GUEST EDITORIAL

Toward sustainable ecosystem services from the Aleutian Archipelago

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ABSTRACT

The new research reported in this special issue of *Fisheries Oceanography* expands our understanding of the Aleutian Archipelago ecosystem. Yet our knowledge remains very limited, while the use of this ecosystem for commercial activities, recreation and other purposes expands. Given this situation, how can we sustain the ecosystem services (food, fuel, fibers as well as spiritual, recreational, educational and other non-material benefits to society) of this region? The region has a mixed history; healthy populations of many species exist, but so do species extinctions (e.g. Steller sea cow, *Hydrodamalis gigas*) and population depletions, including the sea otter (*Enhydra lutris*), Steller sea lion (*Eumetopias jubatus*), whiskered auklets (*Aethia pygmaea*), Pacific ocean perch (*Sebastes alutus*), and red king crabs (*Paralithodes camtschaticus*), associated with human impacts. The solution to our limited knowledge in this poorly studied region is increased funding for ecosystem research, including its responses to climate change and human impacts. Knowledge is not sufficient, however; a change in management approach is also needed. We emphasize the need to maintain a broader set of ecosystem services objectives rather than the traditional narrower focus on commercial fishery yields. To do so, we recommend the development of an integrated ecosystem services management plan for the Aleutian Islands. Such a plan requires that state and federal regulatory agencies coordinate with a broad stakeholder community involving sectors of commercial and recreational fishing, subsistence, conservation, oil and gas development, coastal development, shipping, tourism, and others.

Key words: Aleutian Islands, climate change, ecosystem services, human use, integrative management approach

INTRODUCTION

The purpose of this supplement is to report results of recent research on aspects of the Aleutian Archipelago ecosystem, where field studies were conducted mainly between Samalga and Tanaga Passes (Fig. 1). In this Guest Editorial we integrate these results into the framework of existing knowledge as a basis for suggesting actions leading to sustainability of Aleutian ecosystem services. The term ecosystem services is increasingly appearing in ecological literature (e.g. Anon., 2003; Palmer *et al.*, 2004) in place of natural resources, and is defined as food, fuels and fibers that also provide spiritual, recreational, educational and numerous other non-material benefits to people.

We first discuss selected aspects of the Aleutian ecosystem, highlighting contributions appearing in this supplement, and then describe the circumstances that resulted in availability of funding for the research. The heart of this paper is a discussion of maintaining sustainability of ecosystem services, which brings with it research challenges and management issues. We conclude with a discussion of tools to attain sustainable ecosystem services in the Aleutian Archipelago.

THE ALEUTIAN ARCHIPELAGO ECOSYSTEM

Topography

The Aleutians are a chain of islands forming an arc in the northern North Pacific (NP) Ocean. The name possibly originated from the Chukchi word 'aliat' for island (Wikipedia, 2005). The U.S. portion of this archipelago extends more than 2200 km westward from the western margin of the Alaska peninsula (False Pass)

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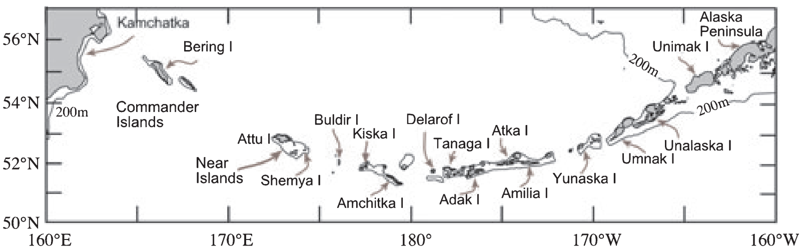


Figure 1. Map of the Aleutian and Commander Islands. The 200-m isobath is shown as a thin line (after Hunt and Stabeno, 2005).

to Attu Island. The islands were formed by volcanic activity associated with the ongoing collision of the Pacific and North American tectonic plates; these tectonics also created a very narrow continental shelf, ~80 km at its widest in the eastern Aleutians. A cross section of all the passes and the mean circulation features are shown in Stabeno *et al.* (2005). Following the nomenclature of Ladd *et al.* (2005a), the region east of Samalga Pass (just west of Umnak Island) is the eastern Aleutian Islands, which are separated by relatively shallow (<100 m), narrow (<20 km) passes. The central Aleutians extend from Samalga Pass west to Amchitka Pass (east of Amchitka Island); these passes are relatively deep (>400 m) and wide (>100 km). The western Aleutians lie between Amchitka and Attu Island on the eastern side of Kamchatka Strait. As we discuss later, the topography of the Aleutian Archipelago strongly influences biophysical processes and hence regional ecosystem function and form.

Atmospheric features

Paleoclimate data demonstrated that large regional to global-scale climate changes have occurred with periods from years to decades (e.g. Higgins and Vellinga, 2004). Analyses of lake sediment samples collected in southwestern Alaska (near the Bering Sea) revealed that variations occurred in climate and ecosystem during the Holocene (Hu *et al.*, 2003). In the Aleutians, more recent analyses (Causey *et al.*, 2005) substantiate the earlier findings with respect to variations in climate (alternating periods of warm-wet and cold-dry conditions) forcing changes in the ecosystem, as manifested in changes in marine bird populations.

Regional atmospheric characteristics are connected to global- and hemispheric-scale phenomena (e.g. NPRB, in press; Stabeno *et al.*, in press). Among the major atmospheric climate features (i.e. those on time scales of seasons and longer) influencing the NP and Bering Sea, are the El Niño/Southern Oscillation (e.g. Overland *et al.*, 2001), atmospheric-related patterns in sea surface temperature, such as the Pacific Decadal Oscillation and the Victoria Pattern (e.g. Bond *et al.*, 2003), and the Northern Annular Mode (e.g. Overland *et al.*, 1999; a.k.a. Arctic Oscillation). Rodionov *et al.* (2005b) examined in depth the regional climatology resulting from the interactions of the larger scale atmospheric features. The primary regional feature, the Aleutian Low, is a statistical feature that results from frequent migration of storms eastward along the archipelago (Schumacher *et al.*, 2003). It is a prominent atmospheric centre of action in winter but practically disappears in summer (Rodionov *et al.*, 2005a,b). Rodionov *et al.* (2005b) identified a climatological transition zone (at ~170°W) between the eastern and the central and western Aleutians. There are differences in interannual and long-term surface air temperature patterns such that the eastern Aleutians experienced two regime shifts in the past three decades, whereas in the central and western Aleutians these were much less pronounced (Rodionov *et al.*, 2005b). The NP index provides a measure of the strength of the Aleutian Low (Trenberth and Hurrell, 1994); it has undergone abrupt 'regime shifts' in 1976/77 and 1988/89. A regime may be defined as a persistent (decades) state in climate (i.e. the state of atmosphere and ocean over periods longer than a season) and biological systems (Beamish *et al.*, 2004). A regime is thus a quasi-stable ecosystem state that can shift with climate change. This has occurred in the NP Ocean, where changes in indices of atmospheric and oceanic features (i.e. climate) were concomitant with changes in biota (e.g. Hare and Mantua, 2000; Hollowed *et al.*, 2001).

Oceanic features

The oceanic component of the Aleutian ecosystem consists of two major currents, each with their own water properties, chemistry and biology. Mean northward transport occurs through the eastern and central passes (Schumacher and Stabeno, 1998; Stabeno *et al.*, 1999). Water flowing through the eastern passes includes the Alaska Coastal Current, connecting the Gulf of Alaska and eastern Bering Sea continental shelves. Oceanic (Alaskan Stream) waters of the NP flow into the Bering Sea through the central passes.

This exchange fuels the rich ecosystem of the eastern Bering Sea (e.g. BEST, 2004; PICES, 2004) and it also feeds the bottom-up energy flow through the Aleutian ecosystem. This supplement reports significant progress to understand the nature of physical phenomena themselves and also on how they influence biological components of this ecosystem. As was presented in the palaeoecological (Causey *et al.*, 2005) and atmospheric climate (Rodionov *et al.*, 2005b) studies, the examination of currents indicates an east–west transition that is centred at Samalga Pass (Ladd *et al.*, 2005a). Also, the processes of tidal current mixing within passes and subsequent re-establishment of vertical structure result in a north–south transition; the northern side of the Aleutian archipelago (particularly in the lee of the islands) is more productive (Ladd *et al.*, 2005a). Tidal mixing contributes to the nutrient flux into the Bering Sea from the shallower eastern passes (Stabeno *et al.*, 2005). The volume transport through Amukta Pass appears to be five times greater than previously estimated (Stabeno *et al.*, 2005). Thus, the contribution of this nutrient-rich flow through Amukta Pass to formation of the Aleutian North Slope Current is far greater than previously thought. Importantly, variations in volume transport at longer (>1 month) time scales are related to the position and strength of the Alaskan Stream (Stabeno *et al.*, 2005).

