to effects of climate change.	22.9
NS 6.2 Fish & Wildlife	Coordinate state and federal management to minimize or slow the loss of species, where mitigation of climate change effects is feasible, and ensure that information and tools are in place for adaptive management to be implemented.	20
NS 5.1 Comm Fish	Invest in and support measures to assist commercial fishing communities and user groups in effectively adapting to changes in the commercial fishing industry brought about by climate change.	19.7

Option No. (see Catalog)	**Adaptation Option**	**Average Ballot Score** (of 30)
NS 2.1 Forestry	Invest in economic development and infrastructure to attract and facilitate development of industrial capacity at appropriate scales to use insect- or fire-damaged timber, and underutilized and new sources of wood biomass.	20
NS 1.1 Agriculture	Support and expand sustainable agriculture in Alaska at the local level: A. Invest in and support "Alaska Grown" local agricultural production, to achieve sustainable and economical food production that will improve food security for local communities. B. Strengthen intrastate transport and marketing of Alaskan agricultural products, to improve food security for Alaska. C. Expand Production - Invest in and support the production of food and the expansion of markets (within Alaska and outside of Alaska) for products that can be produced economically in Alaska under changing climatic conditions.	12.7-16.6

NS-1: Agriculture

AGRICULTURE – IMPACTS DUE TO CLIMATE CHANGE

Context for Recommendations: Changing climatic conditions and increased costs of transportation in the future may necessitate shifts in Alaskan's food supply, as costs of imported food escalates and the abundance and distribution of local subsistence foods (fish, wildlife, native plants) changes. In-state agricultural production can help provide a sustainable food supply for Alaskans. State policies and programs need to support expanded, sustainable local agricultural production to meet community food needs, enhance intrastate use of Alaskan agricultural products, and increase production of products that are favored by changing climatic conditions.

Current impacts – increasing 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 pathogens 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 feasible in more northerly locations; greater increase in invasive species, pests, and pathogens; more water deficits (in Fairbanks, under low emissions scenario, almost a doubling by 2071); potential for increased animal husbandry.*

*Reference: Juday, G. P., Barber, V., Duffy, P., Linderholm, H., Rupp, S., Sparrow,S., Vaganov, E., and Yarie, J. 2005. Forests, Land Management, andAgriculture. Chapter 14 (pp 781 - 862) IN: Symon, C., Arris, L., andHeal, B. (eds.) Arctic Climate Impact Assessment. Cambriodge University Press.

Option No.	Adaptation Action / Policy Option (includes regulatory and management options)	Extended Actions	Parties involved in implementation	Expected Outcomes / Notes/Comments	AVG BALLOT SCORE (of 30)
NS 1.1 Sustainable Agriculture at Local Level	Support and expand sustainable agriculture in Alaska, at the local level, including: A. Invest in and support "Alaska Grown" local agricultural production, to achieve sustainable and economical food production that will improve food security for local communities.	Examples of extended actions: • Develop and implement State agricultural strategic plan for sustainable local agriculture. • Provide grants or start-up funding for local / community food production, processing and storage. • Increase public awareness of local suppliers of shellfish, livestock and produce. • Through land use planning, zoning and tax structure, identify and retain lands suitable for agricultural development near communities.	State of Alaska Alaska Muni. League Municipalities AFN Univ. of Alaska NRCS Farm Service Agency Farm Bureau Master Gardeners Alaska Shellfish Growers others		12.7-16.6

	B. Strengthen intrastate transport and marketing of Alaskan agricultural products, to improve food security for Alaska.	Examples of extended actions: • Review and address laws, policies, or regulations that are an impediment to intrastate transport of Alaskan products. • Increase public awareness of Alaskan suppliers of shellfish, livestock and produce.	State of Alaska Farm Bureau TSA		
	C. Expand Production - Invest in and support the production of food and the expansion of markets (within Alaska and outside of Alaska) for products that can be produced economically in Alaska under changing climatic conditions.	Examples of extended actions: • Conduct active research and development into products, technologies and best practices for Alaskan agriculture. • Develop and improve food crops suitable for Alaska's climate. Examples include varieties of short-maturing grain, grain able to winter over, shorter season canola and other oilseeds. • Conduct a critical review and update of State laws, regulations, and policies to promote agricultural sustainability. • Request alteration of USDA definitions of food production so that Alaskan agricultural products are considered food (rather than horticulture) and are eligible for USDA subsidies.	State of Alaska University of Alaska Plant Materials Center Farm Bureau NRCS		

