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HEARING ON
THE EFFECTS OF CLIMATE CHANGE AND OCEAN ACIDIFICATION ON LIVING
MARINE RESOURCES

BEFORE THE
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Introduction

Madam Chair and members of the Committee, it is my honor to testify to you this morning. My name is Gordon Kruse. Since 2001, I have been the President's Professor of Fisheries and Oceanography at the School of Fisheries and Ocean Sciences, University of Alaska Fairbanks. Prior to my current position, I directed the marine fisheries research program for the Alaska Department of Fish and Game for 16 years, where I was the lead science advisor to the State of Alaska on state and federal marine fishery management. I have been a member of the Scientific and Statistical Committee (SSC) of the North Pacific Fishery Management Council (NPFMC's) for seven years, including the two most recent years as chair (2005-2006) and the two prior years as vice-chair (2003-2004). I served an additional 11 years as a member of the NPFMC's Crab Plan Team and Scallop Plan Team and co-authored the original crab and scallop Fishery Management Plans. I am the current chair of the Fishery Science Committee for the North Pacific Marine Science Organization (PICES), an international marine science organization involving China, Japan, South Korea, Russia, Canada and the U.S.

Objectives of Testimony

My objectives are to discuss: (1) potential mechanisms and effects of climate change on living marine resources in Alaska, (2) future outlook for these resources and implications for management under continued global warming, and (3) uncertainties associated with gaps in our understanding that require further research.

Importance of Marine Ecosystems off the Coast of Alaska

Alaska is unique in that it is bounded by three large marine ecosystems: the North Pacific Ocean, Bering Sea, and Arctic Ocean (including the Beaufort and Chukchi Seas). These are some of the

world's most productive ecosystems, supporting thousands of marine mammals, millions of seabirds, and trillions of fish and shellfish belonging to hundreds of species.

These Arctic and subarctic oceans provide priceless ecosystem services, including human use. Since before recorded history, Native Alaskans have depended on the bounty of these ecosystems for their very existence. Still today, many of these communities remain as subsistence-based (barter) economies, and their harvests of fish, shellfish, mammals and other resources (e.g., bird eggs, kelp) provide the majority of their diets.

These ecosystems support extremely valuable commercial fisheries that provide both U.S. food security and foreign exports that contribute toward the national balance of trade. More than half of the total U.S. fishery landings come from the waters off Alaska. In 2005, landings from Alaska totaled 5.7 billion pounds, representing 59% of the total 9.6 billion pounds landed in the U.S. (NMFS 2007). While important fisheries occur in the Gulf of Alaska and Aleutian Islands, most of this catch is taken from the eastern Bering Sea, owing to its broad, highly productive continental shelf. In 2005, the nation's top seafood port was again Dutch Harbor-Unalaska, accounting for 888 million pounds of landings worth \$283 million exvessel (before value-added processing). Moreover, seven of the nation's top 20 seafood ports are located in Alaska. The Bering Sea supports the world's largest fishery (walleye pollock), largest flatfish fishery (yellowfin sole), and largest salmon (sockeye) fishery. Other valuable commercial fisheries target a diversity of species of crabs, rockfishes, flatfish (flounders and soles), cod, halibut, herring, and other fish and invertebrates. These same waters provide world-class recreational fishing opportunities for non-resident visitors and Alaskan residents alike for salmon, halibut, rockfish and other species.

Resource Sustainability versus Variability

In their report to the nation, the Pew Oceans Commission (2003) noted that Alaska's fisheries were *"arguably the best managed fisheries in the country. With rare exception, the managers have a record of not exceeding acceptable catch limits set by scientists. In addition, the North Pacific Fishery Management Council and Alaska Board of Fisheries have done more to control bycatch and protect habitat from fishing gear than any other region of the nation."* The sustainability of groundfish, salmon and other fishery resources in Alaska is tied directly to conservative, science-based fishery management.