Volume transport, tidal mixing, presence of oceanic and shelf waters, and fronts all have impacts on the nutrient–phytoplankton–zooplankton sequence and higher trophic level dynamics. Nutrient data and estimates of the volume transport (Stabeno *et al.*, 2005) indicate that flow through Amukta Pass accounts for more than 75% of the total nutrient flux between Unimak and Tanaga Passes (Mordy *et al.*, 2005). These authors also note that due to the vigorous tidal mixing, it appears that new primary production is inhibited within the passes, but substantial blooms occur downstream after stratification occurs. A zooplankton community consisting of oceanic genera existed in the central passes, whereas the eastern passes contained a mixture of oceanic and neritic zooplankton species (Coyle, 2005). The interaction of tidal currents with topographic features results in fronts, regions with strong horizontal gradients of ocean properties that separate well-mixed and stratified regions (Ladd *et al.*, 2005b). These authors noted that depending on feeding strategies (e.g. picking prey at the surface, subsurface foraging or plunge-diving deep feeding), seabird concentrations were associated with either fronts or convergence zones in the mixed water. As with other elements of the ecosystem, there was a differentiation in the types of birds most abundant in the eastern (short-tailed shearwaters *Puffinus tenuirostris* and tufted puffins *Fratercula cirrhata*) versus the central passes (northern fulmars *Fulmarus glacialis* and some shearwaters) owing to the differences in physical process (Jahncke *et al.*, 2005). It appears that the lack of physical features in some foraging regions (i.e. as observed in the deeper central and western passes) likely affects the transfer of energy from lower to higher trophic levels. Not only do the deeper passes have less primary production, but also the transfer of that production to higher trophic levels may be constrained (Ladd *et al.*, 2005b).

Fish and crabs

Although not part of the directed funding, considerations of the impact of commercial fisheries are crucial toward understanding ecosystem dynamics. We provide a brief account of the commercial fisheries in the Aleutian Archipelago [based on information from the Stock Assessment and Fishery Evaluation (SAFE) report (NPFMC, 2004a) unless otherwise noted]. The primary groundfish fisheries in the Aleutian Archipelago are Pacific ocean perch *Sebastes alutus*, walleye pollock *Theragra chalcogramma*, Atka mackerel *Pleurogrammus monopterygius* and Pacific cod *Gadus macrocephalus* (NRC, 2003). A marked impact of commercial fishing occurred in the 1960s and early 1970s when the foreign trawl fishery depleted Pacific ocean perch stocks, with the greatest landings of 109 100 metric tonnes (t) in 1965. The current domestic fishery is managed under a rebuilding plan that constrains landings to sustainable levels, such as 10 331 mt in 2004. Estimates of total Pacific ocean perch biomass from the 1991–2004 triennial trawl surveys show that, on average, 45% of the biomass was in the western Aleutians; the central and eastern Aleutians each have ~27% of the total. Although pollock are the principal food item for many species in the eastern Bering Sea food web, including humans (Livingston, 1995), they are less important in the Aleutian Island ecosystem. A small fishery began in the late 1970s, primarily in the eastern Aleutian Islands and over the basin westward to ~180°W (Bowers Ridge); from 1989 to 1998, the fishery was more dispersed along the entire chain. This fishery peaked at 98 604 mt in 1991 and declined thereafter. The North Pacific Fishery Management Council (NPFMC) applied a precautionary management approach when it closed the fishery after 1998 to eliminate a possible impediment to recovery of the endangered western stock (west of 144°W) of Steller sea lions (*Eumetopias jubatus*). By legislative fiat, however, a pollock fishery will be opened in the

Aleutians starting in 2005 (see section, 'Sustaining ecosystem services: improving management'). The former foreign fishery for Atka mackerel became an entirely domestic fishery in 1990. It was the largest (by weight) groundfish fishery in the Aleutian Islands in the 1990s (NRC, 2003); in 1996, over 100 000 t were caught. The biomass distribution among the western, central and eastern Aleutians varies among surveys; in 2004, it was 30%, 42% and 28%, respectively. Steller sea lion predation was the third largest identifiable source of Atka mackerel mortality based on estimates during 1990–94. Since the early 1990s, Pacific cod contributed an increasing proportion of the total commercial catch in the Aleutian Islands. From 2000 and 2003, the catch averaged 34 250 t. Pacific cod are the greatest source of mortality of Atka mackerel, accounting for nearly 10% more than do Steller sea lions and 4% more than commercial fishing.

Commercially exploited crabs also provide an important commercial ecosystem service in the Aleutian Archipelago. Species harvested include red king crab (*Paralithodes camtschaticus*), golden king crab (*Lithodes aequispinus*), scarlet king crab (*L. couesi*), Tanner crab (*Chionoecetes bairdi*), triangle Tanner crab (*C. angulatus*), and grooved Tanner crab (*C. tanneri*, NPFMC, 2004c). Some of these stocks are not surveyed, and others are only surveyed on a limited basis so that population trends are not known. Red king crab fisheries began in the western Aleutians in the early 1960s, collapsed in the early 1970s, and did not recover (Orensanz *et al.*, 1998). Red king crab harvests in the eastern Aleutians began in the late 1960s, declined in the late 1970s, increased in 1980–81, and collapsed in 1982. The demise of the red king crab fisheries throughout Alaska caused disastrous social and economic consequences, which are well documented (Wooster, 1992). After the collapse of the red king crab fisheries, fishermen began to target golden king crab in the eastern (~22% of the total Alaskan catch) and western (70% of the total Alaskan catch) management areas of the Aleutian Islands in the early 1980s. Directed fisheries presently exist for triangle Tanner crab (0.05–0.2 million pounds guideline harvest level) in the eastern Aleutian Islands and golden king crab (5.7 million pounds guideline harvest level) for which harvests are roughly split equally between the areas east and west of 174°W.

Seabirds

In the Aleutian Islands there are 144 bird colonies, including three with breeding populations over 1 million birds and two with over 3 million birds (NPFMC, 2004b). Short-tailed shearwaters, northern fulmars, and tufted puffins are extremely abundant species in the Aleutians (Piatt and Springer, 2003). Physical features of the ecosystem provide factors that affect distribution of seabirds. The interaction of strong currents with bathymetric features results in zones of vertical currents, mixing and convergences that make island passes attractive foraging regions (Ladd *et al.*, 2005b). For instance, whiskered auklets (*Aethia pygmaea*) concentrate at sites where there are strong tidal currents and forage exclusively on zooplankton concentrated in tiderips, swirls, tidal pumps and fronts and other areas of strong upwelling near islands or offshore reefs (Williams *et al.*, 2003). The distribution and abundance of auklets in the Aleutian Islands has been regulated by the introduction of non-native Arctic foxes (*Alopex lagopus*) in the 18th to 20th centuries for fur farming (Williams *et al.*, 2003). Whiskered auklets have been designated as a United States Fish and Wildlife Service (USFWS) Bird of Conservation Concern in the Alaska Region due to concerns over its localized breeding distribution on Buldir Island (USFWS, 2002). As noted by Dragoo *et al.* (2004), the productivity (chicks fledged per nest) of several key species showed spatial variation, e.g. black-legged kittiwakes (*Rissa tridactyla*, surface fish-feeders) had high (1.26) productivity on Bogoslof Island (eastern Aleutians), moderately high (0.8) productivity on Koniuji Island (central Aleutians), and low productivity (0.07) on Buldir Island (western Aleutians) in 2002. The percentage of maximum number of birds, however, has been steady (1996–2002) at ~80% on Buldir, whereas it has gone from an average of ~90% (1996–98) to <50% (2002) on Koniuji Island. Likewise, for thick-billed murres (*Uria lomvia*), productivity on Buldir Island has been relatively constant since 1987 at a mean of ~0.70, while in the central region (Kasatochi Island) productivity declined rapidly between 1997 and 1998 (~0.40 to <0.01), and it has remained at that level. Numbers of Glaucous-winged gulls (*Larus glaucescens*, surface fish-feeders) have declined significantly at Buldir Island.

Mammals

The Aleutian Islands have no native terrestrial mammals west of Umnak Island (Bailey, 1993). Sea otter populations in southwestern Alaska and the Aleutians, once the home of more than half of the world's sea otters (*Enhydra lutris*), declined by an average of 58% over 1965–92 (Estes *et al.*, 1998). More recently, data show that the Aleutian portion of the southwestern Alaska stock contains 22% of the total and is declining, with the greatest decreases occurring in the central Aleutians (Angliss and Lodge, 2004). The total uncorrected count for the area in 2000 was 2442 animals, indicating that sea otter populations had declined 70% between 1992 and 2000.