NS-2: Forestry

FORESTRY – IMPACTS DUE TO CLIMATE CHANGE

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.*

Impacts on forestry: Current impacts – loss of some available trees due to fire, disease, and climate stress. Insect- and fire-damaged trees have potential use as heating fuel in rural communities. *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.*

Option No.	Adaptation Action / Policy Option (includes regulatory and management options)	Extended Actions	Parties involved in implementation	Expected Outcomes / Notes/Comments	AVG. BALLOT SCORE (of 30)
NS 2.1 Use of climate-damaged wood biomass for fuel/energy	Invest in economic development and infrastructure to attract and facilitate development of industrial capacity at appropriate scales to use insect- or fire-damaged timber, and underutilized and new sources of wood biomass.	Examples of extended actions: • Develop capacity to produce wood pellets, wood chips, or fuel wood from damaged timber near urban and rural communities. • Use as fuels for heating the biomass generated from hazard fuel treatment projects to reduce fire risk to communities. • Provide incentives to support installation of high-efficiency (low pollution) wood heat/power systems for rural public buildings. • Research available types of harvesting equipment for small diameter timber and biomass to facilitate acceptance and use by local commercial contractors. Demonstrate use; establish lease program. • Calculate sustainable annual harvest under climate change conditions for ecologically acceptable timber sources. • Conduct demonstration wood biomass projects by UAF and State agencies. • Use hardwood species, birch, aspen, willow that have a	Alaska Division of Forestry; other State agencies; UAF	Expected Outcomes: Offers an element of mitigation via use of carbon neutral wood fuels. Addresses high cost of fossil fuels. Offers economic opportunities. Notes: Electrical generation could be considered by stand-alone wood systems, or co-firing with coal at utilities, but this is more complex than relatively simple space heating wood systems. This will require Alaska-based training to develop technologies that are	**20**

		large under-utilized allowable cut or no current commercial use for biomass fuels. • Explore alternative harvest strategies such as bringing firewood to access points that are easily accessed by the public.		appropriate for Alaska, for example the capacity to efficiently harvest small-diameter woody biomass.	

NS-3: Wildland Fire

WILDLAND FIRE – IMPACTS DUE TO CLIMATE CHANGE

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 but potential increase in food availability for other species, such as moose. *Future projections – greater fire impacts including possibility of fires in southeast Alaska*.

Tundra fires: Current impacts – larger and more severe tundra fires (almost 250,000 acres in 2007); modification of tundra habitat from wildfires. *Future projections – more tundra fires combined with change to climate conditions favorable to shrub or forest growth may result in loss of habitat for tundra-dependent species (e.g., slow response of lichen regeneration for caribou range).*

Option No.	Adaptation Action / Policy Option (includes regulatory and management options)	Extended Actions	Parties involved in implementation	Expected Outcomes / Notes/Comments	AVG. BALLOT SCORE (of 30)
NS 3.1 Wildland Fire Management	Modify wildland fire policies in the context of climate change (appropriate responses to wildfires in forests and tundra in a warmer climate). Provide information, technical assistance and funding to enable communities to develop and implement wildland fire protection plans appropriate to a warmer climate.	Examples of extended actions: • Examine strategic application of wildland fire use to break up extensive areas of fire-prone black spruce forest, in part by creating fuel breaks of less flammable early successional post-fire vegetation that connects to other natural fuel breaks such as wetlands. • Evaluate change from Limited to Full suppression response in tundra environments. • Engage the public in wildland fire prevention, fire protection, and risk mitigation programs near communities. • Engage rural communities more actively in deciding and implementing fire management and fuel management activities near their communities.	Alaska Wildland Fire Coordinating Group; Alaska Division of Forestry; Stakeholders (local governments, structure and volunteer fire departments, Native organizations, agencies, others)	Expected Outcomes: Updated wildland fire policies and practices that incorporate anticipated effects of climate change on environmental response to fire. Spinoff benefits would depend on fire responses adopted: a) Fuel management projects in boreal forest could improve habitat for moose and other wildlife and generate biomass fuels. b) Reductions in wildfire would reduce CO_2 emissions and smoke/health impacts. c) Reduction in tundra fires could reduce negative	**24.4**

