Fishery management responses to climate change in the North Pacific

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In the North Pacific, warming trends, coupled with declining sea ice, raise concerns about the effects of climate change on fish populations and ecosystem dynamics. Scientists are only beginning to understand the potential feedback mechanisms that will affect everything from plankton populations to major commercial fish species distributions, yet fishery managers have a responsibility to prepare for and respond to changing fishing patterns and potential ecosystem effects. There are ways for fishery managers to be proactive, while waiting for better information to unfold. The North Pacific Fishery Management Council (Council) and the National Marine Fisheries Service have jurisdiction over offshore fisheries in Alaska, USA. Recently, the Council has undertaken risk-averse management actions, in light of uncertainty about the effects of warming trends (and loss of sea ice) and resulting changes to fishing activities in the North Pacific. The Council has assessed whether opportunities for unregulated fishing could result from changes in fish distribution, has closed the Arctic Ocean to all commercial fishing pending further research, and has established extensive area closures where fishing with bottom-trawl gear is prohibited to protect vulnerable crab habitat and to control the northern expansion of the trawl fleet into newly ice-free waters. In cases where linkages between climate variables and fish distributions can be identified, the Council is developing adaptive management measures to respond to varying distributions of fish and shellfish. Finally, the Council has also tried to re-examine existing information to gain a better understanding of climate and ecosystem effects on fishery management. The pilot Fishery Ecosystem Plan for the Aleutian Islands maps interactions among climate factors and ecosystem components and suggests indicators for the Council to monitor.

Keywords: Alaska, Arctic fishery management, climate change, Fishery Ecosystem Plan, North Pacific, salmon bycatch, trawl closures.

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Introduction

The effects of climate change on commercial fisheries are only beginning to be understood, yet fishery managers have a responsibility to prepare for and respond to changing conditions. At a national level, managers are trying to develop a strategy to incorporate climate change into management of ocean and coastal areas (Griffis *et al*., 2008). Although knowledge of potential changes to fishing patterns and effects on ecosystem dynamics may be imperfect, there remains scope for managers to be proactive. The North Pacific Fishery Management Council (Council) has recently undertaken several risk-averse management actions, in light of uncertainty about the ecosystem effects of warming trends (and loss of sea ice) and resulting changes to fishing activities in the North Pacific. This paper discusses three ways how fishery managers can prepare for changing conditions: (i) assess whether opportunities exist for unregulated fishing; (ii) where linkages between climate variables and fish distributions can be identified, explore the use of adaptive management measures; and (iii) evaluate existing information to gain a better understanding of climate and ecosystem effects on fishery management.

The Council is one of the eight regional councils in the United States established under the Magnuson Fishery Conservation and Management Act of 1976 (which has been renamed the Magnuson-Stevens Fishery Conservation and Management Act; MSA) to oversee management of the nation's fisheries in collaboration with the National Marine Fisheries Service (NMFS). The Council has 11 voting members, six from Alaska, three from Washington, one from Oregon, and a Federal representative, the Alaska Regional Administrator of the National Marine Fisheries Service. The non-federal voting members represent state fisheries agencies, commercial and recreational fisheries, fishing communities, and the public. The Council also has four non-voting members representing the US Coast Guard, the US Fish and Wildlife Service, the Pacific States Marine Fisheries Commission, and the US Department of State. With jurisdiction over the 900 000 mile^2 exclusive economic zone (EEZ) off Alaska (3–200 nautical miles offshore; Figure 1), the Council's responsibilities include developing, and amending as necessary, fishery management plans (FMPs) for all fisheries under its authority. The FMP defines how a federal fishery may be prosecuted, including the assessment of harvest quotas, allocation programmes, permit requirements, authorized gear types, time and area restrictions, discard and retention requirements, and recordkeeping, reporting, and monitoring requirements. The Secretary of