The Aleutian Archipelago is also home to the Steller sea lion. In 1960 there were 99 000 in the region, accounting for 40% of the total western stock; by 1989 there had been a decrease of ~81%, and the Aleutians accounted for only 22% of the total (NRC, 2003). Based on counts from 2000 and 2002 (Eberhardt *et al.*, in press), population trends in the central Aleutians appear to have leveled off and may be slightly increasing, while trends in the eastern Aleutians have been erratic. Counts in the western Aleutians continue to decline at ~10% per year. Concern over the potential role of commercial fisheries in the decline provided impetus and funds for a greatly expanded research programme. A summary of these results includes: (1) diet studies of Steller sea lions revealed a strong prevalence of Atka mackerel, pollock, and Pacific cod (all targeted by groundfish fisheries); (2) size ranges of fish consumed by sea lions and those targeted by fisheries overlapped considerably, as did the depths and geographic locations used by both fisheries and sea lions; (3) while these results suggested the potential for competition for prey; and (4) other analyses of the distribution of the Atka mackerel and pollock fisheries also indicated that there was likelihood they could affect survival and/or recovery of Steller sea lion populations (Ferrero and Fritz, 2002).

Atka mackerel is a major item in the diet of Steller sea lions in the central and western Aleutian Islands (Sinclair and Zeppelin, 2002; Zeppelin *et al.*, 2004). The Atka mackerel fishery used to concentrate in several locations, most of which were adjacent to Steller sea lion haulouts and rookeries and inside critical habitat. Lowe and Fritz (1996) presented evidence of localized depletion of Atka mackerel based on reductions in catch per unit effort over the course of the fishing season. Between 1999 and 2002, regulations were put into effect that reduced the catches from critical habitat and addressed the temporal compression problem, thus reducing the likelihood of creating localized depletions of sea lion prey (NPFMC, 2004a).

SOURCE OF FUNDS

The eastern Bering Sea, Aleutian Islands and Gulf of Alaska together support the world's largest groundfish fisheries. In the most recent (2003) economic assessment (Hiatt *et al.*, 2004) of the U.S. Exclusive Economic Zone (EEZ),[1] the commercial groundfish catch off Alaska totalled 2.2 million mt. Pollock accounted for 71% and Pacific cod for 12.1% of the total landings, and the gross value of the catch after primary processing was approximately $1.5 billion (F.O.B. Alaska). By weight, about half the commercial fish and shellfish harvest of the entire United States occurs in Alaska. At one time, these heavily fished waters were home to vast populations of marine mammals. Commercial exploitation of ecosystem services began after Vitus Bering's voyage in 1741, and over the next two centuries, that exploitation brought the Steller's sea cow (*Hydrodamalis gigas*) to extinction and the sea otter, northern fur seal, walrus and bowhead whale nearly to extinction (Fay, 1981). In the case of the Steller sea lion, after a steep (>15% per year) population decline in the 1980s, they were listed as threatened under the U.S. Endangered Species Act in 1990 (Ferrero and Fritz, 2002). In 1997, the population was split into western (west of 144°W) and eastern (east of 144°W) stocks, and the western stock was re-listed as endangered due to a continuing decline, e.g. in non-pups at trend sites between 1990 and 2002 of 4.3% per year (Angliss and Lodge, 2004). The eastern stock remained classified as threatened, despite a steady increase in total population counts since the 1980s. Believing that the fishery competed with the Steller sea lion for prey (groundfish), environmental organizations led by Greenpeace challenged the U.S. National Marine Fisheries Service (NMFS) in federal district court. From April 1998, the time of filing of the suit, Greenpeace versus National Marine Fisheries Service, until March 2003, the court (and Judge Thomas S. Zilly) was the effective manager of the NP commons (McBeath, 2004).

Having the court as 'manager' of the fisheries, with the potential that fisheries might be closed, concerned commercial and other interests. Senator Ted Stevens was instrumental in having legislation passed so that in fiscal year 2001, NOAA received supplemental funding to augment the scientific bases for management decisions regarding fisheries and marine mammal interactions in Alaska. In the Announcement of Opportunity for these funds, it was stated that… 'There are several possible factors causing this decline. One of these factors is commercial fishing in habitat

[1]In 1976, the United States asserted jurisdiction over fishery resources within 200 nautical miles from its shores (MSFCMA). In 1982, the United Nations Convention on the Law of the Sea created EEZs extending generally out to 200 nautical miles from the shores of all coastal states.

critical to the Steller sea lion, thought to cause a harmful reduction in Steller sea lion prey availability. To determine if other factors might be important in the decline of the western Steller sea lion population, NOAA was directed to conduct research focused on two of the other hypothesized factors, namely impacts of ocean climate regime shifts, and changes in predator/prey relationships' (e.g. http://www.pmel.noaa.gov/steller/ssl_goals.shtml, June 2005).

EMPHASIS ON SUSTAINABILITY OF ECOSYSTEM SERVICES

Recognizing the necessity of maintaining ecosystem services in the context of a broader (e.g. including quality of life) set of management objectives rather than the traditional sole focus on commercial fishery 'resources' is consistent with the intent and wording of the objectives of the NOAA Fisheries (a.k.a. National Marine Fisheries Service, NMFS). According to NMFS (2005),

> As a steward, NOAA Fisheries conserves, protects, and manages living marine resources in a way that ensures their continuation as functioning components of marine ecosystems, affords economic opportunities, and enhances the quality of life for the American public.

Ecosystem-based management and sustainability are also objectives of the NPFMC (Witherell *et al.*, 2000; NPFMC, 2002), which was established by the Magnuson Fishery Conservation and Management Act of 1976 (and revised in 1996 as the Magnuson-Stevens Fishery Conservation and Management Act, MSFCMA). Recent reports on the status of our nation's oceans also support ecosystem-based fisheries management with the goal of sustainable services and ecosystem-wide health (POC, 2003; USCOP, 2004). The Pew Oceans Commission's (hereafter 'the Commission') report emphasizes the importance of the connection between healthy ecosystems and commercial interests in its Executive Summary:

> The fundamental conclusion of the Pew Oceans Commission is that this nation needs to ensure healthy, productive, and resilient marine ecosystems for present and future generations. In the long term, economic sustainability depends on ecological sustainability.

The USCOP (2004) identified a guiding principle that '… U.S. ocean and coastal resources should be managed to reflect the relationships among all ecosystem components, including humans and non-human species and the environments in which they live. Applying this principle will require defining relevant geographic management areas based on ecosystem, rather than political, boundaries.'

The present surge of interest in the health of marine ecosystem services needs to be put into action. The path toward attaining management that follows ecosystem-based principles and policies (Fluharty *et al.*, 1999) requires a combination of research to improve the 'best scientific information available' standard (e.g. NRC, 2004a), as well as the development and application of improved management strategies. To attain sustainable ecosystem services, we must develop a better understanding of how natural forcing (e.g. climate change, disease epidemics) and human influences (e.g. fisheries harvest, direct and indirect fishing impacts to habitat, hazardous material spills) affect ecosystem function and structure. Science is a necessary, but not sufficient basis for environmental decision-making (Bryant, 2005) that can lead to sustainability; adaptive management strategies (e.g. Walters, 1996) that take into account ecological, economic and sociological factors also need to be employed.

Resilience and sustainability

Ecosystems exist in quasi-stable states in which forcing or 'shocks' can shift them into another regime of behaviour, i.e. to another quasi-stable state (Holling, 1973). Resilience is measured by the magnitude of disturbance that can be absorbed before the system redefines its structure by changing the variables and processes that control behaviour (Gunderson *et al.*, 2002). Ecosystems experiencing diminished resilience (e.g. due to excessive human pressure on a resource), which are then subjected to a shock (e.g. disease, climate change), can be pushed beyond a critical threshold (NRC, 2004b) and shifted into a new, potentially less desirable state with a reduced capacity for life-supporting services for society (Scheffer *et al.*, 2001).

SUSTAINING ECOSYSTEM SERVICES: RESEARCH CHALLENGES

While much has been elucidated in this supplement, our present knowledge of the Aleutian ecosystem function and structure is still rudimentary and needs to be improved. Improvement is necessary if we are to have a chance to distinguish natural from human forcing, thereby putting boundaries on the issues that managers must address. Sustainable use of ecosystem services is unlikely without a more comprehensive understanding of the capacity of ecosystems to provide those services (Gunderson and Holling, 2002) and the development of ecologically sound management policies. The overarching question is: what is the resilience of the Aleutian ecosystem?