				impacts on caribou and other wildlife and potentially reduce negative effects of fire on hunting access or activities. 2. More active involvement of rural communities in deciding and implementing fire management and fuel management activities near their communities: a) Reduced risks to life and property, and reduced health risks and economic costs related to smoke events. b) Spinoff benefits could include habitat improvement for moose and other wildlife. Notes: Development of a community wildfire protection plan has been funded by the Immediate Action Working Group for Koyukuk.	

NS-4: Invasive or Erupted Species and Pathogens*

(*pathogens that may affect Alaskan flora and fauna)

Context for Recommendations: Invasive species threaten every Alaskan ecosystem, from near-shore marine environments to arctic tundra. Invasions by non-native species have the potential to damage important economic sectors (fisheries, forestry), as well as to alter fire cycles and subsistence opportunities. If allowed to become wide-spread, invasive species can cause gradual and irreversible degradation of entire ecosystems. Therefore, it is the Natural Systems TWG's recommendation that the State of Alaska become a committed and active partner in a variety of well-established invasive species efforts already underway around the state.

Currently, a wide network of agencies and organizations collaborate on a voluntary basis to address the growing problem of invasive species in Alaska. The least active member of this network has been the State of Alaska. The State of Alaska needs to require involvement in invasive species issues from State agencies and employees at all levels. A second important step is to support the formation of the Alaska Invasive Species Council, and act on its recommendations.

Invasive and eruptive forest insects and pathogens: Current impacts – greater incidence of existing destructive forest insects such as spruce bark beetle, which resulted in significant tree mortality over four million acres of land in south-central Alaska; as well as other outbreaking insects including larch saw fly (killed 90% of larch near Fairbanks), birch leaf miner, aspen leaf miner, and spruce bud worm. Widespread alder dieback is occurring in SC and Interior Alaska; cause is not clear. *Future projections – native insects and pathogens may be more likely to go into outbreak mode, we anticipate increased detections of forest insects and pathogens new to Alaska, possibly leading to widespread infestations and ecosystem degradation.*

Invasive insects and pathogens in shipments: Current impacts – exotic insects are being brought into Alaska on and in shipping containers every year, including recent arrivals of the Asian gypsy moth and the rosy gypsy moth. *Future projections – more exotic insects and pathogens will be detected in Alaska with possible widespread infestations and ecosystem degradation.*
Invasive plants: Current impacts – numerous highly invasive plant species have either become established in Alaska (reed canarygrass, Japanese knotweed, Canada thistle, birdvetch) or are being detected in small populations in or near the state (spotted knapweed, leafy spurge, purple loosestrife, garlic mustard). The distributions of most of these are limited to areas along the road systems, but a few have begun to move onto river floodplains, into burned habitat, and into undisturbed forests. *Future projections – increased invasive plants both on and off the road system, as invasives gradually become dominant the result is irreversible ecosystem degradation.*

Invasive species in freshwater systems: Current impacts – little is known about the status of Alaska's rivers and lakes with respect to invasive species. At present, two invasive wetland plants (reed canarygrass, purple loosestrife) are known to occur here. Pike and red-legged frogs are two non-native aquatic species that are spreading in Alaska. *Future projections – greater threat in numbers, types, and abundance of injurious invasive species, with the potential to impact freshwater ecosystems. One highly invasive aquatic species that isn't in Alaska yet but is likely to arrive here soon: Eurasian water milfoil.*

Marine invasives: Current impacts – the catch of Atlantic salmon in Alaskan waters (presumably from fish farms off British Columbia), ballast water discharge, the migration of invasive tunicates and the European green crab north along the coast of British Columbia all indicate that invasive organisms are arriving in Alaskan marine environments. The potential exists for species replacement and widespread ecosystem degradation. *Future projections – greater threat in numbers, types, and abundance of injurious invasive species, with the potential to impact marine ecosystems.*