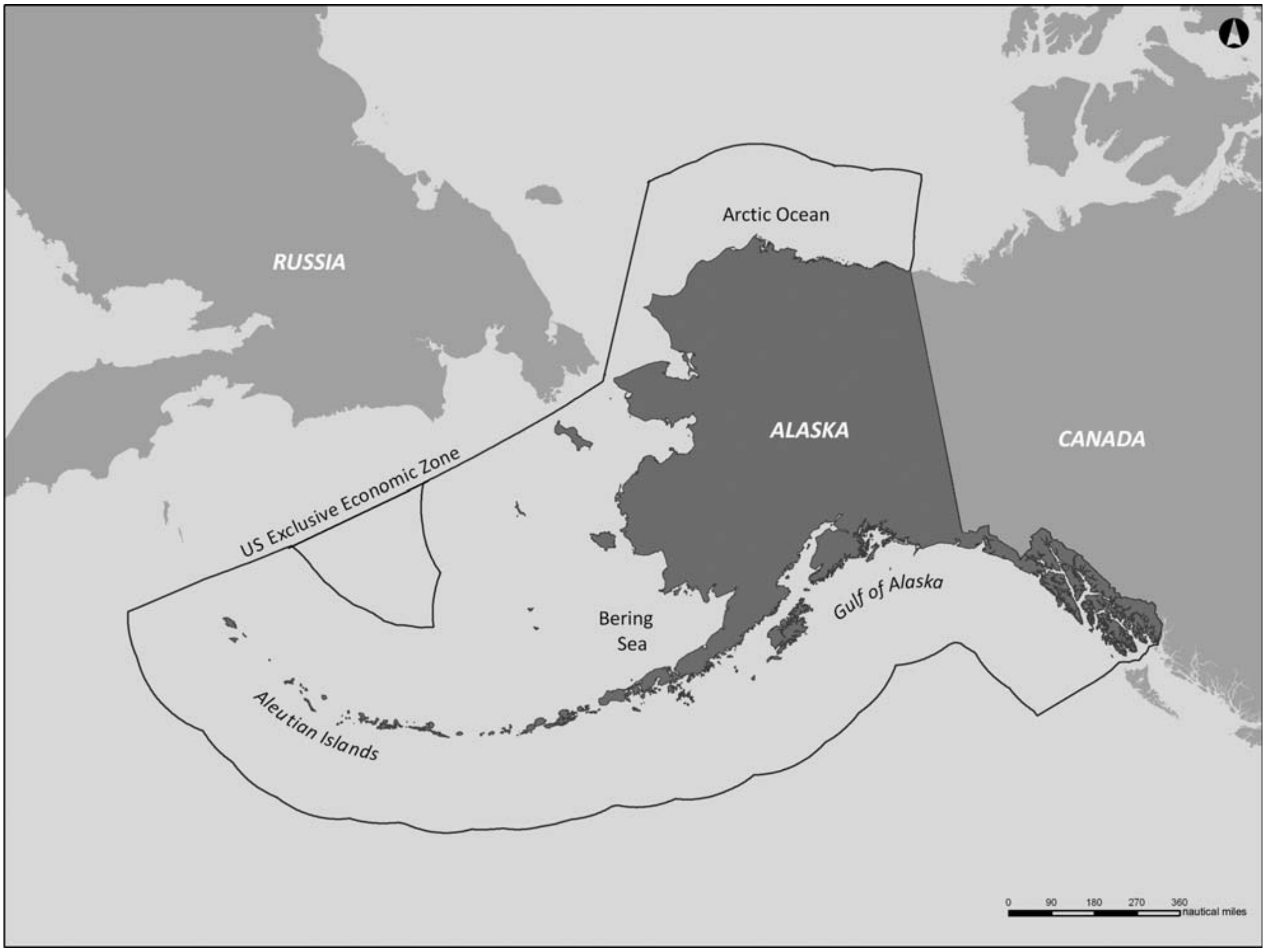

Figure 1. The US EEZ off Alaska, which extends 3–200 nautical miles offshore from the coastline of Alaska, or to international maritime boundaries with Canada and Russia. The four main management areas within the Alaska EEZ are noted.

Commerce reviews the Council's recommended FMP, and once approved, implements the management measures in federal regulations. The Council conducts public hearings regarding the FMPs and their implementation. It also reviews annual stock assessments and recommends harvest specifications for its FMP species. The Council has five established FMPs. Gulf of Alaska groundfish (NPFMC, 2009a, established in 1978) and Bering Sea Aleutian Islands (BSAI) groundfish (NPFMC, 2009b, established in 1979) are its primary management responsibilities. Under the other FMPs [Alaska Scallops, established in 1995 (NPFMC, 2006); BSAI king and Tanner crab, established in 1989 (NPFMC, 2008); and Salmon, established 1990 (NPFMC, 1990)], management is essentially deferred to the State of Alaska, with federal oversight. The Council also makes allocation and limited entry decisions for Pacific halibut (*Hippoglossus stenolepis*).