Limited knowledge of biota

A basic hurdle toward answering this question is the present limited state of knowledge, particularly of biota. The limited state of knowledge is clearly illustrated by the fact that huge changes in ecosystem components (e.g. marine mammals, crabs) have occurred in the Aleutian Islands region and, with just a few exceptions (e.g. Steller's sea cow), their causes remain equivocal. Cold-water corals provide another example of both the limited nature of our knowledge and uncertain management actions in light of this reality. It is only in the last few years that the extent and potential importance of cold-water corals in the Aleutian Islands has been recognized. The Aleutian Islands may harbour the highest diversity and abundance of cold-water corals in the world, and these communities likely provide important habitat for a variety of fish and invertebrates (Heifetz *et al.*, 2005). The NPFMC recognized the need to protect the coral gardens because of their uniqueness and contribution to biodiversity and fish habitat. In February 2005, to protect Essential Fish Habitat, the Council voted to ban bottom-trawling everywhere in the Aleutians, except in the relatively small areas where commercial fishing already exists (minus a few coral-rich areas that already are off limits). Both fishermen and environmental groups applauded this act by the Council (Welch, 2005). It must be noted, however, that longlines and crab pots also damage corals and other benthic habitats, and these methods have not been restricted, except in a small subset of areas designated as Habitats of Particular Concern, where all bottom contact gear is banned.

Stock assessment provides yet another example of our limited knowledge and the potential resultant pitfalls. The most useful and essential elements of any management scheme or examination of ecosystem dynamics are the estimates of species (e.g. fish, shellfish, marine mammals and birds) abundance. This information is provided by routine trawl and hydroacoustic surveys and observer data collected on both agency-operated and chartered fishing vessels, as well as counts of seabirds and marine mammals by field crew deployments. For a particular example, in the Aleutian Island ecosystem three 'management' stocks of pollock have been identified, which probably have some degree of genetic exchange (NPFMC, 2004a). Although pollock stocks in the Gulf of Alaska and Bering Sea have been assessed by complex mathematical age-structured stock assessments for more than a decade, the development of such models for the Aleutian Islands began in 2003 only (Barbeaux *et al.*, 2003). The assessment scientists are well aware of potential pitfalls of this assessment, including: (1) the assumption that pollock are homogenously available during the 'depletion' period can confound results; (2) paucity and inconsistency of available data; and (3) substantial uncertainty in the stock structure. Thus, fishery management of one of the most important and numerous fish species in the Aleutian Islands region is severely hampered by large uncertainty. Development of ecosystem models (e.g. Aydin, 2002) provides some promise for a more complete understanding of the ecosystem, but for model simulations to approach reality, improved and expanded data collection is required.

Limited knowledge of the impact of climate change

Research issues also exist regarding the physical components of the ecosystem, namely how the atmospheric and oceanic components of the NP ecosystem will respond to global climate change (e.g. Hollowed, 1996; Schumacher and Alexander, 1999; Schumacher *et al.*, 2003). Two potential changes with relevance to the Aleutian Archipelago are: (1) storms are expected to become less severe but more frequent and be warmer and wetter than present, and (2) the volume flux of the Alaskan Stream into the Bering Sea will decrease. At the same time, the Alaska Coastal Current will likely increase due to enhanced precipitation in the Gulf of Alaska and adjacent coastal areas. The warmer, wetter scenario has occurred before and had consequences on biota (Hu *et al.*, 2003; Causey *et al.*, 2005). Further, as surface air temperatures rise, physiological rates of biota will also be affected. The change in volume flux, and associated nutrients and plankton, has a direct influence on primary and secondary production and possibly on the transfer of energy to higher trophic levels. As shelf and oceanic waters become warmer, the flora and fauna will likely also change to a more temperate species composition. The increase in water temperatures throughout the upper 250 m of the water column has already been accompanied by a decrease in salinity (Royer, 2005). In this supplement (Stabeno *et al.*, 2005), the strength of the Alaskan Stream flow through Amukta Pass was shown to be a function of the stream's location and strength. How will these characteristics change with the changing atmospheric climate? We know that eddies can block or even reverse northward flow through the passes (Reed and Stabeno, 1993). If the strength of the Alaskan stream decreases (Hollowed, 1996), will eddies become more frequent and severely impact volume transport through the Aleutian passes?

Solution: increased funding

How do we best address the questions presented above? One part of the answer is to increase funding for integrated (both biotic and abiotic) ecosystem research. As noted in recent ocean commission reports, management decisions need to be based on the best possible science. That body of knowledge is poorly funded at present:

> The nation must increase investment in ocean science and research, particularly broader ecological monitoring programmes and investigations. To support this endeavour, the Commission recommends that Congress at least double funding for basic ocean science to 1.5 billion dollars annually... (POC, 2003)

The USCOP (2004) had a similar recommendation (#25–1): 'Congress should double the federal ocean and coastal research budget over the next five years, from the 2004 level of approximately $650 million to $1.3 billion per year.' Environmental organizations have an established track record of using email campaigns to lobby legislators and thereby impact decision-making. This method and others could be used to support increases in funding for ecosystem monitoring and research. The National Research Council (NRC, 2004b) and North Pacific Research Board (NPRB) have identified integrated ecosystem studies as a central theme; NPRB presents one for the Aleutians (NPRB, 2005). The Alaska Ocean Observing System (AOOS: http://www.aoos.org, June 2005) identified pulse points for monitoring in Alaskan waters, including volume transport and water properties in Amukta Pass.

SUSTAINING ECOSYSTEM SERVICES: IMPROVING MANAGEMENT

The current state of the Aleutian Archipelago ecosystem is a result of its history that includes substantial human and natural forcings that operate on various time and space scales. Overfishing of Pacific ocean perch in the 1960s, the collapse of the red king crab fisheries, the declining population of rougheye rockfish (*Sebastes aleutianus*, ~50% decline in estimates of biomass between 1980 and 2005, NPFMC, 2004a) all demonstrate that such forcings have impacted maintenance of ecosystem services. The intersection of natural and human forcing affects the resilience of the Aleutian Islands ecosystem. Will ecosystem services remain as available as they are now? The strategy to resolve ongoing and future ecosystem issues requires the melding of well-focused research and expanding some of the present management policies, especially those that are precautionary in the face of uncertainty. In addition, strategies need to be developed for improving the use of the best scientific information by management (NRC, 2004a). Even with such strategies, however, value and policy judgments must also be made. Management needs to consider exploring new approaches that could more effectively incorporate established ecosystem-based principles and policies (e.g. Fluharty *et al.*, 1999; Witherell *et al.*, 2000; NPFMC, 2002).

Balancing economic with ecosystem considerations

In a recent action by the U.S. Congress (in an attachment to an appropriations bill), the NPFMC (NPFMC News, 2004) was instructed to apportion a quota (up to 40 000 mt) to the Aleut Corporation (an Alaskan Native organization) for a directed pollock fishery in the Aleutian Islands. (The pollock fishery had been closed by the NPFMC since the end of the 1998 season as a precautionary measure with respect to Steller sea lions.) The intent of the legislation is to provide for economic development in the community of Adak and through the Aleut Corporation. The reestablishment of Aleut presence in the Aleutian Archipelago has been an ongoing process; the Department of the Interior transferred 47 291 acres of land on Adak Island, including the former Adak Naval Air Facility, to the Aleut Corporation. Adak is in the middle of one of the world's richest fishing regions and existing facilities make it economically possible to handle primary processing on the fishing grounds and deliver higher quality seafood to demanding European consumers (http://www.alaska.net/~vwadak/, June 2005). Currently cod, crab, halibut and other groundfish are being processed.

In response to a request from the Aleut Corporation, the State of Alaska is currently exploring opening a small-boat (<60 feet) pollock fishery in state waters (≤3 miles from shore), which could impact recovery of Steller sea lion populations. This highlights the issue of mixed-agency management of an ecosystem – a state fishery within areas closed by federal agencies – as fish do not obey political boundaries. On the other hand, such a fishery provides an opportunity to conduct an adaptive management experiment comparing open versus closed fishing areas around rookeries to estimate the impact of fishing on Steller sea lions (e.g. Bowen *et al.*, 2001; NRC, 2003). The objective of such an experiment would be to determine whether commercial fishing (e.g. reduction in local fish abundance, dispersion of fish schools) is energetically costly to foraging Steller sea lions. The timing and location of fisheries relative to foraging patterns of marine mammals may prove to be a more relevant management concern than total removals. Sinclair and Zeppelin (2002) identified another potential effect of fishing by demonstrating that, for the western stock of Steller sea lions, diet diversity was highest where the population trends were most stable. In addition to identifying data and monitoring requirements to include in adaptive management options, the NRC (2003) recommended several such alternatives, identifying that the one that offered the greatest benefits with regard to increasing understanding of the effects of fisheries on Steller sea lions was to use replicated open and closed rookeries to experimentally evaluate localized fishing impact. Natural forcing, through an array of processes, has also been hypothesized as the primary factor in the changes in the Steller population. The NRC (2003) suggested that bottom-up processes invoking nutritional stress are unlikely to be the primary threat to recovery, leaving direct mortality by predation as the mostly likely candidate. If a state fishery is developed for pollock in the Aleutians, it is imperative to establish a research and monitoring programme so as not to squander this potential adaptive management opportunity to shed light on the question of potential competition between the fishery and Steller sea lions.