Option No.	Adaptation Action / Policy Option (includes regulatory and management options)	Extended Actions	Parties involved in implementation	Expected Outcomes / Notes/Comments	AVG. BALLOT SCORE (of 30)
NS 4.1 State commitment to invasive species control	Support establishment of an all-taxa Alaska Invasive Species Council and invest in the staffing, policy and program development needed to implement a statewide strategic plan of action to address invasive and erupted plans, insects, pathogens, and marine invasives.	Examples of extended actions: • Provide agencies with new and adequate funding for these efforts. • Conduct training for natural resource and DOT/PF employees in recognizing invasive marine organisms, plants, insects and pathogen outbreaks. • Invest in staff required for invasive species detection, control and response; and enforcement of measures to control invasives. • Invest in early detection / rapid response (EDRR) for insect infestations. • Support local control/response efforts. • Control/respond to invasive on public lands and at public facilities. • Support development of non-invasive plant material supplies. • Provide effective regulatory controls. • Provide public education and outreach regarding identification, control and response to invasives.	Alaska Invasive Species Working Group	The Alaska Invasive Species Council will be a mechanism for cooperation, communication and collaboration, and will develop a statewide strategic plan of action. State representatives will include ADF&G, DNR, DEC, ADOT&PF and University of Alaska. Council will review current funding mechanisms and levels for state agencies to manage invasives on land and water under their authority. Council will establish criteria for prioritization of invasive species response actions.	22.9

NOTE: The following very specific list of actions was identified by the TWG during compilation of this section of the Natural Systems Adaptations Catalog:

Cross-Spectrum

1. Support Alaska Weed and Pest Coordinator Position in Alaska Division of Agriculture, and preparation of a strategic plan to address weeds and pests, in coordination with the University of Alaska Cooperative Extension Service. (Position is responsible for coordinating State response to invasive plans in all settings and insects in agricultural settings. Need active participation of all affected state agencies (e.g., DOT/PF, DNR) in weed and pest strategic planning process. Support and advance the policy recommendations of the plan.)
2. Work with the government of Canada through appropriate diplomatic channels to encourage the control and eradication of a variety of weeds, insects, aquatic nuisance species, and marine invasives (e.g. spotted knapweed, *Spartina*, green crab) in British Columbia, the Yukon, and NWT to reduce their spread towards Alaska.
3. Establish a dedicated plant/wood products quarantine inspector with regulatory authority. (Currently, the only plant/agricultural materials entering the state that are inspected in any way are potatoes and tomatoes. The inspection program should include all nursery materials and Christmas trees entering the state as well as inspection of wood shipping containers, pallets and wood products for exotic wood-borers.)

Invasive Plants

4. Refill the integrated vegetation management position at the Alaska Dept. of Transportation and Public Facilities (vacant since Jan. 08) Expect position to work closely with Division of Agriculture Weed and Pest Coordinator, particularly in arena of road maintenance operations.
5. Support Alaska Division of Mining, Land and Water in developing a weed-free gravel pit certification program. (Encourage that gravel used by ADOT&PF and in other state construction projects come from certified pits only.)
6. Support ADNR in developing modern and comprehensive noxious weed regulations. (Current regulations are inadequate, serving only to limit the amount of contamination by 12 species in seed sold in state. Model legislation on that in western US.)
7. Provide consistent State support for local Cooperative Weed Management Area (CWMA) efforts. (Establish small-grants program to assist in funding grass-roots, volunteer-run organizations.)
8. Recognize UAF for Weed Task Force's management plan for significant invasive plan infestations on UAF campus. (Use these projects as a starting point from which to address and manage invasive plant infestations around all state-owned public facilities.)
9. Encourage Alaskan agricultural producers, greenhouses and nurseries to enter the native-plants-as-revegetation-materials market. (Initiate a small grants program to support and expand such production. Currently, there is more demand for native plan seed and containerized native plans for use in revegetation projects than can be met by the few existing growers.)
10. Active participation by State of Alaska (Division of Ag and DOT/PF) in eradication of highly invasive plant species. (Alaska still has the opportunity to eradicate a number of highly invasive plant species with very limited distributions in the state (e.g., garlic mustard, spotted knapweed, purple loosestrife).

