DRAFT

Bering Sea Ecosystem Research Plan

For copies of the report contact:

Pat Livingston
Alaska Fisheries Science Center
National Marine Fisheries Service
7600 Sand Point Way, NE
Seattle, Washington 98115-0070
(206) 526-4242

Ron McCoy
Office of the Secretary
Department of the Interior
1689 C Street, Suite 100
Anchorage, Alaska 99501-5151
(907) 271-5485

Gordon Kruse
Alaska Department of Fish and Game
Commercial Fish Management and Development
PO Box 25526
Juneau, Alaska 99802-5526
(907) 465-6106

September 1998

Preface

On December 4 and 5, 1997, the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Interior (USDOI), and the Alaska Department of Fish and Game (ADF&G) sponsored a Bering Sea Ecosystem Workshop in Anchorage, Alaska. The purpose of the workshop was to promote research coordination and data sharing among organizations that study, manage, and utilize resources of the Bering Sea. One of the recommendations of the workshop led to the development of an integrated Bering Sea ecosystem research plan.

Scientists from NOAA, the USDOI, and ADF&G completed a first draft of this research plan on April 24, 1998. This draft was distributed for broader review and consideration by other groups involved in the Bering Sea and a second Bering Sea Ecosystem Workshop was held on June 2 and 3, 1998 in Anchorage, Alaska to receive further input on the research plan from these other groups. The draft plan contained herein incorporates these comments.

Contents

Bering Sea Ecosystem Research Plan

Vision of the Bering Sea

We envision a productive, ecologically diverse Bering Sea ecosystem that will provide long-term, sustained benefits to local communities and the nation.

The Bering Sea is the most productive marine ecosystem off the coast of the United States and one of the most productive in the world. Over the last few years observed changes elicit our concern for the status of the ecosystem and help shape our vision for its future. Attaining our vision requires incorporation of traditional knowledge and implementation of coordinated research to improve our understanding of how this extraordinary ecosystem functions and how to manage it wisely. Coordinated research must focus on vital management issues that that relate to the ecosystem and provide methods to improve prediction of ecosystem production and status. Key aspects of implementing this research strategy are sustained support, coordination, communication, and involvement of local communities and stakeholders. Finally, we must translate traditional knowledge and scientific understanding into advice that will be help managers develop dynamic management policies that promote optimal consumptive and non-consumptive uses of present Bering Sea resources, anticipate changes in resource abundance and distribution, and ultimately reduce the uncertainty in the decisions that we make regarding use of marine biological resources and their environment.

Introduction

The Bering Sea is one of our nation's richest marine resources. In the last few years, at least ten agencies and institutions have expressed concerns about environmental changes being observed in the Bering Sea and have developed science plans addressing aspects of the ecosystem. Many of these agencies participated in a Bering Sea Ecosystem Workshop held in Anchorage, Alaska, on December 4th and 5th, 1997 (Bering Sea Organizing Committee 1997). One of the recommendations from this workshop is to develop an integrated Bering Sea Ecosystem Science Plan and this is the primary purpose of this document. Coincidentally, Congress created an Environmental Improvement and Restoration Fund to be administered by a North Pacific Research Board to "conduct research activities on or relating to the fisheries or marine ecosystems in the North Pacific Ocean, Bering Sea, and Arctic Ocean (including any lesser related bodies of water)." It is hoped that this draft Bering Sea Research and Implementation Plan might serve the North Pacific Research Board (NPRB) in guiding needed research in the Bering Sea. Later, similar science plans will need to be developed for the North Pacific Ocean and Arctic Ocean.

Rather than duplicating previous efforts, our intent is to integrate the recommendations of all concerned programs and institutions and synthesize recent research plans and recommendations (Appendix) developed by the National Research Council (NRC); Bering Sea Impacts Study (BESIS); Arctic Monitoring and Assessment Program (AMAP); Global Ecosystem Dynamics (GLOBEC); North Pacific Marine Science Organization (PICES); and the National Oceanic and Atmospheric Administration (NOAA) through the Arctic Research Initiative (ARI), Fisheries-Oceanography Coordinated Investigations (FOCI), Coastal Ocean Program's Bering Sea FOCI and Southeast Bering Sea Carrying Capacity (SEBSCC), and the Marine Mammal Protection Act (MMPA) Bering Sea Ecosystem Study. In addition to these research plans specific to the

Bering Sea, a number of other planning efforts have resulted in research plans for marine resources off the coast of Alaska. Such relevant efforts include: (1) Alaska Regional Marine Research Board's Alaska Research Plan (ARMRP 1993), (2) Minerals Management Service's Alaska Environmental Studies Strategic Plan, FY 1999-2000 (MMS 1997), (3) future research needs for North Pacific flatfish (Smith 1995), (4) crab research needs identified at an international crab symposium (Paul 1996), (5) an interagency long-term plan for crab research (Kruse 1996), (6) future research needs for rockfish (Clasby 1987), and (7) research needs on forage fishes (Hay 1997). We feel that a sound, integrated Bering Sea Ecosystem Research Plan can be developed by synthesizing these accumulated research recommendations, recognizing those needs that have been addressed by recent and ongoing programs, and identifying remaining gaps in knowledge.