In recommending management changes to the FMPs under its jurisdiction, the Council must balance the competing requirements of federal law, especially of the MSA. The requirements of the MSA call for a conservation and management programme that *inter alia* optimizes fishery yield, while ensuring conservation of fish stocks and long-term protection of essential fish habitats (EFH).

This paper looks at specific ways that the Council has recently taken action to be proactive in preparing for and responding to climate change. The Council recently adopted an FMP to close the Arctic Ocean to all commercial fishing until additional research into its unique characteristics can be evaluated. Extensive trawl area closures have been established to protect vulnerable crab habitat and to slow the northern expansion of the trawl fleet into newly ice-free waters. Management measures are being developed to respond adaptively to varying distributions of target and bycatch fish species, because of changing climate in the North Pacific, and a pilot Fishery Ecosystem Plan (FEP) has been developed for the Aleutian Islands, which maps interactions among climate factors and ecosystem components and suggests indicators for the Council to monitor.

Close selected areas to unregulated fishing

Arctic fishery management

To date, not much commercial fishing has been done in the Arctic Ocean. The Arctic Ocean is a reasonably pristine ecological environment that is experiencing substantial change. Compelling evidence from studies of changes in Arctic climate, ocean conditions, sea ice cover, permafrost, and vegetation indicate that the Arctic is experiencing warming trends in ocean temperatures and major and rapid declines in seasonal sea ice (IPCC, 2001; ACIA, 2005; Richter-Menge *et al.*, 2006). Greater ice-free seasons, coupled with warming waters and fish range expansion, could create conditions that will certainly result in commercial fishery development. Species of finfish and shellfish are found in these waters, and they could conceivably support commercial fisheries, if exploitable biomass levels were sufficiently high. Until now, there have been no commercial fisheries in the Alaska EEZ in the Arctic Ocean, nor have there been any routine fish surveys in the region. Historically, fishing in the Arctic required prior authorization from the State of Alaska for state-registered vessels, but unregistered vessels faced no prohibitions or restrictions.

In February 2009, the Council adopted an Arctic FMP to establish federal fishery management in the Alaskan Arctic. The FMP will probably be approved by the Secretary of Commerce and be implemented in 2009. The FMP is necessary to prevent unregulated commercial fisheries from developing in the Arctic, a region currently lacking a fishery management framework and adequate scientific information on fish stocks. The Council's intent is that the FMP would initially close the Arctic waters to commercial fishing until adequate information and data are acquired upon which to make sound decisions about future fishery development, and the effects of fishing on fish stocks and related components of the ecosystem are understood. Initially, no commercial fishing will be allowed under the authority of the new Arctic FMP.

The Arctic Management Area includes all US federal marine waters of the Chukchi and Beaufort Seas, 3–200 nautical miles offshore of the coast of Alaska, from north of Bering Strait, westwards to the US–Russia Convention Line of 1867, and eastwards to the US–Canada maritime boundary (Figure 2).

Trawl closures to slow northward fleet expansion

Given the apparent trend towards warming ocean temperatures, especially in Polar Waters, the Council became concerned that some non-pelagic trawl fisheries may shift northwards into previously unfished habitats of the eastern Bering Sea. Flatfish catch per unit effort from the NMFS summer trawl survey is correlated with near-bottom temperature over 1982–2004 (Spencer, 2006). Flathead sole (*Hippoglossoides elassodon*) and rock sole (*Lepidopsetta polyxystra*) were distributed farther to the north and northwest during warm periods. As ocean temperatures increase, in the absence of management actions, it is likely that flathead sole and rock sole would be harvested farther north, but the extent of movement of the fisheries cannot be predicted (Spencer, 2006).

Warming temperatures not only affect species range extensions, but also may determine ecological interactions among species. For instance, productivity of some species, such as crabs, may be determined, in part, by changes in their geographic distributions relative to those of their predators, prey, and competitors (Zheng and Kruse, 2006). In the past few decades, the distributions of mature female red king crab (*Paralithodes camtschaticus*) shifted to the northeast, those of snow crab (*Chionoecetes opilio*) shifted to the northwest, and those of Tanner crab (*Chionoecetes bairdi*) displayed no such systematic changes. With regard to groundfish predators and competitors of crabs, Pacific cod (*Gadus macrocephalus*), flathead sole, and arrowtooth flounder (*Atheresthes stomias*) populations shifted to the northwest, and rock sole, skates (*Bathyraja* spp.), and Alaska plaice (*Pleuronectes quadrituberculatus*) shifted to the northeast, whereas the yellowfin sole (*Limanda aspera*) population displayed no change in the distribution (Zheng and Kruse, 2006). These distribution changes appeared to be directly related to mean ocean bottom temperature.