Invasive Insects and Pathogens in Forest

11. Establish a dedicated position and consistent dedicated funding to focus on forest insect EDRR (early detection, rapid response.) (Currently, there is no dedicated state funding for detection of either exotic or native-outbreaking insects in Alaska's forests.)
12. Establish a new position in the Division of Forestry focused on introduced forest pathogens. (There is no forest pathology expertise in the Alaska Division of Forestry or elsewhere in state government.)

Marine Invasives

13. Work with shipping industry to adopt treatment technologies now available to reduce impacts of ballast water in Alaska. Consider state regulation (such as in WA and OR) to address ballast water release. (Has potential to transfer pathogens (e.g., Vibrio outbreak). Implications to health of shellfish industry and human health.)
14. Support statewide tunicate/fouling organism monitoring. Develop tunicate/fouling organisms response plan, to address potential for a highly invasive species be found in state marine waters.
15. Support outcomes of an ADF&G funded green crab response plan (funding already dedicated.) (Monitor green crab statewide. Work with mariculture industry to educate and monitor for occurrence. Use habitat suitability modeling to identify potential invasion hot spots.)
16. Fund research to determine salmon pathogens that could be transported to Alaska by Atlantic salmon; develop an anticipatory action plan.
17. Support outcomes of a NMFS-funded Spartina response plan (funding already dedicated.)
18. Determine if State action should be taken to address hull fouling as a vector to Alaska. (Evaluate results of research funded by Prince William Sound Regional Citizen's Advisory Council for possible follow-up on additional research, education or best management practices.)
(If Invasives Species is recommended to the AAG as a high priority adaptation option, this detailed list could also be incorporated into the "white paper" presented to the AAG.)

NS-5: Commercial Fishing

Context for Recommendations: Commercial fisheries is one of the State's primary economic sectors supporting strong, diversified coastal communities, therefore the state should invest in, determine and implement the actions necessary to adapt to changes in the commercial fishing industry brought about by climate change.

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; more frequent observations of exotic 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 *– potentially broad scale changes in species distributions, range extensions/contractions, opening up of the northern Bering Sea and Arctic Ocean to the possibility of commercial fishing; increased abundance of exotic species with possible long term changes in distributions; need for new gear; continued declines in benthic species; potentially more dangerous fishing conditions due to greater storms, less predictable weather, and the need to travel farther distances; potential for impacts caused by invasive species and pathogens in freshwater and marine environments. Fisheries management must adapt to changing species abundances and distributions. Other potential changes include increased rationalization of other fisheries. Likely economic impacts on coastal community – mostly negative, some positive.*

Aquaculture: *Future projections - Hatcheries can mitigate climate change effects, but once fish are released they are subject to same stressors as wild counterparts. For farmed shellfish, warmer water and abundant microalgae blooms improve growth; however, oceanographic conditions that generate blooms are complex and have a profound affect on ocean productivity. Alaskan farms are located in areas with high ocean circulation; during warmer periods reduced circulation results in decreased growth. Increasing harmful algal blooms and human pathogens associated with high temperatures have recently resulted in cessation of live shellfish sales. Introduction of exotic species such at colonial tunicates can destroy the aquaculture operations for an entire region.*

Option No.	Adaptation Action / Policy Option (includes regulatory and management options)	Extended Actions	Parties involved in implementation	Expected Outcomes / Notes/Comments	AVG. BALLOT SCORE (of 30)
NS 5.1 Community and User Group Adaptation to Commercial Fishing Changes	Invest in and support measures to assist commercial fishing communities and user groups in effectively adapting to changes in the commercial fishing industry brought about by climate change.	Examples of extended actions: • Provide socio-economic information about changes in commercial fisheries to communities on a regular basis, to allow them to prepare and respond. • Invest in and support potential new fishing opportunities (e.g. develop new harbor capacity, improve forecasting, develop additional processing and transportation options) • Work with user groups to develop fuel cost transition plan. • Conduct education and outreach for new entrants into commercial fishing industry. • Evaluate and pursue allocation and permit responses for communities that need new fishery opportunities due to loss of other food sources.	ADFG, NMFS, ADCCED, Univ. of Alaska, ISER, ADOT&PF, Communities, User groups, National Weather Service, AK Sea Grant Marine Advisory Program		19.7