Declines of sea otters

Population studies in the Aleutian Islands indicate that observed declines in sea otter abundance are the result of increased adult mortality (Angliss and Lodge, 2004). One current theory proposes that predation by transient killer whales may be a leading cause of the population decline (Estes *et al.*, 1998). Estes *et al.* (1998) support this with observations of a significant increase in killer whale attacks on sea otters during the 1990s, scarcity of beach-cast otter carcasses, and markedly lower mortality rates for sea otters in a sheltered lagoon (where killer whales cannot go) compared with an adjacent exposed bay. The NRC (2003) notes that a switch of fewer than four killer whales to feeding exclusively on sea otters could account for the additional annual mortality in the central Aleutians during the rapid decline of the sea otter population.

Angliss and Lodge (2004) noted that sea otter abundance in southwestern Alaska is not likely to be significantly affected by commercial fishery interactions at present; there is virtually no fishing activity for their primary invertebrate prey in the region. While the catastrophic release of oil has the potential to take large numbers of sea otters, there is no evidence that routine oil and gas development and transport have had a direct impact on the southwestern Alaska sea otter stock. Other potential threats to sea otter populations include natural fluctuations, such as disease or predation, and indirect effects of other human activities. Disease, starvation and contaminants are not presently indicated in the Aleutians, however further evaluation of these factors is warranted along with additional investigation of the predation hypothesis to better elucidate the cause(s) of the decline. Sea otters play an important role in maintaining the coastal ecosystems they inhabit. In nearshore kelp beds, sea otters function as keystone species, strongly influencing ecosystem functions. In the Aleutian Archipelago, sea urchins are a dominant herbivore and an important food source for sea otters (Estes *et al.*, 1998). In areas of reduced sea otter abundance, sea urchin populations are released from the control of sea otter predation, and urchins overgraze the kelp forests, creating so-called urchin barrens. As detached kelp is swept away, fish and invertebrates lose protective cover, and an important source of organics is lost from the nearshore areas (Estes *et al.*, 1998).

Threats to seabirds

Seabird foraging success may be key to overall health of species and colonies. Among the primary factors affecting food availability are: (1) spatial and temporal changes in forage fish availability due to ecosystem effects, (2) commercial fishery removals of forage fish, either through directed catch or bycatch, (3) enhancements to forage fish stock and availability due to commercial fishery removal of predators, and (4) provisioning of food to seabirds through discard and offal from commercial fisheries (NPFMC, 2004b). Local seabird reproduction will fail if food supplies are reduced below the amount needed to generate and incubate eggs, or if the specific species or size of prey needed to feed chicks is unavailable (Hunt *et al.*, 1996). Other fishery interactions occur through incidental catch of seabirds in longline and trawl fisheries.

In addition, the introduction of invasive species to the Aleutians has greatly affected bird populations through predation of eggs and young chicks. Rats invaded several islands as recently as World War II, foxes were stocked (for fur ranching) on islands with bird colonies as late as 1945, and caribou were released on Adak Island in the late 1950s (Ebbert and Byrd, 2002). Although most rat and mouse introductions were accidental, other rodents (deer mice, arctic ground squirrels, voles and shrews) were intentionally stocked by fox ranchers as alternate prey (http://alaska.fws.gov/nwr/akmar/whatwedo/bioprojects/restorebiodiversity/

historical.htm, June 2005). Rats extirpate most species of burrow-nesting seabirds, and they probably reduce populations of shorebirds and other ground-nesting species. The formerly endangered Aleutian Canada goose provides an example. Listed as endangered in 1967 because of predation by Arctic foxes, these birds were particularly vulnerable to such an unprecedented land predator (Bailey, 1993). Removal of foxes, reintroduction of the geese, and protection of many breeding locations reestablished the Aleutian populations of the Aleutian geese, a remarkable success story in the Aleutians.

Contaminants and shipping

The Aleutian ecosystem faces other challenges from human forcing. Studies show that sea otters and bald eagle eggs from the western Aleutians carry potentially harmful levels of DDT and other contaminants (Estes *et al.*, 1997). Although the researchers cannot pinpoint the sources of the pollutants, their distribution patterns yield some clues. PCBs may come from former military activity on some of the islands; the DDT could be windborne or waterborne contamination from agricultural use in Asia. With increasing industrialization in China, further impacts (e.g. acid rain and other pollutants) are likely to occur in the Aleutians. Finally, Unimak Pass is on the great circle route between the western U.S. and Canada and the Asian portion of the Pacific Rim, so it is a frequently used shipping traffic lane. Thus, accidents will occur, such as the M/V *Selendang Ayu*, which ran aground and spilled hundreds of thousands of gallons of oil near Unalaska Island between Skan Bay and Spray Cape in 2004. This region is especially vulnerable, as it is home to many species of fish, marine mammals, and seabirds, including several species of special concern, such as the Steller's eider (threatened), sea otters (threatened) and Steller sea lions (endangered).

TOOLS FOR SUSTAINABLE ECOSYSTEM MANAGEMENT

Adaptive management – a tool suited to the task

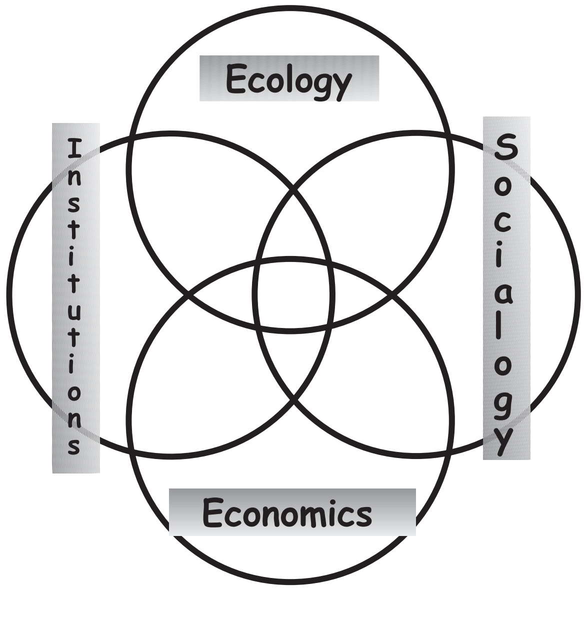
Goals of adaptive management are to improve management by 'learning by doing' and to understand the impact of incomplete knowledge (Sabine *et al.*, 2004). This approach is particularly relevant to managing ecosystem services. 'Learning by doing' is an appropriate approach given the inherent complexity of ecosystem function and dynamics. Our knowledge of the Aleutian Islands ecosystem is rudimentary at best. Understanding the consequences of incomplete knowledge (i.e. uncertainty) is necessary for management. As Goodman *et al.* (2002) noted, given scientific uncertainty, there is merit in approaching ecosystem management in the spirit of cautious experimentation. Further, they asserted that embracing uncertainty and avoiding false precision in fishery management may require us to forgo the hope of precise and finely tuned management plans, opting instead for a series of indicators that can be broadly categorized. Indicators or reference points are specific values of measurable properties of systems – ecological, social, or economic – used as benchmarks for management and scientific advice. Ecosystems are complex, adaptive systems that require flexible governance with the ability to respond to environmental feedback (Olsson *et al.*, 2004). So, the institutional and organizational landscape should be approached as carefully as the biophysical if management is to successfully attain reference points and standards. In their synthesis of adaptive management techniques, Sabine *et al.* (2004) concluded that the best outcomes require a rigorous and formalized approached to planning, collaboration, modeling (based on appropriate monitoring for inputs) and evaluation. Finally, simulating potential outcomes (i.e. developing a set of narratives of most likely scenarios) of an adaptive management cycle in the presence of existing uncertainty can help identify strategies that are most likely to succeed with respect to clearly stated goals. As one concrete example, if the State of Alaska opens a pollock fishery within State waters, then the opportunity would exist to apply this iterative process to the question of how fishing in the vicinity of a rookery impacts mortality of Steller sea lions in the Aleutians.

Integrative management – a tool for attaining sustainable ecosystem services

The Ecosystem Principles Advisory Panel to Congress (Fluharty *et al.*, 1999) recognized that ecosystems are likely to have thresholds which, when exceeded, may cause the system to shift to a new, potentially irreversible state. Defining these levels for ecosystems, however, is more difficult than for single species due to the complex interactions and greater uncertainties associated with larger numbers of parameters, and the ability to predict ecosystem behaviour is limited. This suggests that traditional reductionist disciplinary science and expert predictions, the basis for much of the advice given to managers, have limited applicability (Kay *et al.*, 1999).