Background

Description of the Bering Sea

The Bering Sea, a northern extension of the North Pacific Ocean, is the world's third-largest semi-enclosed sea. Its wide eastern shelf makes up about half its total area. The Bering Sea is home to a rich variety of biological resources, including the world's most extensive eelgrass beds; at least 450 species of fish, crustaceans, and mollusks; 50 species of seabirds; and 25 species of marine mammals. The abundant fish and wildlife of the Bering Sea have supported the lives and livelihoods of Asians and North Americans since prehistoric times. Presently, the U.S. Bering Sea fishery contributes over half of the nation's fishery production, with a total commercial catch value of one billion dollars in 1997. Walleye pollock comprise much of the fish landings, Bristol Bay supports the world's largest sockeye salmon fishery, and the snow crab fishery is currently the largest crustacean (by weight) fishery in the U.S. In addition to supporting a large portion of the nation's fishery production, the Bering Sea also supports 80% of the U.S. seabird population comprising 36 million birds of 35 species. Furthermore, many unique and endemic species such as red-legged kittiwakes and whiskered auklets are found in the Bering Sea and further highlight the significance of this region. A variety of recent agreements designed to protect marine mammals, birds, and fish resources have been adopted by the United States, other nations, and international organizations interested in the Bering Sea. Despite these agreements, some species of the Bering Sea and adjacent regions have undergone large and sometimes sudden population fluctuations. While the root cause of these fluctuations is still unknown, they could be a reflection of either natural, climate related changes or human-induced change.

The Bering Sea is always changing. Large-impact, easily documented perturbations recently occurred that can be attributed to climate fluctuations or human impact on the ecosystem. The relatively warm and calm summer of 1997, for example, brought a rare bloom of coccolithophores, a phytoplankter more typical of nutrient-limited subpolar waters, a massive die-off of marine birds, and a commercial fishery failure in Bristol Bay salmon. Human-induced change in consort with climate change is a premise of the Cascade Hypothesis proposed by the National Research Council in 1996. The hypothesis relates declines in some sea bird, sea lion, and seal abundances during the last two decades to substantial removals of fish and whales from the mid-1950s to the early 1970s and pollock-favorable environmental conditions associated with a decadal regime shift in the late 1970s.

Brief history of ecosystem research

Much of the early ecosystem research in the eastern Bering Sea was conducted to address questions related to the international fishery. Between the mid-1970s and late 1980s, additional issues became important. There were resource assessments over much of the eastern shelf as part of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), ecosystem research over the southeastern (Processes and Resources of the Bering Sea -- PROBES) and northern (Inner Shelf Transfer and Recycling in the Bering and Chukchi Seas -- ISHTAR) shelf, and examination of ice related phenomenon (Bering Sea Marginal Ice Zone Experiment -- BS MIZEX).

In the 1990s, the Bering Sea ecosystem received even more attention, due in part to the collapse of the U.S. fishery on the New England continental shelf. The scope of research has broadened to consider the ecosystem in its entirety, with a focus on integrated, multidisciplinary studies that include studies of ocean processes to ecosystem interactions (e.g., Southeast Bering Sea Carrying Capacity—SEBSCC, Arctic Research Initiative --ARI, and Seabird, Marine Mammal and Oceanography Coordinated Investigations—SMMOCI). Summaries of recent programs, their histories, and scientific issues are presented in the appendix of this document.

Fishery and ecosystem management issues and concerns

Not all previous Bering Sea scientific plans have explicitly outlined the key management issues that drive the need for research. However, there are presently many management issues that require a focused research program, particularly issues that are linked to concerns about the ecosystem. Some management issues are particularly acute because they require immediate action in the face of uncertain scientific knowledge. Other issues require a long-term commitment to research.

The most pressing management issues concern the possible effects of humans on the ecosystem. Perhaps the greatest concerns involve the potential effects of fishing on endangered or threatened marine mammals, and seabirds, and on benthic communities and habitats. Although the direct impacts of fisheries on some of these groups has been studied, the nature and extent of the indirect or food chain effects of fishing are unknown. Specific concerns include localized depletion of prey by fishing in important mammal foraging areas, effects of fishing activities on attached invertebrates and bottom habitat structures that may provide important food and cover for some species, effects of discards on benthic predator-prey dynamics, potential effects of removal of carbon on long-term productivity of the system, and possible effects of truncated size structure on predator-prey dynamics and on a fished population’s ability to withstand periods of poor recruitment.