Groundfish species distributions have also altered with changing temperatures (Mueter and Litzow, 2008). The area formerly covered by sea ice (and associated cold pool) has become favourable habitat for many Subarctic species, and consequently, increases in biomass for most fish stocks have been observed in the area. Although there has been a linear response to bottom temperatures, there is an additional non-linear accelerating shift in biomass and a shift in distribution that cannot be accounted for by temperature alone. Hence, predictions into the future under a warming scenario are extremely uncertain (Mueter and Litzow, 2008).

Given these indications of warming trends and associated northward expansion of commercial fish and shellfish distributions, the Council adopted in June 2007 precautionary measures to conserve benthic fish habitat in the Bering Sea by "freezing the footprint" of bottom trawling and limiting non-pelagic trawl effort only to those areas more recently trawled (Figure 2). These new measures prohibited bottom trawling in a deep slope and basin area (47 000 nautical mile^2) and in the Northern Bering Sea Research Area, which includes the shelf waters to the north of St Matthew Island (85 000 nautical mile^2). A research plan for the Northern Bering Sea Research Area is scheduled for completion by 2010. It may include an adaptive management design, which could allow bottom trawling in designated areas to evaluate trawling effects, or research using other experimental fishing approaches. Specific areas within the Northern Bering Sea Research Area, however, will remain closed to bottom trawling. At the same time, marine protected areas were also established to conserve blue king crab habitat and other EFH where subsistence fishing and small-scale local fisheries already take place, and include the nearshore areas of Nunivak Island and Kuskokwim Bay, and around St Lawrence and St Matthew Islands. The research plan may also identify additional protection measures for blue king and snow crab, marine mammals, endangered species, and subsistence needs for western Alaska communities in nearshore areas (NMFS, 2008).

Explore opportunities to link climate variables and fish distributions

Salmon bycatch in the pollock trawl fishery

Salmon (*Oncorhynchus* spp.) and pollock (*Theragra chalcogramma*) both support important fisheries for Alaska. Salmon support large and critically important commercial, recreational, and subsistence fisheries throughout Alaskan waters and are the basis of a cultural tradition in many parts of the state. Average annual value of the 2000–2004 commercial harvest was more than \$230 × 10^6 (Woodby *et al.*, 2005). Subsistence fisheries are vitally important in Alaska, with communities depending heavily on subsistence-caught salmon for food and cultural purposes. Chinook salmon runs in western Alaska have declined in recent years relative to run strengths observed over the past 20 years, with the 2008 runs in some areas the poorest on record (NMFS and NPFMC, 2008).

The commercial pollock fishery is the largest US fishery by volume, with annual catches ranging from 1.49×10^6 t in 2003 to 1.35×10^6 t in 2007 (Ianelli *et al.*, 2008). Pollock represents more than 40% of the global whitefish production, with annual