		• Develop new fishing gear to target new species and avoid bycatch species.			
NS 5.2 Adaptation of State commercial fishery management	Consider climate change impacts on species abundance and distribution when assessing fish stocks and developing commercial fisheries policy and management plans.	Examples of extended actions: • Adopt a State Arctic Salmon Management Plan that includes a precautionary approach to establishment of new commercial fisheries in the Arctic, as has already been adopted by the North Pacific Fishery Management Council (NPFMC) for federal waters. • Develop more responsive fish stock assessment tools, to address climate change information and adaptation needs. • Preserve a broad range of management options, or consider the need for new management options, for responding to changing fishery conditions. • Specifically consider potential ecosystem impacts when making decisions on commercial fisheries.	ADF&G, AK Board of Fisheries, NMFS, NPFMC, Fisheries enforcement officials, Communities, User groups	State management policy and plans are broadly responsive to changing patterns of species distribution and abundance. Specifically recognizing climate change as a forcing factor will assist managers in crafting timely and appropriate responses.	25

NS-6: Fish and Wildlife Management*

(*Note, commercial fishing addressed in Section NS-5)

Context for Recommendations: The harvest of fish and wildlife for subsistence and sport harvest is extremely important to Alaskans. For Alaska's tribes and many of its communities, subsistence harvests are interwoven with community culture, health, economy and other attributes. Sport hunting is an important economic sector in Alaska, as well as an element of the Alaskan way of life. It is essential that Alaska's fish and wildlife regulatory structure be poised to adapt to changes in fish and wildlife abundance, distribution and health brought about climate change that may affect harvests.

Decline in traditional subsistence food availability: Current impacts – decline and disease in traditional subsistence foods; 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).*

Impacts to sport hunting: 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).*

Impacts to sport fishing: *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).*

Option No.	Adaptation Action / Policy Option (includes regulatory and management options)	Extended Actions	Parties involved in implementation	Expected Outcomes / Notes/Comments	AVG. BALLOT SCORE (of 30)
NS 6.1 Fish and wildlife harvest regulations	Review State fish and wildlife management laws, policies and practices to improve timely, coordinated and effective adaptation to climate change.	Examples of extended actions: • Allow for regulatory process to respond more quickly to climate change effects. (For example, revise state statute AS 44.62.270, which defines the situations under which "emergency" regulatory changes can be made by the Alaska Boards of Fish and Game to include "an unforeseen, unexpected weather or climate change effect that would restrict a reasonable opportunity for customary	ADF&G, Board of Fish, Board of Game, Federal Subsistence Board, Federal agencies, Alaska State Legislature, Fish and Game Advisory Committees,	Expect outcomes: Ability to respond in a timely and effective manner to a wide range of climate change effects on the use and users of fish and wildlife, such as the need to respond to: - changing wildlife migration	22.9

		and traditional fish and wildlife uses, as defined in AS 16.05.258(1).”) • Improve management tools and adaptive approaches for responding to climate change impacts on fish and wildlife populations and harvest success. • Improve coordination between state and federal management and decision-makers to ensure a consistent and effective response to the complex and important management issues created by climate change.	Regional Advisory Councils, other stakeholders	timing or routes - changes in species diversity, ranges, abundance and distribution - species conversation issues - hunting access and travel safety issues Notes: The successful harvest of fish and wildlife is essential to the economy, health, culture and well-being of many Alaskans, communities and businesses. There seems to be and increase in climatic occurrences that are impacting harvest (e.g., warm, dry fall making it difficult to harvest moose in interior locations; changes in caribou migration). Loss of access to one or more species will cause change in other harvest practices, that must be understood and managed. It is essential that the State have policies, practices and management tools that can adjust fish and wildlife management quickly and effectively, when such change is required.	
NS 6.2 Adaptive fish and wildlife management	Coordinate state and federal management to minimize or slow the loss of species, where mitigation of climate change effects is feasible, and ensure that information and tools are in	Examples of extended actions: • Increase funding and efforts to update the Alaska Anadromous Waters Catalog. • Invest in the management plans, monitoring and			

	place for adaptive management to be implemented.	management actions necessary to respond to climate change effects on both game and non-game species. • Improve coordination between state and federal managers to ensure a consistent and effective response to the complex and important management issues created by climate change.			