Better results may be obtained through a more integrative ecosystems approach. The heart of this

Figure 2. A conceptual model that shows how sustainable management practices exist at the intersection of economics (e.g. commercial interests and personal income), ecology (e.g. scientific and conservation interests), sociology (cultural and spiritual interests), and institutional interests.



approach is the search for common ground among the various stakeholder groups or sectors (Fig. 2). The concept is that there is an inner core where the ideas, beliefs and needs of all sectors share common goals and vision. These should then form the basis of establishing policies that support the whole ecosystem. Using this conceptual model requires input from all shareholders in a collaborative process that produces integrated and adaptive management plans, strategies and actions for social, economic, environmental and institutional sustainability (Rutherford *et al.*, 2005). This model is part of the integrative management approach that is being applied in several developed countries around the world (e.g. Canada, Kay *et al.*, 1999; O'Boyle and Keizer, 2003; Rutherford *et al.*, 2005; and European member nations of the International Council for the Exploration of the Sea, Anon., 2000). The recent vote by the NPFMC to exclude vast regions in the Aleutian Islands from trawling, which was applauded by both environmentalists and commercial fishers, provides an example of attaining the common ground.

In the integrative management approach, the first step is the development of conceptual management objectives (e.g. conserve enough biodiversity, species abundance) focused on maintaining the natural resilience of the ecosystem. These objectives would be based on input from the various ocean sectors (commercial fishing and non-governmental organizations, government agencies, science and other shareholders, etc.) and would be designed to address all dimensions of sustainable development (environmental, social, economic and institutional). The next step is that these conservational objectives are then transformed into operational objectives that explicitly state indicators and reference points. For example, if the conservational objective is to maintain biodiversity of benthic communities, then the operational objective is to maintain the area of disturbance within limits. The ecosystem indicator could be the actual percentage of area disturbed and the reference point could be the percentage of area disturbed that does not irreversibly impact the resilience of the benthic community (based on the best science available). Finally, management actions then allocate the percentage of area allowed to be disturbed to each sector (e.g. commercial fishing, oil and gas development, marine protected areas). In addition to indicators that provide direct feedback on the objectives, there are indicators of ecosystem state (e.g. NPFMC, 2004b) that provide information on forcing external to managed activities that could influence the selection and adjustment of reference points.

Canada has embarked on Integrated Management[2] planning for the Eastern Scotian Shelf (O'Boyle and Keizer, 2003; Rutherford *et al.*, 2005). Similar plans are already in development for other U.S. waters (e.g. Chesapeake Bay Fisheries Ecosystem Advisary Panel, 2005), and a wealth of information regarding tenets, principles, and other guidance for sustaining healthy marine ecosystems exist (e.g. Fowler, 2003; Pikitch *et al.*, 2004). To apply this type of approach to Alaskan marine ecosystems such as the Aleutians requires cooperation among all agencies with management mandates. For example, for fisheries only, the agencies include NMFS, NPFMC, Alaska Board of Fisheries, Alaska Department of Fish and Game, and Alaska Commercial Fisheries Entry Commission. To highlight just how complex the management landscape is, consider that for seabirds the USFWS is the lead Federal agency and is responsible for monitoring distribution, abundance, and population trends, where all species are protected under the U.S. Migratory Bird Treaty Act (16 USC 703 et seq.). The U.S. Geological Survey-Biological Resources Division (USGS-BRD)

[2]See Canada Department of Fisheries and Oceans Integrated Management: http://www.dfo-mpo.gc.ca/canwaters-eauxcan/oceans/im-gi/index_e.asp, August 2005.

plays a critical role in seabird research in Alaskan waters in support of these activities, focusing primarily on seabird colonies. Additionally, the NMFS, with its fisheries management responsibilities, plays a critical role in working with industry and other agencies to focus on characterizing seabird incidental takes and reducing incidental takes in commercial fisheries. Multiple state and federal agencies are likewise involved in marine mammal research and management. To develop a realistic integrated ecosystem services management plan for the Aleutians requires that all of the above agencies coordinate with the shareholder community, which includes such sectors as commercial and recreational fishing, subsistence, conservation, oil and gas development, coastal development, shipping, tourism, etc. One way to accomplish this cooperation is for NPFMC and NMFS to establish from all these sectors a panel with a balanced membership whose mandate is to develop a Sustainable Ecosystem Services Plan for the Aleutian Archipelago.

A suite of options for special management of the Aleutian Islands region is currently being considered by the NPFMC. The Scientific and Statistical Committee (SSC) of the NPFMC recognized that an opportunity exists for the council to be proactive and develop the first fishery ecosystem plan for Alaskan waters:

> The SSC received the [NPFMC] staff presentation [a summary of a paper they prepared] …on future management alternatives for the Aleutians, including a special management area within the BSAI (Bering Sea & Aleutian Islands) FMP [Fisheries Management Plan], a separate FMP for the Aleutian Islands, or a fishery ecosystem plan. The motivation for this paper was the recurrent focus of management issues in the Aleutian Islands, including Steller sea lions, pollock stock issues, the pollock allocation to the Aleut Corporation, the discovery of cold-water coral gardens, and issues related to habitat (SSC, 2004)

Establishing a fishery ecosystem or sustainable ecosystem services plan for the Aleutians could be the first step toward establishing similar plans throughout Alaskan waters. These opportunities give us cause for optimism about the future of the Aleutian Islands marine ecosystem.

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REFERENCES

Angliss, R.P. and Lodge, K.L. (2004) Alaska marine mammal stock assessments, 2003. *NOAA Tech. Mem.* NMFS-AFSC, Vol. 144, 230 pp.

Anon. (2000) Report of the study group on ecosystem assessment and monitoring. *ICES C.M. 2000/E:09 Ref.: ACME.* http://www.ices.dk/products/CMdocs/2000/CM2000.pdf [accessed on ?? June 2005], 43 pp.

Anon. (2003) *Ecosystems and Human Well-being. A Report of the Conceptual Framework Working Group of the Millennium Ecosystem Assessment.* Washington, D.C.: Island Press. http://pubs.wri.org/pubs_pdf.cfm?PubID=3927 [accessed on ?? June 2005], 266 pp.

Aydin, K.Y. (2002) North Pacific models of the Alaska Fisheries Science Centre and selected other organizations. In: *Appendix F of the GEM Program Document.* http://www.evostc.state.ak.us/gem/documents.html [accessed on ?? June 2005].

Bailey, E.P. (1993) *Introduction of Foxes to Alaskan Islands - History, Effects on Avifauna, and Eradication.* Washington, DC: United States Department of Interior. U.S. Fish and Wildlife Service Resource Publication 193, 53 pp.

Barbeaux, S., Ianelli, J.N. and Brown, E. (2003) Aleutian Islands walleye pollock SAFE. In: *Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. N. Pac. Fish. Mgmt. Counc.* **1A:**839–888.

Beamish, R.J., Benson, A.J., Sweeting, R.M. and Neville, C.M. (2004) Regimes and the history of the major fisheries off Canada's west coast. *Progr. Oceanogr.* **60:**355–386.

BEST (2004) *Bering Ecosystem Study Science Plan.* Fairbanks, AK: Arctic Research Consortium of the US, 82 pp.

Bond, N.A., Overland, J.E., Spillane, M. and Stabeno, P.J. (2003) Recent shifts in the state of the North Pacific. *Geophys. Res. Lett.* **30:**2183–2186.

Bowen, W.D., Harwood, J., Goodman, D. and Swartzman, G.L. (2001) *Review of the November 2000 Biological Opinion and Incidental Take Statement with Respect to the Western Stock of Steller Sea Lion, with Comments on the Draft August 2001 Biological Opinion. Final Report.* Anchorage, AK: N. Pac. Fish. Mgmt. Counc.

Bryant, B. (2005) Lessons from the interface of science and law in fisheries management. In: *Summary Proceedings Improving Fishery Management: Melding Science and Governance.* W.S. Wooster (ed.) Seattle, WA: School of Marine Affairs, Univ. Washington, pp. 41–42.

Causey, D., Corbett, D.G., Lefevre, C. *et al.* (2005) The palaeoenvironment of humans and marine birds of the Aleutian Islands: three millennia of change. *Fish. Oceanogr.* **14(Suppl. 1):**259–276.

Coyle, K.O. (2005) Zooplankton distribution, abundance and biomass relative to water masses in eastern and central Aleutian passes. *Fish. Oceanogr.* this issue.