Nonetheless, there are clear historical cases of overharvest and resultant collapse of living marine resources, even in Alaska – examples include the Steller's sea cow (hunted to extinction in 1768), northern fur seal (1700s – early 1800s and again in the late 1800s – early 1900s), great whales (mid 1800s – mid 1900s), sea otters (mid 1700s – early 1900s), yellowfin sole (1960s), and Pacific ocean perch (1960s – 1970s). Causes of recent declines in Steller sea lions, northern fur seals, shrimp, and king, Tanner and snow crabs are much less clear. Although human effects have been implicated in many of these recent examples and undoubtedly humans have contributed to varying degrees, a large body of scientific evidence has emerged in support of climate change as being primarily responsible for major shifts in the marine ecosystems off Alaska. Environmental variability affecting marine ecosystems occurs over a wide range of time scales; the scales most relevant to most marine animal populations are seasonal to decadal and

longer. Owing to our rather short history (few decades) of research and monitoring of marine organisms in Alaska, much of our outlook for impacts of global warming on marine ecosystems is based upon our understanding of the mechanisms and effects operating on shorter time scales, as summarized below.

Effects of Seasonal Climate Variability on Living Marine Resources in Alaska

Seasonal climate variability is vital to the productivity of temperate, subarctic and Arctic marine ecosystems. In these regions, there is a seasonal “battle” between winds that mix deep, nutrient-rich waters into the photic zone and solar heating that warms the upper layers of the ocean, causing thermal stratification that retains microscopic plants (phytoplankton) in the upper layers of the ocean where they can grow under sufficient light penetration and nutrient concentrations.

In the spring, when solar heating wins the battle, an intense bloom of large phytoplankton occurs, providing large amounts of food to microscopic animals (zooplankton) that, in turn, bloom in abundance. This sequential burst in abundance of phyto- and zooplankton serves as food to higher trophic levels, including the planktonic early life stages (larvae) of many commercially important species of fish and shellfish, as well as adults of some species of planktivorous marine mammals (e.g., humpback whales) and seabirds (e.g., crested auklet). In other words, this spring bloom fuels the engine that supports much of the productivity of marine ecosystems in Alaska. The timing of herring spawning, hatching of red king crab larvae, and outmigration of salmon smolts are tied to this remarkable annual event. As summer progresses, nutrients in the warm upper layers of the ocean become depleted, overall production tends to decline, and other species of small phytoplankton adapted to low-nutrient conditions become prevalent.

In the fall, as winds strengthen and solar heating diminishes, the water column mixes, stability breaks down and a smaller fall bloom may occur. However, phytoplankton are mixed to deeper waters where light levels are too low to sustain net growth and the engine that fuels the marine ecosystem slows down. In winter, productivity is low, but, even at this time of year some species (e.g., some flatfish) have adapted strategies for optimum survival as winter spawners. In the following spring, the cycle is repeated again.

Each species has evolved unique life history strategies to be successful in these seasonally dynamic marine ecosystems. For many species of marine fish and invertebrates, their success depends upon the synchrony in time and space of their early life stages (eggs and larvae) with abundances of suitable food, the abundance (or lack thereof) of predators, and ocean currents that carry them (advection) to nursery areas most amenable to their survival. Likewise, the success of seabird and marine mammal populations depends largely upon the ability of adults to secure adequate prey while feeding their young on rookeries.

Effects of Interannual and Decadal Climate Variability on Living Marine Resources in Alaska

El Niño

Although an understanding of seasonal variability in environmental variables is important toward understanding the strategies by which species thrive within marine ecosystems, it is the year-to-year (interannual) variability in climate and ocean processes that determines how animal populations change over time. One important component of interannual variability that occurs every 2-7 years is El Niño/La Niña, an oscillation of a coupled ocean-atmosphere system in the tropical Pacific having important consequences for weather in the North Pacific and around the globe. Prominent features of an El Niño include the relaxation of the trade winds and a warming of sea surface temperature in the equatorial eastern Pacific, extending along the U.S. west coast into Alaskan waters. Species more typical of subtropical and tropical waters extend their distributions into Alaska during El Niño events. For instance, during the 1997-1998 El Niño, albacore tuna were caught off Kodiak Island and ocean sunfish were observed in the northern Gulf of Alaska (Kruse 1998). Global surface mean temperature anomalies provided by NOAA's National Climate Data Center suggest that El Niños became more intense and more frequent in the latter half of the 20th Century, quite possibly as a manifestation of global warming. Thus, range extensions and first-time sightings of southern species have become more common in recent years.