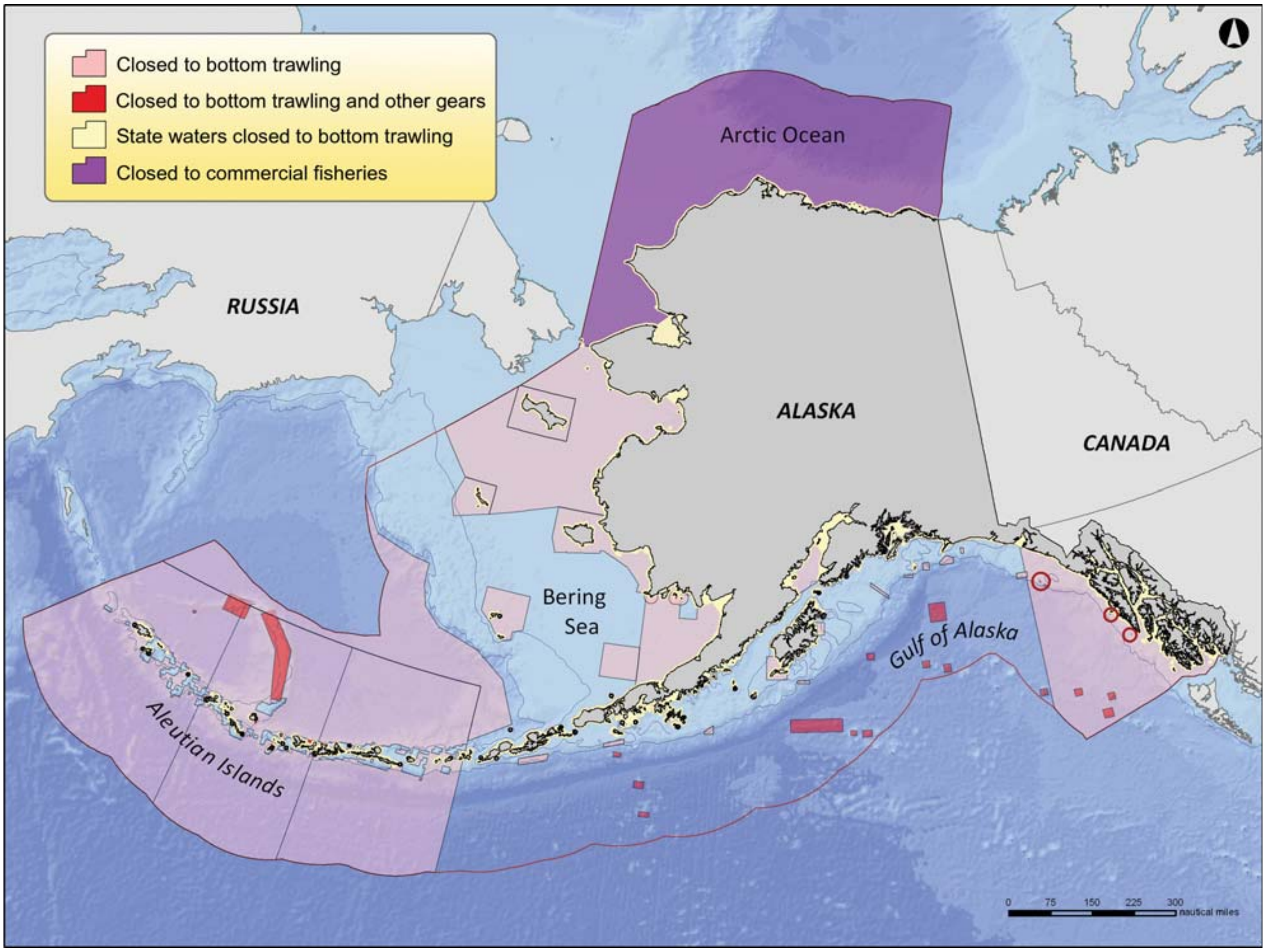

Figure 2. Various year-round fishing gear closure areas around Alaska. Source: J. Olson, National Marine Fisheries Service, Alaska Region (pers. comm.).

revenues from the fishery estimated in 2007 at $1.25 billion (NMFS and NPFMC, 2008). Participation in the fishery (through royalties and employment) is important for many of the same western Alaska communities that also participate in salmon fisheries, because some receive a percentage of the pollock quota for community development.

Because of the importance of salmon for coastal and inland fisheries, it is unlawful to retain salmon caught incidentally in offshore fisheries, such as those for groundfish. However, salmon are caught unintentionally in the offshore eastern Bering Sea pollock trawl fishery and to a lesser degree in the offshore Gulf of Alaska pollock fishery. Despite bycatch control measures implemented in the pollock fishery since the mid-1990s, Chinook salmon bycatch has increased over time, and reached a historic high in 2007 (Figure 3). The Council is required to balance minimizing salmon bycatch to the extent practicable, with achieving optimal yield from the pollock fisheries.

It is unclear whether the observed increase in salmon bycatch was the result of an increase in salmon abundance, or whether there has been a greater degree of co-occurrence between salmon and pollock stocks, because of changing oceanographic conditions (NMFS and NPFMC, 2008). The distribution of the pollock fishery could also have changed in recent years, resulting in greater bycatch, but evidence of this is lacking (Stram and Ianelli, in press). Pollock biomass has declined since 2003 and it is projected to continue to decline through 2009 to approximately half of the 2003 level, owing to a period of recent below-average recruitment levels (Ianelli *et al.*, 2008). Pollock distribution is