Despite the scarcity of scientific studies on these areas of concern, fisheries have been restricted in many areas and at certain times of year to mitigate possible effects of fishing on different ecosystem components. Examples include closures due to concerns about benthic habitat in areas important to red king crab and concerns about forage species near sea lion rookeries. However, these restrictions were made with little information to guide managers. It is not known whether these actions are having the desired effect or whether different measures might be more effective. Regardless, these restrictions have had negative effects on some commercial fisheries, and so there are costs associated with lack of information. Directed research on the effects of fishing on the ecosystem is required to help fisheries managers make better informed decisions.

Other concerns from human activity include effects of large-scale salmon enhancements, coastal development in sensitive shallow-water nursery areas, mitigation of past introductions of non-native species on islands, prevention and detection of introduction of exotic species via ballast water or live tanks, and introduction of contaminants, plastics, and other materials into the environment. The build-up of contaminants poses a potential threat to marine populations and to sustainable subsistence and commercial use of living marine resources of the Bering Sea. An understanding and prediction of the trends in contaminant levels, especially as these relate to long-range transport from other more polluted regions, is needed to assure the maintenance of a diverse and productive Bering Sea ecosystem.

Other issues facing fishery and wildlife managers are those that relate to ensuring the long-term productivity of the resources. Decadal scale climate shifts have been linked to changes in ocean productivity and shifts in species available for harvest. Improved understanding of climate and its effects on living marine resources will assist in developing management strategies that can accommodate to changes in production and ease economic dislocations that might result from such changes. Management strategies are needed that are not solely based on steady-state models of fish production, but which also incorporate climate-induced variability in fish production. In addition, climate factors may shift the distribution and abundance of key resources such as pollock to areas outside the eastern Bering Sea where they might be exposed to a less conservative management regime. A program that focuses on understanding the effects of climate change on resource production will help managers design better management strategies.

Finally, the issue of managing the availability of marine resources to support a subsistence life style in Alaska needs to be addressed. Specifically, regarding Alaska Natives, the Marine Mammal Protection Act (MMPA), as amended in 1994, provides a direction for developing agreements as provided under Section 119 for the purpose of conserving marine mammals and providing co-management of subsistence use. At a minimum, the incidental mortality of marine mammals by commercial fisheries is to be managed under the MMPA such that the taking of animals by subsistence hunters in combination with all other takes does not compromise the health of any marine mammal stocks. That is, the priority use of marine mammals under the mandates of the MMPA is to support the subsistence life style of Alaska Natives. Further research may be required to determine the extent to which the indirect effects of commercial fisheries can adversely impact stocks of marine mammals, and subsequently impact Alaska Native subsistence hunters and their families.

Scientific issues

Many of the changes in the Bering Sea ecosystem are physically forced by climate variability. These variations include storm tracks and storm intensity that change vertical mixing and sea ice, cloud cover, thermohaline circulation, ocean currents and water mass exchange with adjacent oceans, and nutrient concentrations. Climate forcing of these oceanographic features affect the productivity and species composition of lower trophic levels which provide food for other components of the ecosystem. The distribution and abundance of upper trophic level species in the Bering Sea can be influenced by climate variability either directly or indirectly. Direct effects may be alteration of physical habitat (temperature, mixed layer depth, or bottom disturbance) and implications on growth, mortality, and reproductive success. Indirect effects may be bottom up (effects of changes at lower trophic levels) or top down (effects of predator abundance or distribution).

The combined effects of variability in physical forcing, the structure and function of food webs, commercial harvest levels, and other anthropogenic disturbances can cause changes in the Bering Sea ecosystem. Alterations in either physical forcing, or commercial harvest practices may force the ecosystem into a new state, in which a new set of species dominate. Understanding the complex biophysical system interactions, including direct and indirect effects of fishery removals, that structure the Bering Sea ecosystem is critical to determining and monitoring diversity and production. With this knowledge, not only can human-induced changes be mitigated, but management strategies can be designed that incorporate natural variability.

Overarching hypotheses

The synthesis of previous programs suggests a pair of hypotheses that span current management and science issues.

1. Natural variability in the physical environment causes shifts in trophic structure and changes in the overall productivity of the Bering Sea.
2. Human impact leads to environmental degradation, including increased levels of contaminants, loss of habitats, and increased mortality on certain species in the ecosystem that may trigger changes in species composition and abundance.

Research themes and approaches

These overarching hypotheses suggest several research themes, associated scientific questions, and approaches for answering the questions. Recommended research addresses ecosystem understanding and management, and recognizes the long-term, critical science questions that will remain when currently funded programs are completed. Research themes are variability and mechanisms in the physical environment, individual species responses, food web dynamics, contaminants and other introductions, and habitat.

Variability and mechanisms in the physical environment

Natural climate variability influences the Bering Sea on time scales from individual storms, through seasonal to interannual and on to decadal and longer periods. At present, much research throughout the North Pacific and Bering Sea is focused on the decadal scale. Climate change at decadal time scales, often referred to as regime shifts, appears to have a significant impact on the ecosystem through alterations of the nutrient-phytoplankton-zooplankton sequence (bottom-up effect) and there is ample reason to believe that significant effects also occur at higher trophic levels (top-down effect). Such changes in the ecosystem are of utmost importance to management concerns about sustaining productivity and protecting endangered species. Climate change on the decade scale originates primarily in the atmosphere and spans the North Pacific Ocean, northeastern Asia and the western Arctic. It is unclear how much decadal variability is generated in the atmosphere and how much is forced through feedback with sea ice extent, snow cover and sea surface temperature.