Dragoo, D.E., Byrd, G.V. and Irons, D.B. (2004) Breeding status, population trends and diets of seabirds in Alaska, 2002. *U.S. Fish and Wildl. Serv. AMNWR* **04/15:**91.

Ebbert, S.E. and Byrd, G.V. (2002) Eradication of invasive species to restore natural biological diversity on Alaska Maritime National Wildlife Refuge. In: *Turning the Tide: The Eradication of Invasive Species*. C.R. Veitch & Clout, M.N. (eds) Switzerland and Cambridge, UK: IUCN SSC Invasive Species Specialist Group, pp. 102–109.

Eberhardt, L.L., Sease, J.L. and DeMaster, D.P. (in press) Projecting the trend of Steller sea lion populations in Western Alaska. *Mar. Mamm. Sci.*

Estes, J.A., Bacon, C.E., Jarman, W.M., Norstrom, R.J., Anthony, R.G. and Miles, A.K. (1997) Organochlorines in sea otters and bald eagles from the Aleutian Archipelago. *Mar. Pollut. Bull.* **34:**486–490.

Estes, J.A., Tinker, M.T., Williams, T.M. and Doak, D.F. (1998) Killer whale predation on sea otters linking oceanic and near shore ecosystems. *Science* **282:**473–476.

Fay, F.H. (1981) Marine mammals of the eastern Bering Sea shelf: an overview. In: *The Eastern Bering Sea Shelf: Oceanography and Resources*, Vol. II (D.W. Hood & J.A. Calder (eds) Seattle, WA: Univ. Washington Press, pp. 807–811.

Ferrero, R.C. and Fritz, L.W. (2002) Steller sea lion research and coordination: a brief history and summary of recent progress. *NOAA Tech. Mem.* NMFS-AFSC **129:**42 pp. http://www.ntis.gov/, PB2002107912.

Chesapeake Bay Fisheries Ecosystem Advisory Panel (National Oceanic and Atmospheric Administration Chesapeake Bay Office). (2005). *Fisheries Ecosystem Planning for the Chesapeake Bay*. Bethesda, MD: American Fisheries Society, Trends in Fisheries Science and Management 3.

Fluharty, D., Aparicio, P., Blackburn, C. *et al.* (1999) *Ecosystem-based fishery management. Report to Congress.* ????: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 54 pp available from http://www.nmfs.noaa.gov/sfa/EPAPrpt.pdf [accessed June 2005].

Fowler, C.W. (2003) Tenets, principles, and criteria for management: the basis for systemic management. *Mar. Fish. Rev.* **65:**1–55.

Goodman, D., Mangel, M., Parkes, G. *et al.* (2002) *Scientific Review of the Harvest Strategy Currently used in the BSAI and GOA Groundfish Fishery Management Plans*. Anchorage, AK: N. Pac. Fish. Mgmt. Counc., unpublished report, 153 pp.

Gunderson, L.H. and Holling, C.S. (2002) (eds) *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, D.C.: Island Press, 448 pp.

Gunderson, L., Holling, C.S., Pritchard, L. and Peterson, G.D. (2002) Resilience. In: *The Encyclopedia of Global Environmental Change, Vol. 2, The Earth System: Biological and Ecological Dimensions of Global Environmental Change*, pp. 530–531 (ISBN 0-471-97796-9).

Hare, S.R. and Mantua, N.J. (2000) Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Progr. Oceanogr.* **47:**103–146.

Heifetz, J., Wing, B.L., Stone, R.P., Malecha, P.W. and Courtney, D.L. (2005) Corals of the Aleutian Islands. *Fish. Oceanogr.* **14(Suppl. 1):**131–138.

Hiatt, T., Felthoven, R., Seung, C. and Terry, J. (2004) *Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Island area: economic status of the groundfish fisheries off Alaska, 2003*. Seattle, WA: Alaska Fisheries Science Center, 142 pp http://www.afsc.noaa.gov/refm/docs/2004/economic.pdf [accessed June 2005].

Higgins, P.A.T. and Vellinga, M. (2004) Ecosystem responses to abrupt climate change: teleconnections, scale and the hydrological cycle. *Clim. Change* **64:**127–142.

Holling, C.S. (1973) Resilience and stability of ecological systems. *Ann. Rev. Ecol. Syst.* **4:**1–23.

Hollowed, A.B. (1996) Report on the climate change and carrying capacity of the North Pacific ecosystem. *GLOBEC Rep.* **15:**99.

Hollowed, A.B., Hare, S.R. and Wooster, W.S. (2001) Pacific basin climate variability and patterns of northeast Pacific marine fish production. *Progr. Oceanogr.* **49:**257–282.

Hu, F.S., Kaufman, D., Yoneji, S. *et al.* (2003) Cyclic variations and solar forcing of Holocene climate in the Alaskan subarctic. *Science* **301:**1890–1892.

Hunt, G.L., Jr. and Stabeno, P.J. (2005) Oceanography and ecology of the Aleutian Archipelago: spatial and temporal variation. *Fish. Oceanogr.* **14(Suppl. 1):**292–306.

Hunt, G.L., Jr, Kitaysky, A.S., Decker, M.B., Dragoo, D.E. and Springer, A.M. (1996) Changes in the distribution and size of juvenile walleye pollock as indicated by seabird diets at the Pribilof Islands and by bottom trawl surveys in the eastern Bering Sea. In: *Ecology of Juvenile Walleye Pollock, Theragra chalcogramma*. R.D. Brodeur, P.A. Livingston, T.R. Loughlin & A.B. Hollowed (eds) *NOAA Tech. Rep. NMFS* **126:**133–147.

Jahncke, J., Coyle, K.O. and Hunt, G.L. (2005) Seabird distribution, abundance, and diets in the central and eastern Aleutian Islands. *Fish. Oceanogr.* **14(Suppl. 1):**160–177.

Kay, J.J., Regier, H.A., Boyle, M. and Francis, G. (1999) An ecosystem approach for sustainability: addressing the challenge of complexity. *Futures* **31:**721–742.

Ladd, C.A., Hunt, G.L., Jr, Mordy, C.W., Salo, S.A. and Stabeno, P.J. (2005a) Marine environment of the eastern and central Aleutian Islands. *Fish. Oceanogr.* **14(Suppl. 1):**22–38.

Ladd, C.A., Jahncke, J., Hunt, G.L., Jr, Coyle, K.O. and Stabeno, P.J. (2005b) Hydrographic features and seabird foraging in Aleutian Passes. *Fish. Oceanogr.* **14(Suppl. 1):**178–195.

Livingston, P. (1995) *The Trophic Interactions Program: Improving Multispecies Models Using a Data-based Approach*. Seattle, WA: AFSC Quarterly Report July-August-September, 6 pp http://www.afsc.noaa.gov/Quarterly/Features/feature_jas95.pdf [accessed June 2005].

Lowe, S.A. and Fritz, L.W. (1996) Atka mackerel. In: *Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska Region as Projected for 1997*. Gulf of Alaska Plan Team (ed.) Anchorage, AK: N. Pac. Fish. Mgmt. Counc., pp. 331–361.