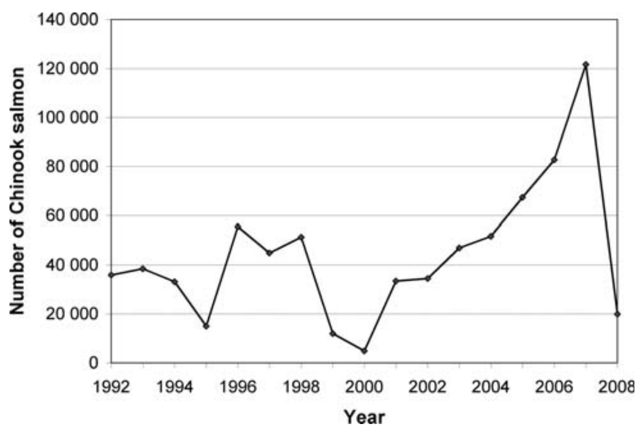

Figure 3. Annual Chinook salmon bycatch in the Bering Sea pollock trawl fishery, 1992 – 2008, extrapolated totals from observed estimates. Source: National Marine Fisheries Service, Alaska Region, Catch Accounting Database.

known to be affected by bottom temperatures, with highest densities found in areas where the bottom temperatures are $>0^{\circ}$C (Ianelli *et al.*, 2008). Specific ocean temperature preferences for salmon species are poorly understood, although some evidence exists for a contraction of ocean habitats for salmon species under global warming scenarios (Welch *et al.*, 1998).

Archival tags affixed to Asian chum salmon indicate that behaviour and migration in juvenile, immature, and maturing fish are linked to temperature gradients (Friedland *et al.*, 2001) and that immature chum exhibit a tendency to remain above the thermocline along the continental shelf (Azumaya *et al.*, 2006). Anecdotal information suggests that Chinook and chum salmon prefer different (warmer) ocean water temperatures than adult pollock. Currently, a study linking temperature and bycatch rates is underway and preliminary evidence indicates that bycatch rates appear to be positively correlated with warmer temperatures, even when factoring for month and area (Ianelli *et al.*, 2009).

As the pollock population shifts spatially, the commercial fishery moves to target the available biomass. The winter fishery commences on 20 January and extends until late March or early April, depending on allowable catch levels and fishing conditions. This fishery is normally focused on the southeast Bering Sea and targets prespawning fish to market pollock roe, whereas the flesh is used primarily for fillets or surimi. The summer/autumn fishery starts in June and continues generally until mid-October for the remaining quota. This fishery is typically spread over the outer shelf edge of the Bering Sea, extending to the international boundary. Salmon bycatch in the pollock fishery happens during both fishing seasons. As the fishery moves to target shifting pollock stocks, the array of salmon stocks taken as bycatch changes, because of the spatial variability of the stock of origin of salmon in the ocean (Myers and Rogers, 1988; Myers *et al.*, 2004). Many efforts are underway to assess the relationship between oceanographic conditions, ocean mortality of salmon, and their maturation timing to their respective rivers of origin for spawning (e.g. Bering Aleutian Salmon International Survey; Ocean Carrying Capacity Programme; Alaska Department of Fish and Game Management and Research).

In the absence of definitive information on the cause of the bycatch increase, but given indications that warming trends may exacerbate recent bycatch levels, the Council is currently evaluating measures to limit the overall number of Chinook salmon that may be taken annually by the pollock fishery, by season and sector of the fishery, whereafter pollock fishing would cease for some or all participants. The Council is expected to take final action on these new measures in 2009. As evidence unfolds for a better prediction of the correlation between salmon and pollock distributions in the Bering Sea, the Council could revisit appropriate bycatch control measures.

Re-evaluate existing information to focus on climate and ecosystem interactions

Aleutian Islands FEP

The Council began the Aleutian Islands FEP as a pilot project in 2005, both to better conserve important Aleutian Islands resources (fish stocks, Steller sea lions, seabirds, and benthic habitats that support corals and sponges) and to evaluate whether FEPs are a useful tool for Alaska (NPFMC, 2005). The purpose of the FEP was to integrate information on the Aleutian Islands ecosystem dynamics, across all fisheries and FMPs in the area (groundfish, crab, halibut, and scallop), and to include information from other agencies actively researching aspects of the Aleutian Islands marine environment. The Council created an interagency Aleutian Islands Ecosystem Team, comprising expertise from a variety of specialties, to develop the FEP. The team first focused on characterizing what is known of the main physical, biological, and socio-economic relationships that comprise the Aleutian Islands ecosystem (NPFMC, 2007a), and the natural and anthropogenic influences on the system.