The Bering Sea system underwent a major change in 1977, from a cold regime to a warm regime. This change was primarily due to an intensification of the Aleutian Low over the North Pacific Ocean. The primary forcing resulting from climate change is a change in surface wind stress which in turn affects horizontal and vertical (upwelling) currents and mixing in the surface layer (mixed layer depth). Air-sea heat and moisture fluxes are also altered, as can be the location of such features as fronts and the generation of eddies. One index of climate variability suggests that a shift occurred in 1990, while another indicates that the warm regime established in the 1970s has persisted through spring 1998. Global warming occurs on longer time scales, and its effects will be superimposed on decadal and annual changes. Natural climate cycles can be influenced by anthropogenic factors, and anthropogenic variations are often masked by natural fluctuations. Knowledge of existing and emerging climate patterns is useful toward predicting impacts of climate change on the ecosystem. Determining how climatic changes are transferred via the ice-ocean system to the biota, however, is essential. An understanding of the mechanisms of interaction will permit management choices based on knowledge rather than inference.

The eastern Bering Sea consists of an oceanic and shelf regime. Within the broad (> 500 km) shelf regime, three distinct domains exist which are characterized by contrasts in water column structure, currents and biota. The balance between mixing (tidal and wind) and buoyancy flux (freshwater discharge, ice melt, solar radiation) generates the domains. In the coastal domain (bottom depths less than 50 m), tidal and wind mixing usually overlap resulting in a weakly stratified or mixed water column. These waters are separated from deeper waters by a structural front located near the 50-m isobath. The dynamics of this feature result in prolonged primary production which via zooplankton supports vast numbers of sea birds and other biota. Over the middle shelf domain (bottom depths between 50 and 100m), the overlap between the top and bottom mixed layers is limited. During summer, moderate wind stirring results in a two-layered water column where lower layer temperatures often are < 2° C throughout the summer (these waters are know as the "Cold Pool"). These two layer-waters are separated from deeper water by a very broad (> 100 km) middle front with complex dynamics. The outer shelf domain (bottom depths between 100 and 200 m) is oceanic in character with mixed upper and lower layers. A shelfbreak front (most noticeable in the horizontal gradient of salinity) exists between the shelf and oceanic waters. It is processes her that might limit the offshore flux of iron to the oceanic domain. The zooplankton community in the two shallower Domains is comprised primarily of the small (1-4mm), coastal copepods and euphausiids, whereas in the Outer Shelf Domain and in the Oceanic Regime large (4-10mm) oceanic copepods are numerically dominant.

North of ~62° N, changes in topography, tidal energy, and river discharge (Yukon River) modify the boundaries between domains. The width of both the coastal and middle shelf domain increase. North of Nunivak Island, the inner front moves to the vicinity of the 30-m isobath as tidal mixing energy decreases. In the vicinity of the Yukon River delta, freshwater discharge can result in stratification in waters <30 m. The water column (generally < 20 m) in Norton Sound typically exhibits two-layered structure during summer. During winter, strong heat and salt fluxes result in a vertically mixed water column.

South of St. Lawrence Island, three water masses exist across the shelf: Alaskan Coastal, Bering Shelf, and Anadyr. The accompanying regional salinity field is characterized by a zonal gradient with salinity decreasing from east to west. The saline waters which flow northwestward across the mouth of the Gulf of Anadyr carry relatively warm nutrient rich water, which suggests advection of outer shelf/slope water. North of St. Lawrence, all three water masses are present and can be identified as they flow northward through Bering Strait.

Time-series collected in Bering Strait of salinity and temperature confirm that Alaskan coastal waters are relatively warm with low salinity and flow through the eastern channel of the strait. Bering Shelf water is of higher salinity, but loses its identity through mixing with Anadyr water north of the strait. This latter water mass flows through the western channel of Bering Strait. The salinity data imply that ice formation extends over a large region well beyond that of the coastal polynyas.

Over the western shelf, the dominant circulation feature is the Anadyr Current, a coastal flow extending from the Gulf of Anadyr westward past Cape Navarin. In both the Gulf of Olyutorski and Karaginski Bay, quasi-stationary eddies are reported to exist, and similar features also occur in embayments along the Kamchatka coast. As with the eastern shelf, atmospheric processes that regulate the heat balance and result in formation of ice are primary features of the environment that dictate oceanographic conditions on the western shelf. Ice typically covers the entire western shelf in winter. Variability still exists, however, in terms of the amount of ice formation in a given winter and its influence on spring and summer conditions. A cold pool is an annual feature in the Gulf of Karaginski. Along the coast between Cape Navarin and Cape Olyutorski, bottom temperatures are 0.5 - 3.0°C greater than those in the inner regions of the Gulf of Karaginski. This results from transport of relatively warm slope waters that impinge on the shelf between the two capes.