NS-7: Water Conservation and Management

Context for Recommendations: Alaskan communities and industry depend on sufficient fresh water for domestic and industrial water supplies, as well as stream flows sufficient to meet the needs for productive fish habitat and for dependable boat transport. The NS TWG therefore recommends that the State of Alaska protect in-stream flows sufficient to meet these needs in watersheds used by Alaskan communities, to the extent possible in a warming climate.

<u>Future projections</u> - *Changing permafrost and hydrology will affect resource development in the North in many ways, including stability of ice roads and their season of use, effects of rain-on-snow events on winter logging, drought effects on forests, and access to thawed soil for mining. As permafrost degrades, soil becomes increasingly permeable to water. When permafrost degrades sufficiently, perched lakes and other surface water sources could disappear for much of the year. These lakes and streams constitute a source of freshwater for many arctic communities. In many cases, communities may not find a groundwater source to replace lost surface water. With less permafrost, rivers will have lower peak flows, possibly limiting navigation of rivers that require high flows for boat travel.*

Option No.	Adaptation Action / Policy Option (includes regulatory and management options)	Extended Actions	Parties involved in implementation	Expected Outcomes / Notes/Comments	AVG. BALLOT SCORE (of 30)
NS 7.1 Watersheds and Instream Flow	Establish policies and take actions to identify and protect watersheds needed to meet the estimated future water needs, under conditions of climate change, of Alaskan communities, and to reserve water in streams to ensure that instream flows are adequate for productive fish habitat.	• Identify water needs of Alaskan communities, both domestic and commercial, using assessment tools such as the Arctic Water Resources Vulnerability Index (AWRVI). • Gather data on hydrologic parameters throughout the state to establish baselines, so the effects of climate change on these parameters (e.g., precipitation, snowpack, and streamflow) can be evaluated. • Review appropriateness of water reservations in areas of greatest change. • In light of projected climate-change effects on future water supply, provide means to protect and maintain community water supplies and productive fish habitat. • Streamline the adjudication process for applications related to community water supplies and reservation of in-stream flow for fish to provide flexibility to adapt to climate change.	ADFG ADNR ADEC	Provides a basis for water planning in Alaska. Provides a systematic look at our existing uses, future uses, climate change, and sets about an informed prioritization process.	23.6

Section III. "Cross-Cutting" Recommendations

Capacity-Building, Education & Outreach

Option No.	Adaptation Action / Policy Option (includes regulatory and management options)	Extended Actions	Parties involved in implementation	Expected Outcomes / Notes/Comments
CC-1 Climate change capacity building	Provide a centralized source of information (e.g., climate projections, accurate mapping), adaptation tools, technical assistance and funding for communities, agencies, organizations and businesses to access to enhance their capacity to respond to climate change.	• Extend and expand the scope of the mini-grant program, and establish other technical assistance and funding sources, to support communities in development of locally-appropriate climate change adaptation plans. (See also NS 3.1 regarding community wildfire protection plans.) • Establish an Alaska Climate Change Action Center at the University of Alaska to provide climate change related expertise, information and technical assistance. • Review the Alaska Coastal Management Act and other laws to determine the need for additional authorities and tools for local communities to use to prepare for and respond to climate change effects. • Improve accuracy and currency of mapping and aerial photographs, to assist communities with planning for adaptation to climate change.		The general goal is to build local capacity to engage in decision-making about how to adapt to climate change. There is currently no mechanism to efficiently share expertise in addressing climate change with the communities, agencies, organizations and businesses that need access to expertise. Locally-appropriate climate change adaptation plans are needed to launch adaptation steps by individual communities. Information-sharing would provide mechanism for communities to learn from approaches that have proven successful in other communities.
CC- 2 Augment and coordinate existing outreach and education	Identify Climate Change as a high priority subject in the State Science Standards K-12. Increase support for and coordination among existing programs and entities that are addressing climate change education in Alaska's schools	• Develop lesson plans and activities that K-12 teachers can use easily to teach about climate change and provide training in climate change education. • Increase support at the University level for course development and delivery related to climate change, including climate change courses targeted at teachers and natural resource managers. • Support the development of outreach materials about climate change that are effective with the general public.		Many existing programs that are addressing this issue should be augmented, including University of Alaska Cooperative Extension Service, Alaska Sea Grant Marine Advisory Program, Alaska Center for Ocean Science Education Excellence, etc.