Beyond the curiosity of such unusual sightings, more far-reaching marine ecosystem changes can be associated with El Niño events. Coincident with the 1997-1998 El Niño, salmon run failures occurred in western Alaskan river systems imposing severe economic and social hardships in some western Alaskan communities (Kruse 1998). A federal disaster was declared by the U.S. President. Also, in 1997, the first-ever massive bloom of coccolithophores (a non-nutritious microscopic phytoplankton covered with calcium carbonate platelets) was observed in the eastern Bering Sea. The bloom was so dense and expansive, that it was easily observed by satellites orbiting the Earth. A massive die-off of short-tailed shearwaters was associated with reduced availability of their preferred prey (euphausiids). Murres, a dive-feeding seabird, produced fewer offspring, likely because dense coccolithophore concentrations obscured their vision and ability to feed. It is important to recognize that these ecosystem effects were likely the product of an unusual combination of El Niño, decadal climate variability, global warming, and other atypical regional conditions. However, this suite of climatic conditions set the stage for repeated coccolithophore blooms in the eastern Bering Sea for half a dozen years after this initial event.

Decadal Climate Regime Shifts

Much marine ecosystem research in Alaska since the 1980s has documented decadal climate variability patterns that have led to regime shifts every 10-30 years. The Pacific Decadal Oscillation (PDO) is one index of such shifts, based on warm-cold patterns of sea surface temperature in the northern North Pacific Ocean. Some have likened the warm phase of the PDO to an extended El Niño situation. For instance, ocean temperatures in the northeast Pacific were

typically warm in the mid 1920s – mid 1940s, cool during the mid 1940s – late 1970s, and warm since then. The opposite pattern was experienced in the northwestern Pacific.

The regime shift of the late 1970s has been particularly well studied. Since the late 1970s, Alaskan waters have experienced more frequent winter storms associated with an intensified Aleutian Low Pressure System, increased freshwater discharge into the Gulf of Alaska, a stronger Alaska Coastal Current (which flows in a counter-clockwise fashion around the gulf), and warmer ocean temperatures. These changes appeared to have altered the flux of nutrients, leading to a marked increase in the biomass of zooplankton in the Gulf of Alaska. Other major ecosystem changes associated with this regime shift include a decline in forage fishes, crabs, and shrimps and increases in the abundances of salmon and groundfish (Anderson and Piatt 1999). Some research supports the hypothesis that declines in a number of populations of marine mammals and seabirds are related to observed shifts in marine food webs (e.g., decline in forage fish) in Alaska. However, as with any complex ecosystem with limited monitoring, the evidence is less than conclusive.

Decadal-scale variability in the extent of sea ice formation has had profound effects on the Bering Sea marine ecosystem. Sea ice forms and melts seasonally spreading from the northern to southern Bering Sea shelf waters. Timing of the spring bloom depends heavily on ice formation and melt. In years of extensive ice coverage, the ice thaws more slowly and melt water stratifies the upper water column with buoyant, low salinity water. If this stratification occurs sufficiently late (e.g., April), then sunlight is adequate at that time of year to cause an early spring bloom near the ice edge. However, there is a dearth of zooplankton in this cold melt water, so much of the phytoplankton sinks ungrazed to the seafloor where it benefits bottom-dwelling (benthic) species, such as clams, crabs and other invertebrates. On the other hand, in years when ice is thin and less extensive, it melts in February or March; the lesser amount of freshwater is inadequate to stratify the water column and sunlight is too weak at that time of year to support a plankton bloom. In such years, the spring bloom is delayed until May or June after the sun has had sufficient time to heat a stratified layer of warmer water. Warmer ocean temperatures at this time of year support growth of the zooplankton community and much of the phytoplankton production is grazed by water column (pelagic) species, such as walleye pollock.