A system of three hydrological zones exists over the western shelf that is somewhat analogous to those found on the eastern shelf. The coastal, transitional and oceanic zones are easily distinguished by their temperature-salinity characteristics and vertical structure. In both inner zones, a strong seasonal thermocline develops over summer. The oceanic zone is identified by a three-layered vertical structure with relatively warm bottom temperatures that indicate the presence of slope waters. The location of the zones over the western shelf are not stationary, although they can at times be associated with features of the bathymetry as occurs on the eastern shelf. The western shelf is relatively narrow and divided by peninsulas into three separate and somewhat isolated gulfs. The immense width of the eastern shelf eliminates the direct influence of oceanic circulation on all but the outer domain. Such is not the case on the western side where the Kamchatka Current has a profound impact on the location of hydrographic zones. When this current moves toward the coast and flows over the continental slope, all the zones and their frontal divisions are shifted toward the coast.

A number of ocean mechanisms are critical to the dynamics of the ecosystem, including: transport via currents, distribution of temperature, and turbulence (mixed layer depth and temperature). Ocean currents are driven by wind, tides, and the heat and salt balance in the ocean. The source waters for the Bering Sea flow through the Aleutian passes from the North Pacific Ocean and strongly influence circulation. For the eastern shelf, the Aleutian North Slope Current carries Alaskan Stream water primarily from Amchitka and Amukta Pass eastward along the north side of the Aleutian Islands, forming the Bering Slope Current in the southeastern corner of the basin.

Mean northward transport through Bering Strait, driven by a sea level difference between the Bering Sea and Arctic Ocean, provides the only connection and exchange of water between the Pacific and Atlantic Oceans in the northern hemisphere. A regional consequence of the transport is that the supply of nutrient rich water to the northern shelf upwells, thereby stimulating primary production. During ice formation, cold saline water produced over the northern shelf flows northward. Globally, this water plays a role both in maintaining the Arctic Ocean halocline and in ventilation of the deep waters. Regionally, the northward transport requires an onshelf flux of slope waters. Other mechanisms which result in basin-shelf exchange include eddies, meanders in the slope current and transport associated with topographic features. Slope waters provide as much as 50% of the annual nitrogen needed to support primary production. These mechanisms are poorly understood and their link to changes in atmospheric forcing and North Pacific circulation is also not known. Transport through Bering Strait, driven by sea level differences between the North Pacific and Arctic Oceans, will decrease if the Arctic warms to a greater extent than the North Pacific. How this will impact the flux of nutrient rich water onto the eastern shelf is not known, however there is some evidence from carbon isotope data that productivity of the Bering Sea has been declining since the mid-1960s.

At its maximum, seasonal sea ice extent fluctuates over 1000 km from north of Bering Strait in summer to the Alaska Peninsula and southeastern Bering Sea shelf break in winter. The amount of production and advection of ice depends upon storm tracks, with greatest ice production occurring in years when the Aleutian Low is well developed and winds from the north are common. Large variations (100s of km) occur in maximal sea ice extent. Other characteristics (e.g., duration of ice at its southern extent, time of retreat from the southernmost extent, and number of weeks that ice remains over the middle shelf) also vary greatly. Ice melt plays a critical role in heat and salt fluxes, generation of both baroclinic flow and water column structure, and the extent of cold bottom water located over the middle shelf. As seasonal heating occurs, the lower layer becomes insulated and temperatures often remain below 2.0 °C. It is these waters that are commonly called the "cold pool" whose area varies by about 200,000 km2 between maximum and minimum extent. The cold pool has a dramatic influence on the distribution of higher trophic level biota. The phytoplankton bloom associated with sea ice accounts for 10-65% of the total annual primary production. The dynamics of this bloom and the impact of variations in its timing and spatial extent are not well known.

Other oceanographic mechanisms influence the biological component of the ecosystem. It now appears that iron is a limiting element to primary production in large regions of the world's oceans. The source of iron in the Bering Sea is unknown. Shelf-slope exchange processes may provide the essential iron to the Green Belt (a region of implied prolonged primary production located over the outer shelf and slope). Another mechanism which affects biota through the nutrient-phytoplankton-zooplankton sequence is mixing associated with individual storms. The timing and duration of storms can re-supply nutrients and/or alter primary production and other biological processes due to changes in mixed layer depth and increased turbulence.

Processes regulating biodynamics of fronts, their productivity, and their importance to a number of ecologically- and commercially-important species are not fully understood. Structures, such as eddies and fronts, may not only be important to primary production, but they may also be important sites for retention of eggs and larvae of fish and shellfish in areas of high prey abundance needed for survival. Transport of larval animals, e.g., from oceanic spawning areas to nearshore nursery areas may be a factor in regulating recruitment.