Emissions Trading

Option No.	Adaptation Action / Policy Option (includes regulatory and management options)	Extended Actions	Parties involved in implementation	Expected Outcomes / Notes/Comments
CC-3 Emissions Trading	Support cap & trade emissions trading with at least some auctioning of allowances. Recycle emissions fees to fund adaptation actions.	• For example, would generate funding streams into existing programs (e.g., Land & Water Conservation Fund); block grants of recycled fees from federal agencies to state agencies, and to communities.		This is a crucial enabling action to generate resources to implement other adaptation actions. Will probably need to be part of national policy. The State of Alaska should advocate that national legislation include both 1) funding of specific adaptation measures vis recycled emission fees, and 2) "block grant" recycling of emission fees to states.

Alaska Climate Change Strategy
Natural Systems Adaptation Technical Working Group

Criteria for Evaluating and Selecting Adaptation Options / Policy Actions to Recommend to Adaptation Advisory Group

1. *Significance*:
   - Considers the magnitude or extent of the anticipated climate change effects that the option would address. (Can include consideration of the economic or social significance of negative effects, as well as other considerations).
   - Includes consideration of the irreversibility of impacts.
2. *Benefits and effectiveness:*
   - Compares the vulnerability of natural systems to climate change effects if the option is not implemented, to vulnerability if the option is implemented. This difference in vulnerability can be thought of as the primary benefit of the adaptation option or policy action.
   - Ancillary or co-benefits should be considered if the option/action would provide benefits to sectors other than natural systems.
   - This criterion can also include consideration of whether there is a gap in providing the adaptation measure that needs to be addressed by state action (e.g., an adaptation option may be likely to be effective, but is already being adequately addressed through another mechanism.)
3. *Costs:* (NOTE: THIS IS AN "INVERSE" CRITERIA – *HIGH* COSTS SHOULD BE GIVEN A *LOW* RANKING)
   - Addresses whether an option/action is relatively expensive or inexpensive.
   - Includes initial costs of implementation, and may also include costs over time (e.g., operation, maintenance, staffing) and non-economic costs, such as the "cost" of resource value lost if action is not taken.
   - Can the action be afforded over the time required for it to be effective?
4. *Feasibility*:
   - Addresses whether the state can realistically implement the proposed action. Is it within state authority or is it more appropriately the role of the federal government, localities, businesses, etc? Do the necessary

legal, administrative, financial, technical, and other resources exist, and are they available for use on this proposed state action?

- Can the action be implemented within a timeframe that will ensure it can be effective?

5. *Timing*:

   - Assesses whether the action is needed in response to likely immediate vs. longer-term significant impacts. Options that respond to significant impacts already occurring or projected to occur in the near future may be judged to be a more imminent need than those that address longer-term impacts.

   - Includes consideration of the sequence in which effective action(s) must occur. Can this action begin at anytime, or does something else have to happen first? Is this action a necessary precursor to another important action? Does it leverage other programs/activities that requires it to happen at a certain time?

6. *Adaptive Capacity:* (NOTE: THIS IS AN "INVERSE" CRITERIA – IF THE NATURAL SYSTEM HAS *HIGH* ADAPTIVE CAPACITY, SHOULD GIVE A *LOW* RANKING FOR IMPLEMENTATION OF AN ADAPTATION OPTION)

   - Consideration of resilience of the natural system to climate change and the capacity of humans to adapt. Some system components that are more resilient to climate change may require less human adaptation, whereas system components sensitive to climate change may require intervention to enable greater or more rapid human adaptation.