Sea ice in the southeast Bering Sea has declined markedly from covering 6-7 months in the late 1970s to spanning just 3-4 months each winter since the 1990s. As the ice-edge bloom may account for a large fraction of the total annual primary production in the eastern Bering Sea, there is considerable concern that declines in productivity have occurred with reductions in sea ice since the late 1970s. Although long-term records of phytoplankton are lacking, declines in summer zooplankton have been clearly documented in the eastern Bering Sea by the Japanese research vessel *Oshoro Maru* since at least 1990.

Effects of Global Warming on Living Marine Resources in Alaska

Terrestrial Impacts of Global Warming in Alaska

Increases in global air and sea temperatures have been clearly documented since the 1800s. On land, observed changes in Alaska are dramatic and well known, including retreat of nearly all

glaciers, melting of permafrost and associated structural damage to buildings and roads, and increased insect outbreaks (e.g., spruce bark beetle) in coniferous forests and an associated increase in frequency of forest fires. Along the coast of western Alaska, higher sea levels and lack of shore-fast sea ice in winter has led to extensive coastal erosion during storms, prompting the imminent costly relocation of dozens of Native villages.

Climate and Oceanographic Changes with Global Warming

A composite land-ocean index of global temperature provided by NASA shows that temperature changes since the 1880s reflect the combined influences of the two major frequencies already discussed – El Niños (every 2-7 years) and decadal variability (10-30 years) – plus a long-term increase in temperature associated with global warming (≥ 100 years). Because our history of research and monitoring of marine organisms is very short (decades) relative to the century-long time scale associated with global warming, the outlook for living marine resources under continued global warming is based largely upon our rather limited understanding of recent variability and mechanisms associated with those observed changes. The outlook for these marine resources also depends upon the accuracy of future projected changes in temperature, precipitation and winds from climate forecast models.

Based on the working group of the Intergovernmental Panel on Climate Change in 2007, the near-term projection is for an average global increase of 0.2 C per decade over the next two decades. The Arctic has been warming twice as fast as the rest of the globe since the mid 1800s, and this accelerated trend is projected to persist for the higher latitudes into the foreseeable future. Based on these IPCC models, increased precipitation is also very likely in the higher latitudes. High-latitude changes in wind patterns are also projected, but specific details in the projections concerning storm frequency and intensity are somewhat less certain.

Shifts in Species Distribution and Abundance

Each species has its own preferred optimum temperatures within a wider range of temperatures suitable for its growth and survival. With warming ocean temperatures, species at the southern end of their distributions (e.g., snow crabs in the southeastern Bering Sea) are expected to contract, whereas those at the northern ends of their distributions (e.g., Pacific hake in southeastern Alaska) are expected to expand northward.

Increased temperatures may benefit some species and disfavor others. With the warming experienced in the last two decades, in-river temperatures in British Columbia have exceeded 15 C, which causes stress in sockeye salmon, increasing susceptibility to disease and impairing reproduction. Studies have shown that mortality is positively related to temperature and river flow in Fraser River sockeye salmon. Turning back to the poor salmon runs in western Alaska in 1997-1998 mentioned earlier, among other potential causes, anecdotal reports found a high incidence of a parasite, called *Ichthyophonus*. Infected fish did not dry properly when smoked (a common means of preservation by subsistence users) and had white spots on internal organs and muscle. Follow-up studies found that 25-30% of adult chinook salmon returning to the Yukon River in 1999-2002 were infected (Kocan et al. 2003). Many of the diseased fish appear to have died before spawning. The spread and pathogenicity of this parasite is correlated with Yukon

River water temperature in June, which increased from 11 to 15 C over 1975 to 2002 at Emmonak (river mile 24). Such examples of adverse impacts of increasing temperatures on salmon may become more common in Alaska with continued global warming.

Warming temperatures are expected to increase the northward migration of piscivorous predators into the future. Pacific mackerel and jack mackerel, species common to the coast of California, have extended their distributions into British Columbia in recent warm years. The productivity of Pacific mackerel populations is favored during warm years off California. Mackerel compete with and prey on juvenile salmon; reduced survival of sockeye salmon on the west coast of Vancouver Island is correlated with the abundance and early arrival of Pacific mackerel in British Columbia. The impact of mackerel predation and competition with salmon is a concern for Alaska. Mackerel have already been encountered in Southeast Alaska by salmon troll fishermen.