Once available information on ecosystem interactions is synthesized, the FEP identifies a number of key ecosystem interactions of importance to fishery managers (Figure 4). An important subset of these interactions focuses on the effects of climate change, and how resulting changes in the physical environment might affect ecosystem processes. These interactions were used to identify critical indicators for the Aleutian Islands, to be used to monitor and evaluate the status of the ecosystem over time. Such an indicator system is intended to provide an "early warning system" for the Council to alert for signs of ecosystem change. The FEP also includes a qualitative risk assessment of the interactions, providing general guidance to the Council about which issues represent a priority for management attention and further research and analysis (NPFMC, 2007a).

The Aleutian Islands ecosystem provides an ideal pilot area for an FEP. Far less is understood about the ecological interactions in the Aleutians than in the eastern Bering Sea, so the risk of management actions resulting in unforeseen consequences, especially when combined with the uncertain effects of climate change, is of special concern in this region. The Aleutian Islands are ecologically and historically unique, comprising hundreds of small, volcanic islands, separated by oceanic passes that connect the waters of the North Pacific with the Bering Sea. The ecological boundary at Samalga Pass, 169°W, represents a transition from a shelf- (Bering Sea) to a slope-based (Aleutian Islands) ecosystem (Hunt and Stabeno, 2005; Figure 5). This results in an ecosystem where bathymetry and habitat types change drastically within a very short distance, and the degree of interaction between onshore, nearshore, and offshore systems is much higher than in the neighbouring Bering Sea (NPFMC, 2007a). A key management priority that emerged from the FEP was for the Council to recognize the Aleutian Islands ecosystem as a distinct entity, with different processes and properties (NPFMC, 2007a).

The FEP differs from an FMP in that it does not contain any specific management measures that govern fishing activity in the Aleutian Islands. It is an overarching document, which provides an ecological context for fishery management decisions affecting the Aleutian Islands area. The FEP is designed as a policy and planning document and an educational resource (NPFMC, 2007a). The first iteration of the FEP, along with an overview brochure, was published in December 2007 (NPFMC, 2007a, b), but the FEP is a living document. The ecosystem interactions, indicator status, research priorities, and data gaps will be updated periodically. Appropriate changes to management practices that might result from the considerations and priorities suggested in the FEP will be acted upon through BSAI FMP amendments.

Summary

The Council strives to take proactive and precautionary management actions in light of uncertainty about the ecosystem effects of warming trends (and loss of sea ice), and potential expansion