Questions:

1. What are the mechanisms and relevant time scales of climate induced variability of the physical environment which most influences the biological changes of the ecosystem? For example, are physical environmental regime shifts the dominant factor driving major biological changes in the ecosystem?
2. Can we separate anthropogenic effects from natural variability?
3. What would be the effect of global climate warming on the physical environment and how would the predicted change affect the present species mix and productivity of the Bering Sea?
4. How does climate variability affect physical oceanographic processes (e.g., current, fronts, eddies, stratification, etc.) and, in turn, how do these processes affect biological productivity, trophic structure and yield of living marine resources?
5. How does climate variability influence seasonal production and extent of sea ice and what is the impact of such variation on primary production and the food web?
6. How does variability in micro/macro-nutrient availability affect productivity of the Bering Sea?

Possible approaches: The following categories of research approaches (retrospective analysis, monitoring, process studies and modeling) are high priorities. The examples provided are not prioritized nor exhaustive; they merely illustrate the types of research projects envisioned under each approach. Each research approach is identified with respect to feasibility – relatively easy (E), moderately difficult (M), and difficult (D) and with respect to study duration – 1-3 years (1-3), 3-5 years (3-5), and longer (>5).

Retrospective analysis: The objective is to analyze existing observations to elucidate ecosystem (both physical and biological components) status and change.

1. Establish base-line conditions (including inherent variability), e.g., sea ice, mixed layer depth, water column temperature and salinity, cold pool extent and heat content, etc., throughout the study area. [E, 3-5]
2. Establish linkages among atmosphere-ocean-sea ice system, primary production and biological energy flow. Form conceptual models from these linkages. [E, 3-5]
3. Characterize the time and space scale of climate forcing. [E, 3-5]

Monitoring: The objective is to collect physical, chemical and biological observations at pulse-points in the ecosystem.

1. Maintain and enhance time-series (both moored biophysical platforms and discrete samples) at Bering Strait, across the southeastern shelf (PROBES and Southeast Bering Sea Carrying Capacity Lines), Aleutian North Slope Current, Unimak Pass, etc. Incorporate/develop continuous biological sensors and seabird/mammal survey protocols to complement continuous physical sampling systems. Place observations on the World Wide Web in real-time. [E, >5]
2. Develop facilities and train local people to collect physical, chemical and biological observations from islands (St. Paul, St. Lawrence, etc.) and coastal villages. Include local interpretation of these observations in publically-accessible data summaries. [E, >5]
3. Initiate monitoring of the inflow of Alaskan Stream water and its chemical and biological constituents through selected passes of the Aleutian Island chain (Amukta, Amchitka, etc.). [E, >5]
4. Initiate and/or enhance ship of opportunity data collection. Provide long-term support for data analysis and dissemination. Examine the potential use of satellite collars on marine mammals. [E, >5]
5. Archive in geographical registered format and provide preliminary interpretation of all available satellite remote sensing (ice, sea surface temperature, ocean color, synthetic aperture radar, etc.) in near-real time. [E, >5]
6. Maintain or reinstate monitoring of river discharge (particularly the Yukon River). [E, >5]
7. Develop and support a minimal program to piggyback marine bird and mammal observations on suitable monitoring platforms [E, >5]

Process studies: The objective is to examine processes critical to the linkage between physical and biological processes. These typically are field and laboratory studies which could be augmented by model exercises.

1. Examine the mechanisms that determine nutrient replenishment on the continental shelves. What determines the cross-shelf flux of nutrients (both micro and macro nutrients) and what are the time-space scales of such fluxes. [M, 3-5]
2. Determine the mechanism and processes that control survival of early life history stages of commercially valuable species, marine mammals and sea bird fledglings. [M, >5] Determine the strength of the relationship between survival during early life history stages and eventual recruitment.
3. Determine how sea ice, sea surface temperature and the extent of the cold pool affect the transfer efficiency of primary production to the pelagic and benthic food webs. What is the magnitude of the influence. [M, >5]
4. Determine the role of summer storms and their attendant mixing on annual production and trophic efficiency of the Bering Sea shelf. [E, 3-5]
5. Examine the temporal and spatial scale of marine bird and mammal aggregations with respect to ephemeral and stable oceanographic features and prey aggregations [E, 3-5]

Modeling: The objective is to use models as tools to examine how the ecosystem functions and to aide retrospective studies by providing indices of the physical environment.