There are additional concerns about the northward extension of other predators, such as spiny dogfish in Alaska. A colleague from the University of Washington and I have an ongoing project to evaluate the evidence for an increase in dogfish abundance, as well as to evaluate the life history and productivity of dogfish and management implications in Alaska. Bycatch of dogfish is an increasing problem to fishermen, particularly in the salmon gillnet and halibut/sablefish longline fisheries in Alaska. On the one hand, dogfish bycatch causes gear damage (gillnet) and hook competition for more valuable species (sablefish and halibut), but, on the other hand, this species could provide new economic opportunities (dogfish supply the fish and chips industry in Europe). Determination of sustainable harvest levels is problematic for this abundant species that has a low rate of annual productivity associated with delayed maturity and low reproductive rate.

In the Bering Sea, the centers of distribution of adult female red king crab and snow crab have shifted to the north since the late 1960s and early 1970s, likely due to increases in bottom temperature (Loher and Armstrong 2005, Orensanz et al. 2004, Zheng and Kruse 2006). The larval stages of both species are planktonic – subject to passive drift. Given the northward flow of prevailing ocean currents and the probable fixed location of juvenile nursery areas, the northward shift of females has most likely adversely affected the ability of these populations to supply young crabs to the southern end of their distribution in recent decades. At the same time, warming ocean temperatures have allowed predators of young crabs, such as Pacific cod, rock sole, and skates, to shift their distributions to the north. So, the young stages of crab not only have to deal with settlement into suboptimal habitats, but they have to navigate the gauntlet of increased predation by groundfish. These two mechanisms may be leading reasons why crabs have generally fared poorly since the late 1970s regime shift. For these same two reasons, crabs may continue to fair poorly under continued global warming. On the other hand, groundfishes like pollock and cod may continue to benefit.

One species that seems to have benefited greatly from conditions since the late 1970s is the arrowtooth flounder, a species at its highest recorded levels of abundance and still increasing. This species is a voracious predator that consumes large amounts of pollock, cod, and other commercially valuable groundfish and shellfish. Unfortunately, the flesh of the arrowtooth flounder has low market value owing to enzymes that degrade the flesh quality. So, future warm

ocean conditions may continue to result in a shift from commercially valuable species, like pollock and cod, to this species, which has low market value.

Other predatory species that may increase in Alaska with continued global warming include seasonal predators, such as albacore tuna. This species would provide new economic opportunities in Alaska, perhaps to the detriment of salmon fisheries.

Restructuring of Ecosystems

Earlier, I discussed the role of sea ice extent on funneling energy to the benthic ecosystem (early spring bloom) or the pelagic ecosystem (late spring bloom). Although the trend since the late 1970s has been toward a late spring bloom favoring pelagic species (such as pollock) in the southeastern Bering Sea, the spring bloom remains largely an ice-edge bloom in the northern Bering Sea, where the ecosystem remains benthic dominated (e.g., clams). This benthic production is essential for a number of charismatic species, such as walruses and spectacled eiders that feed on benthic clams and other bivalves. All, or nearly all, of the world's populations of spectacled eiders overwinter in a small area between St. Lawrence Island and St. Matthew Island in the eastern Bering Sea. In the past decade with an increase in air and ocean temperatures and a reduction in sea ice, there has been a reduction in benthic prey populations and a displacement of marine mammals (Grebmeier et al. 2006). With a commensurate increase in pelagic fishes, the northern Bering Sea is shifting from a benthic to a pelagic ecosystem, posing risks to benthic prey-dependent species of seabirds and marine mammals. This benthic to pelagic trend is expected to increase and expand northward with continued global warming.