McBeath, J. (2004) Management of the commons for biodiversity: lessons from the North Pacific. *Mar. Pol.* **28:**523–539.
Mordy, C.W., Stabeno, P.J., Ladd, C., Zeeman, S., Wisegarver, D.P. and Hunt, G.L. (2005) Nutrients and primary production along the eastern Aleutian Island Archipelago. *Fish. Oceanogr.* **14(Suppl. 1):**55–76.
NMFS (2005) National Marine Fisheries Service – Welcome. http://www.nmfs.noaa.gov/ [accessed June 2005].
NPFMC (2002) *Responsible Fisheries Management into the 21st Century*. Anchorage, AK: N. Pac. Fish. Mgmt. Counc., 23 pp.
NPFMC (2004a) *Stock Assessment and Fishery Evaluation Report: APPENDIX A – Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions*. Anchorage, AK: N. Pac. Fish. Mgmt. Counc., 1094 pp.
NPFMC (2004b) *Stock Assessment and Fishery Evaluation Report: APPENDIX C – Ecosystem Considerations for 2005*. Anchorage, AK: N. Pac. Fish. Mgmt. Counc., 260 pp.
NPFMC (2004c) *Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions*. Anchorage, AK: N. Pac. Fish. Mgmt. Counc., 235 pp.
NPFMC News (2004) *North Pacific Fishery Management Council News and Notes*, Vol. 1-04. Anchorage, AK: N. Pac. Fish. Mgmt. Counc., p. 7.
NPRB (in press) *North Pacific Research Board Science Plan*. Anchorage, AK: North Pacific Research Board. http://www.nprb.org/ [accessed June 2005].
NRC (2003) *Decline of the Steller Sea Lion: Untangling Food Webs and Fishing Nets*. Washington, D.C: National Academy Press, 202 pp.
NRC (2004a) *Improving the Use of the 'Best Scientific Information Available' Standard in Fisheries Management*. Washington, D.C: National Academy Press, 105 pp.
NRC (2004b) *Developing a Research and Restoration Plan for Arctic-Yukon-Kuskokwim (Western Alaska) Salmon*. Washington D.C.: National Academy Press, 165 pp.
O'Boyle, R. and Keizer, P. (2003) Proceedings of three workshops to investigate the unpacking process in support of ecosystem-based management. Dartmouth, Nova Scotia, February-July 2002, *Can. Sci. Advis. Secret. Proc. Ser.* **2003/004:**37.
Olsson, P., Folke, C. and Berkes, F. (2004) Adaptive co-management for building resilience in social-ecological systems. *Environ. Manage.* **34:**75–90.
Orensanz, J.M., Armstrong, J., Armstrong, D. and Hilborn, R. (1998) Crustacean resources are vulnerable to serial depletion - the multifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska. *Rev. Fish Biol. Fish.* **8:**117–176.
Overland, J.E., Adams, J.M. and Bond, N.A. (1999) Decadal variability of the Aleutian Low and its relation to high-latitude circulation. *J. Clim.* **12:**1542–1548.
Overland, J.E., Bond, N.A. and Adams, J.M. (2001) North Pacific atmospheric and SST anomalies in 1997: links to ENSO? *Fish. Oceanogr.* **10:**69–80.
Palmer, M., Bernhardt, E., Chornesky, E. *et al.* (2004) Ecology for a crowded planet. *Science* **304:**1251–1252.
Piatt, J.F. and Springer, A.M. (2003) Advection, pelagic food webs and the biogeography of seabirds in Beringia. *Mar. Ornithol.* **31:**141–154.
PICES (2004) *Marine Ecosystems of the North Pacific*. Sidney, British Columbia: North Pacific Marine Science Organization, PICES Special Publication 1, ISSN 1813-8527, ISBN 1-897176-00-7, PICES Secretariat, 278 pp. http://www.pices.int/publications/special_publications/NPESR/2005/npesr_2005.aspx [accessed June 2005].
Pikitch, E.K., Santora, C., Babcock, E.A. *et al.* (2004) Ecosystem-based fishery management. *Science* **305:**346–347.
POC (2003) *America's Living Oceans: Charting a Course for Sea Change. A Report to the Nation: Recommendations for a New Ocean Policy*. Arlington, VA: Pew Oceans Commission, 166 pp. http://www.pewtrusts.org/ideas/ideas_item.cfm?content_item_id=1635&content_type_id=8&issue_name=Protecting%20ocean%20life&issue=16&page=8&name=Grantee%20Reports [accessed June 2005].
Reed, R.K. and Stabeno, P.J. (1993) The recent return of the Alaskan Stream to Near Strait. *J. Mar. Res.* **51:**515–527.
Rodionov, S., Overland, J.E. and Bond, N.A. (2005a) The Aleutian Low and winter climatic conditions in the Bering Sea, part I: classification. *J. Climate* **18:**160–177.
Rodionov, S., Overland, J.E. and Bond, N.A. (2005b) Spatial and temporal variability of the Aleutian climate. *Fish. Oceanogr.* **14(Suppl. 1):**3–21.
Royer, T.C. (2005) Hydrographic responses at a coastal site in the northern Gulf of Alaska to seasonal and interannual forcing. *Deep-Sea Res. Part II: Top. Stud. Oceanogr.* **52:**267–288.
Rutherford, R.J., Herbert, G.J. and Coffen-Smout, S.S. (2005) Integrated ocean management and the collaborative planning process: the eastern Scotian shelf integrated management (ESSIM) initiative. *Mar. Pol.* **29:**75–83.
Sabine, E., Schreiber, G., Bearlin, A.R., Nicol, S.J. and Todd, C.R. (2004) Adaptive management: a synthesis of current understanding and effective application. *Ecol. Manage. Restor.* **5:**177–182.
Scheffer, M., Carpenter, S., Foley, J., Folke, C. and Walker, B. (2001) Catastrophic regime shifts in ecosystems. *Nature* **413:**591–596.
Schumacher, J.D. and Alexander, V. (1999) Variability and role of the physical environment in the Bering Sea ecosystem. In: *Dynamics of the Bering Sea*. T.R. Loughlin & K. Ohtani (eds) Fairbanks, AK: Alaska Sea Grant Rep. AK-SG-99-03, pp. 147–160.
Schumacher, J.D. and Stabeno, P.J. (1998) The continental shelf of the Bering Sea. In: *The Sea, Volume 11, Regional Studies and Syntheses*. A.R. Robinson & K.H. Brink (eds) New York: John Wiley & Sons, Inc., pp. 789–822.
Schumacher, J.D., Bond, N.A., Brodeur, R.D., Livingston, P.A., Napp, J.M. and Stabeno, P.J. (2003) Climate change in the southeastern Bering Sea and some consequences for biota. In: *Large Marine Ecosystems of the World: Trends in Exploitation, Protection, and Research*. G. Hempel & K. Sherman (eds) Amsterdam: Elsevier Science, pp. 17–40.
Sinclair, E.H. and Zeppelin, T.K. (2002) Seasonal and spatial differences in diet in the western stock of Steller sea lions (*Eumetopias jubatus*). *J. Mammal.* **83:**973–990.
SSC (2004) *Scientific and Statistical Committee Minutes – December 2004*. Anchorage, AK: N. Pac. Fish. Mgmt. Counc., http://www.fakr.noaa.gov/npfmc/minutes/SSC1204.pdf [accessed June 2005].
Stabeno, P.J., Schumacher, J.D. and Ohtani, K. (1999) Physical oceanography of the Bering Sea. In: *Dynamics of the Bering Sea*. T.R. Loughlin & K. Ohtani (eds) Fairbanks, AK: Alaska Sea Grant Rep. AK-SG-99-03, pp. 1–28.

Stabeno, P.J., Kachel, D.G., Kachel, N.B. and Sullivan, M.E. (2005) Observations from moorings in the Aleutian Passes: temperature, salinity and transport. *Fish. Oceanogr.* **14(Suppl. 1):**39–54.

Stabeno, P.J., Hunt, G.L., Jr, Napp, J.M. and Schumacher, J.D. (2005) Physical forcing of ecosystem dynamics on the Bering Sea shelf. In: *The Sea*, Vol. 14, A.R. Robinson & P.H. Brink (eds) Cambridge, MA: Harvard University Press.

Trenberth, K.E. and Hurrell, J.W. (1994) Decadal atmospheric-ocean variations in the Pacific. *Clim. Dyn.* **9:**303–319.

USCOP (2004) *An Ocean Blueprint for the 21st Century*. Washington, D.C.: Final Report of the U.S. Commission on Ocean Policy, 2004, 610 pp. http://www.oceancommission.gov/documents/full_color_rpt/welcome.html [accessed June 2005].

USFWS (2002) *Birds of Conservation Concern 2002*. Arlington, VA: U.S. Fish and Wildlife Service, Division of Migratory Bird Management, 99 pp. http://migratorybirds.fws.gov/reports/bcc2002.pdf [accessed June 2005].

Walters, C. (1996) Information requirements for salmon management. In: *Pacific Salmon and Their Ecosystems: Status and Future Options*. R.J. Naiman & D. Stouder (eds) New York: Chapman Hall, pp. 61–68.

Welch, C. (2005) Coral concerns spur vast trawling ban. The Seattle Times, 11 February 2005, http://seattletimes.nwsource.com/html/localnews/2002177305_coral11m.html [accessed June 2005].

Wikipedia (2005) Aleutian Islands. http://en.wikipedia.org/wiki/Aleutian_Islands [accessed June 2005].

Williams, J.C., Byrd, V.G. and Konyukhov, N.B. (2003) Whiskered auklets *Aethia pygmaea*, foxes, and how to right a wrong. *Mar. Ornithol.* **31:**175–180.

Witherell, D., Pautzke, D.C. and Fluharty, D. (2000) An ecosystem based approach for Alaska groundfish fisheries. *ICES J. Mar. Sci.* **57:**771–777.

Wooster, W.S. (1992) King crab dethroned. In: *Climate, Variability, Climate Change and Fisheries*. M.H. Glanz (ed.) New York: Cambridge University Press, pp. 14–30.

Zeppelin, T.K., Tollit, D.J., Call, K.A., Orchard, T.J. and Gudmundson, C.J. (2004) Sizes of walleye pollock (*Theragra chalcogramma*) and Atka mackerel (*Pleurogrammus monopterygius*) consumed by the western stock of Steller sea lions (*Eumetopias jubatus*) in Alaska from 1998 to 2000. *Fish. Bull.* **102:**509–521.