1. Development/implementation of a primitive equation model of the entire Bering Sea. [E, >5]
2. Incorporate submodels for: (a) nutrient-phytoplankton-zooplankton, (b) individual based models for nodal or commercially valuable species, and (c) ice dynamics. (a) [E, 1-3], (b) [E, 1-3], and (c) [M, 1-3]
3. Provide indices of transport, current patterns, eddy-fields, etc. from (1). [E, >5]
4. Examine how does climate change alters flow through the Aleutian Passes and hence circulation in the Bering Sea using (1). [M, 1-3]
5. Develop models to examine single processes, e.g., sediment resuspension (in relation to effects of bottom trawls), mixed layer stability and plankton blooms, etc. [E, 1-3]

Individual species responses to perturbations

Our understanding of status of the living marine resources in the Bering Sea ecosystem is largely confined to fish and invertebrates of commercial importance and mammals and birds readily observed from land or air. However, even this limited view of the ecosystem reveals that major changes have occurred among groundfishes, forage fishes, salmon, shellfish, marine mammals and seabirds. Many groundfish increased from the late 1970s through the mid-1980s. Since the mid-1980s, abundances of walleye pollock and Pacific cod have oscillated whereas most flatfish (e.g., yellowfin sole, rock sole, arrowtooth flounder) continued to increase to the early 1990s and remain high. Some groundfish have different trends: Greenland turbot have generally declined since the early 1970s and Pacific Ocean perch declined during the 1960s and 1970s due to overfishing by foreign fleets, increased somewhat in the 1980s and have leveled off at low to intermediate abundance levels in the 1990s.

Data on forage fishes is largely confined to Pacific herring; herring biomass in the Bering Sea is dominated by the Togiak stock. In response to two strong year classes in 1977 and 1978, the Togiak population increased from the late 1970s to mid-1980s, but has since steadily declined to intermediate levels. A smaller stock of Norton Sound herring steadily increased from the early 1980s to the early 1990s, and has since leveled off.

Knowledge of invertebrates is largely restricted to crabs. Most crab stocks declined due to decreasing recruitment during the 1970s, but patterns in the 1980s and 1990s are species-specific. Bristol Bay red king crabs have continued at low abundances although a strong 1990 year class will result in partial stock rebuilding in the near future. On the contrary, red king crabs in Norton Sound have been stable with exceptions of a very strong year class in 1969 and very weak year classes in 1970, 1971, and 1985. Blue king and Tanner crab populations increased in the 1980s due to good recruitment, but since then blue king crabs at Pribilof Islands have declined, blue king crabs off St. Matthew Island remain abundant, and Tanner crabs have declined precipitously since peaking in 1990. Snow crabs experienced good recruitment in the mid-1970s and mid- to late 1980s, and abundance is expected to peak in the late 1990s prior to a sharp decline due to impending poor recruitment.

Eastern Bering Sea salmon production (landings) cycled over time. During the 1980s and 1990s total salmon abundance has been very high, although specific runs, such as chinook and chum salmon in Western Alaska, have been poor. Most of the overall changes are attributable to well-known dominant/weak cycles of returning sockeye salmon. A sharp increase in production was reported in association with a regime shift in the late 1970s. However, this increase in production may have been exaggerated because sockeye fisheries in the Egegik, Ugashik, and northern Alaska Peninsula areas were not fully developed until the 1980s. Management and environmental changes are likely to have combined to cause decadal shifts in return per spawner indices of production.

Several marine mammal and seabird populations in the Bering Sea have undergone major changes in abundance over the past 20-30 years. Steller sea lions experienced declines over all of its Bering Sea range since about 1965, and the species is now considered “endangered” in the western (including Bering Sea) portion of its range. Fur seals also declined in the 1970s, but numbers have stabilized since the early 1980s. Sea otters increased following complete protection after 1950, but recently there had been a decline in the Aleutian Islands.

Patterns of change for marine birds has varied among species, locations, and decades in the Bering Sea over the past 20-30 years. For example, spectacled eiders on the Yukon Delta have declined since 1972, and several other species of sea ducks also seem to be declining. Storm-petrels, surface-feeding planktivores, have increased since the late 1980s at several monitoring sites in the Aleutians, whereas some of the fish-eating species have declined since the mid-1970s in the eastern Bering Sea. For example, murres, diving piscivores, experienced declines in Norton Sound between the mid-1970s and early 1980, and declines in the Pribilof Islands between 1976 and the early 1980s. In contrast, murres increased from the mid-1970s to the mid-1980s in the western Aleutians. At other sites, like Cape Peirce in Bristol Bay, no obvious trends in murre numbers have been detected during this same period. One high-profile example of population decline is for red-legged kittiwake, a Bering Sea endemic, in the Pribilof Islands between the mid-1970s and mid-1980s. The population has remained relatively stable thereafter at mid-1980s levels. Since 80% of the world's population of red-legged kittiwakes occurs at one breeding site, St. George Island, these declines are particularly noteworthy. Nevertheless, red-legged kittiwake populations have increased over the same period at Buldir Island in the western Aleutians.