Loss of sea ice in the Bering Sea is likely to have major impacts on ice-dependent marine mammal species, such as ring seals and bearded seals. Ring seals excavate caves (lair) under the ice in which they raise their young for protection from the weather and predators. Ring and bearded seals feed on a variety of invertebrates and fishes. Both seals are major components of the diet of polar bears. Polar bears also have the capacity to kill larger prey, such as walruses, a species with seasonal migrations also tied to the advance and retreat of sea ice. Therefore, it seems very likely that the loss of sea ice associated with global warming will have serious impacts on these ice-dependent marine mammals.

Potential for Invasive Species

An additional area of concern under global warming is invasive species. With increasing ocean temperatures, cold thermal barriers to warm-water invasive species may become removed. One key species of concern is the European green crab, a species that is native to the North and Baltic Seas. Unintentionally introduced as an invasive species, the green crab has consumed up to 50% of manila clams in California, and it was blamed for the collapse of the soft-shell clam industry in Maine. This species has the potential to alter an ecosystem by competing with native fish and seabirds. Its recent arrival on the U.S. west coast and potential to expand northward with global warming causes concerns for Alaska with respect to our Dungeness crab fishery and aquaculture farms for oysters and clams.

Changes in Seasonal Production Cycle

Increased temperatures may result in earlier stratification, perhaps advancing the timing of the spring bloom. In such case, the continued success of some species depends upon their ability to spawn earlier so that their early life history stages continue to match the spring bloom. Additionally, greater heat in the ocean may lead to prolonged summer-like conditions favorable to small phytoplankton that thrive in low nutrient conditions, including some phytoplankton species that produce toxins, such as paralytic shellfish poisoning. Food chains based on small phytoplankton (typical of summer) tend to be less productive than those based on large phytoplankton (typical of the spring bloom), because they require more steps of energy conversions along the food chain to support upper trophic level species, such as seabirds, marine mammals, and commercially important fish including cod and halibut. So far, this seasonal cycle outlook is based solely upon increased temperatures; other important considerations are the forecasted future changes in storm frequency and intensity. If greater storminess in the Gulf of Alaska and Bering Sea is associated with global warming, then the increased mixing could somewhat compensate for the tendency for increased stratification caused by warmer temperatures, perhaps resulting in little change in the timing of the spring bloom. However, in such case, given the temperature control of the rate of many physiological processes (including reproduction) of cold-blooded marine fish and invertebrates, a challenge for many species will be to maintain current spawning timing despite warming temperature conditions.

Ocean Acidification

As greenhouse emissions continue to increase, the ocean soaks up more and more CO₂, which when dissolved in water, becomes carbonic acid. Such increases lower the pH of seawater, causing a critical concern for species with calcium carbonate skeletons. Preliminary results of studies in Alaska indicate that declining seawater saturation of calcium carbonate induced by ocean acidification may make it more difficult for larval blue king crabs to harden their shells (J. Short, NMFS, Auke Bay Laboratory, pers. comm.). Juvenile king crabs had substantially increased mortality, slower growth, and slightly less calcified shells when exposed to undersaturated seawater conditions projected for their rearing habitat within the coming century in the North Pacific Ocean. These preliminary results indicate that continued increasing carbonation of the ocean surface layer as a result of increasing atmospheric CO₂ may directly affect recruitment of commercially important shellfish. Other witnesses on this panel have outstanding expertise on ocean acidification and will speak in much greater detail on this topic.

Management and Economic Implications

One need not look further than the Bering Sea pollock fishery in 2006 for an example of the sort of management implications expected under global warming. During the B (fall) fishing season, pollock were farther north and west than normal. Diesel fuel prices were high. The at-sea (factory trawler fleet) sector has the ability to conduct 7-10 day fishing trips and a byproduct of their fish harvests is fish oil, which they burn in their boilers and generators. On the other hand, smaller shore-based vessels only have capacity for 2-4 day trips and they cannot produce fish oil. The northward shift of pollock, typical of expectations under global warming, had relatively small impact on the at-sea sector, but had significant adverse impacts on the shore-based fleet,

owing to reduced access to the resource and increased operational costs. Under northward shifts in fish resources, the shore-based fleet will need to shift to a mothership-type fishery or will need to relocate plants in new northern ports at greater investment of capital.