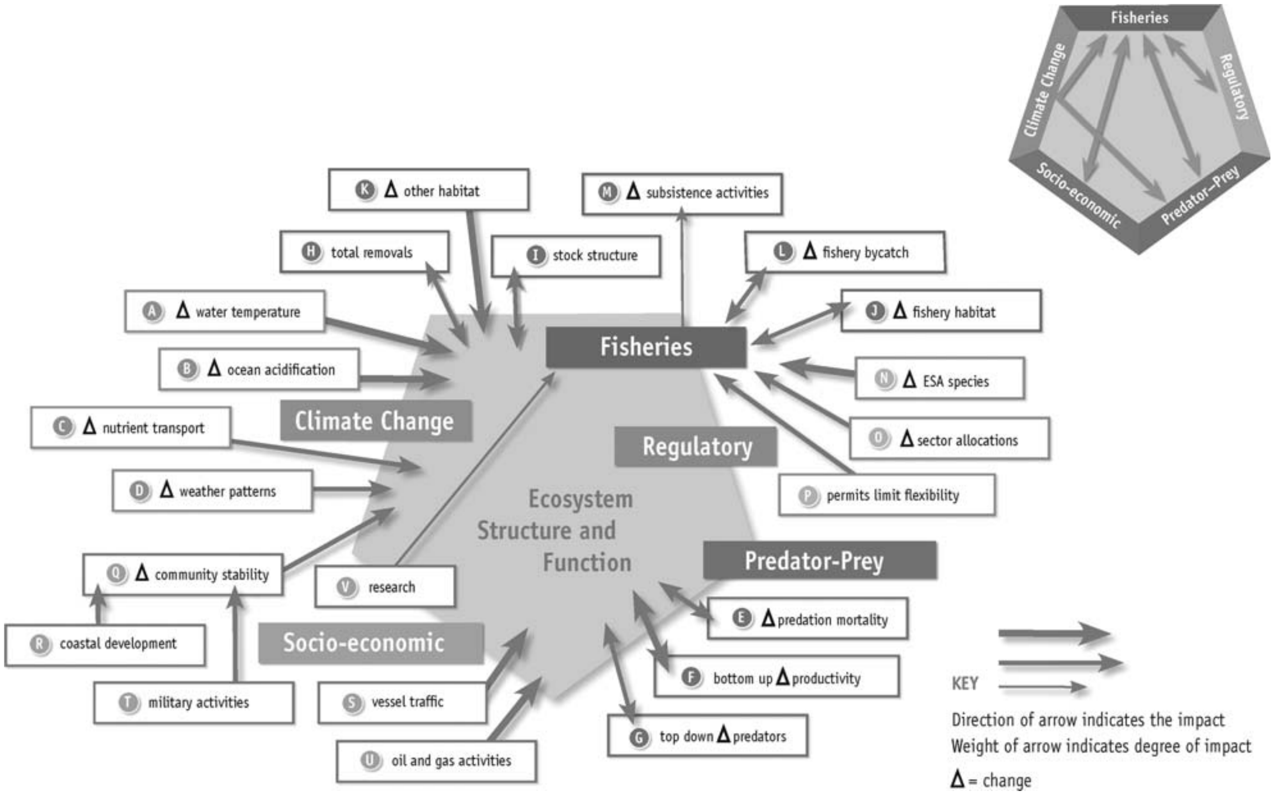

Figure 4. Ecosystem interactions in the Aleutian Islands FEP. Source: NPFMC (2007b).

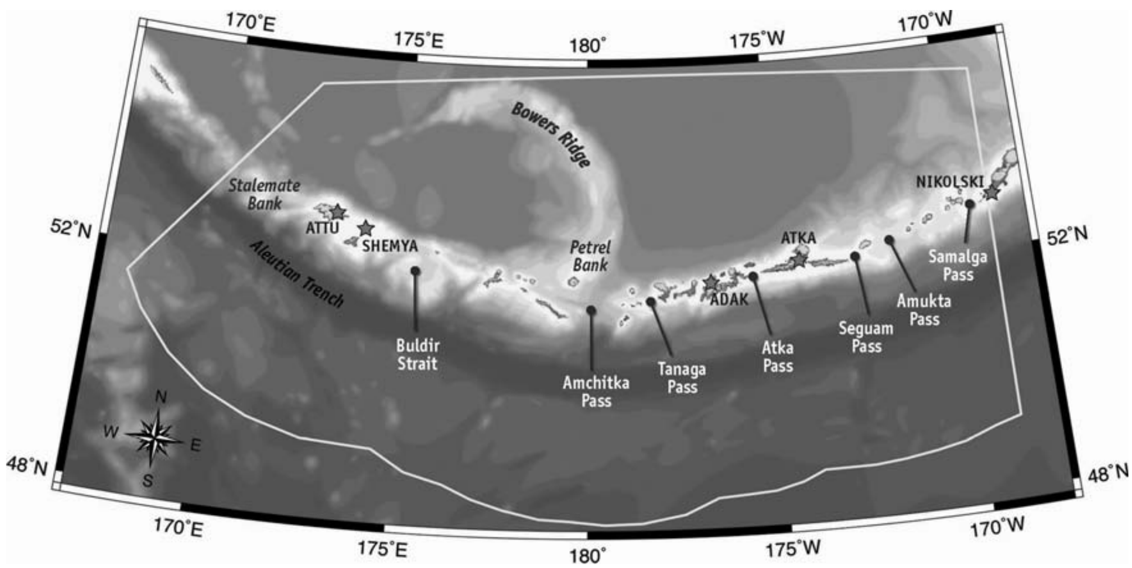

Figure 5. Map of the Aleutian Islands FEP area, indicating key oceanographic features and communities. Source: NPFMC (2007b).

of fishing activities in the North Pacific, to best utilize, conserve, and protect the fisheries resources in this region. The measures described here represent some examples of the fishery management actions underway in the North Pacific as fishery managers and policy-makers operate under a shifting climate and seek to balance various management objectives. These types of action should be of relevance to fishery managers in other regions, as examples of steps that can be taken to be risk averse in preparation for climate change and resulting shifts in fishing patterns.

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