Over the near term, the NPFMC is currently considering management actions with respect to the potential northward expansion of pelagic and other fishery resources into the northern Bering Sea and Arctic Ocean. One major problem is that current surveys do not extend into the northern Bering Sea, much less the Arctic, so allowance of fisheries to follow the fish north would be conducted under increased uncertainty, perhaps at greater risk to previously unexploited benthic resources, which in turn could place sensitive populations of marine mammals (e.g., walrus) and seabirds (e.g., spectacled eider) at risk. At its June 2007 meeting, the NPFMC is scheduled to take action on a proposal to define and mitigate essential fish habitat in the eastern Bering Sea including an SSC proposal to allow fishing in the northern Bering Sea only under an experimentally designed study to test fishing impacts upon which future decisions can be based. Over the longer term, the NPFMC is considering management options for the Arctic Ocean, perhaps under a new Arctic Fishery Management Plan. Management options for the Arctic are constrained by a serious lack of information on the marine fish and invertebrate resources in this region. The reliance of species of marine mammals and seabirds, as well as Native communities, on the living marine resources of these northern areas, heightens the gravity of management decisions for the Arctic Ocean.

Long-term forecasts of the implications of global warming and fisheries management in Alaska are highly speculative, given present levels of understanding. Just as there was a reorganization of marine ecosystems after the regime shift of the late 1970s, marine ecosystems off Alaska might be expected to reorganize again, perhaps to a new unobserved state, in response to a climate regime shift associated with continued global warming. If so, then a commensurate reorganization of the fishing industry is to be expected. Uncertainty increases as conditions (e.g., temperature, percent sea ice cover) move outside the range of historical observations. Under science-based management, increasing uncertainty typically translates into more precaution. Thus, more precautionary management under greater uncertainty, coupled to the increasing use of ecosystem-based fisheries management, will likely result in more conservative fish harvests in Alaska in the future.

Data Gaps and Research Needs

Predictions of future changes of marine ecosystems for the Gulf of Alaska, Aleutian Islands, and eastern Bering Sea are uncertain, partly owing to gaps in our understanding of mechanisms affecting the dynamics of living marine resources and partly due to uncertainties in climate forecast models at the level of detail necessary for the Alaska region. A combination of improved monitoring, process-oriented studies, modeling, and policy development are recommended to improve our ability to forecast and address likely future marine ecosystem changes in Alaska:

- Arctic baselines – very few data are available on the abundance, distribution, and life history of marine species in the northern Bering Sea and Arctic. It is critical at this time to establish baseline understanding of community structure and function before the Arctic region is perturbed by human impacts and climate change.

- Integrated Ocean Observing Systems – establishment of routine observing systems for physical and biological features of marine ecosystems off Alaska is essential to monitoring the effects of global climate change.
- Studies of physiology and life history. Models only go so far; the biology and life history of many species off Alaska are poorly known, including functional relationships between their growth and survival and environmental conditions. In order to understand the effects of global warming and human effects on these populations and associated ecosystem consequences, it is essential to invest in studies of basic biology, life history, and physiology of poorly studied northern marine species. Physiological studies can reveal a great deal about the impacts of increasing temperature on the scope for growth and survival of northern species.
- Coupled climate-ecosystem and climate-fisheries forecasting models. It is imperative to establish explicit linkages between climate forecast models and regional ecosystem and fishery models so that outlooks for changes in marine ecosystems and fisheries can be made more quantitative and less qualitative. In June 2007, PICES will convene a workshop on linking climate and fisheries forecasts, but this is just a very initial step in a process that will require substantial efforts.
- Ecosystem approach to management. Climate change is just one of a suite of both human and naturally occurring factors that need to be considered in the management of living marine resources. Effective management of marine resources off Alaska will become increasingly complex, given the uses of these resources by coastal Native communities and higher trophic level species (e.g., birds and mammals). Potential for increased marine transportation and oil and gas exploration and development further heighten the need for an ecosystem approach to management.

Thank you, Madam Chair, for the opportunity to speak to you and your committee today. I would be pleased to answer any questions you or other committee members may have.

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