The causes for most of these population changes are unknown. Declines of many mammal and bird populations are most likely to be related to prey abundance and availability. Large shifts in species composition of fishes and invertebrates are probably triggered by direct climate effects on individual species through runs of strong year classes that sustains fisheries or runs of poor year classes that lead to stock declines. Physical climatic and oceanographic factors can have direct effects on important population characteristics such as reproductive success, growth, and survival of young. Ocean currents may carry fish eggs and larvae from spawning grounds to nursery areas or to areas unfavorable to survival. Entrainment into eddies and fronts may be essential to larval retention, survival, and formation of strong year classes for some species. These same ocean features may concentrate prey at levels needed for feeding success of sea birds.

Changes in oceanographic conditions can also affect the geographic distribution and availability of a species. For instance, thick-billed murres concentrate between the shelf break front and middle front in the Southeast Bering Sea, a region of rich productivity of pelagic fish and zooplankton. Chinook salmon bycatch in domestic groundfish trawl fisheries is associated with the shelf-break front over 200 m depth contour. As another example, the geographic distribution of yellowfin sole has been related to the distribution of ice cover and formation of the cold pool. Changes in oceanographic conditions, coupled to prey availability, can cause significant changes in growth rates. Decadal changes in the growth rates of Pacific halibut prompted major changes in recent assessments of stock size and annual commercial fishery quotas.

One of the most important anthropogenic influences on the Bering Sea ecosystem is commercial fishing. Fishing can cause local depletions and may reduce overall stock abundance. When coupled to periods of low productivity, overfishing can reduce stocks so low that reproductive success may be jeopardized. Although Bering Sea fish stocks are currently conservatively managed, overfishing has occurred at times in the past. For example, it is generally thought that Pacific Ocean perch were overfished by foreign fleets prior to implementation of the Magnuson Fishery Conservation and Management Act of 1976. Even at moderate harvest rates, fishing can truncate size and age distribution of fish stocks resulting in a large reduction of mean size and age of the population. The loss of older ages may have implications on reproductive success and on a population's ability to withstand periods of poor recruitment.

Questions: Following the two overarching hypotheses in this science plan, the potential roles of anthropogenic and physical factors fall into the following two sets of general questions.

Anthropogenic
1. What are the current and projected changes in human uses (e.g., fisheries) in the Bering Sea?
2. How do different populations of indicator species or species groups respond to anthropogenic perturbation?
3. How should natural resource management systems respond to anthropogenic-induced population change?

Environmental
1. What are the patterns of spatial and temporal change in the atmosphere, ocean, and land components of the Bering Sea?
2. How do different populations of species and species groups respond to physical and biological changes in the Bering Sea?
3. How should natural resource management systems respond to physical and biological change?

Possible approaches: The following categories of research approaches (retrospective analysis, monitoring, process studies and modeling) are high priorities. The examples provided are not prioritized nor exhaustive; they merely illustrate the types of research projects envisioned under each approach. Each research approach is identified with respect to feasibility – relatively easy (E), moderately difficult (M), and difficult (D) and with respect to study duration – 1-3 years (1-3), 3-5 years (3-5), and longer (>5).

Retrospective analysis:
1. Evaluate ongoing monitoring efforts for efficiency and effectiveness (e.g., annual assessment surveys) [E, 1-3]
2. Construct or obtain databases from available information (including traditional knowledge) on indicator species (e.g., walrus harvest data from eastern and western Bering Sea, fish population reconstruction from scales preserved in anaerobic sediments) [M, 3-5]
3. Evaluate the relative impacts of anthropogenic versus physical (and biological) factors on patterns of change with appropriate long-term databases (e.g., sockeye salmon, fur seals) [M, 1-3]
4. Compile historical pelagic seabird database and analyze species distributions and abundance with respect to oceanographic features and climate change [E, 2-3]

Monitoring:

1. Build on existing monitoring programs by establishing partnerships to leverage resources (e.g., groundfish data from crab surveys, coordinated bird and mammal surveys) [E, >5]
2. Establish new monitoring programs for indicator species not currently covered (e.g., sea ducks, copepods, forage fishes) [E, >5]
3. Refine and integrate innovative methods for monitoring status and health of marine birds and mammals at rookeries (e.g., stress hormone levels, automated electronic monitoring of attendance behavior) [E, >5]

<u>Modeling:</u>

1. Conduct statistical and modeling studies on physical (and biological) factors to investigate changes in productivity (e.g., causes of strong herring year classes, ocean front formation and sea bird productivity) [E - depending on the study, 1-3]
2. Model effects of physical and biological factors to analyze alternative natural resource management strategies (e.g., effects of fish harvest on marine mammal productivity, effects of flatfish harvest on crab populations) [E – depending on the study, 1-3]
3. Develop models to forecast responses to perturbations and appropriate mitigation with a feedback loop to experimental studies (e.g., marine mammal behavioral responses to human perturbations) [M, 1-3]

<u>Process studies</u>

1. Evaluate experimental management strategies (e.g., effects of fishery closure zones on marine mammal populations, alternative harvest rates on different stocks of the same fish species, initiate target fisheries in small areas on groundfish that compete for forage with seabirds and mammals) [D, >5]
2. Evaluate causes of changes in trophic interactions (e.g., predator-prey relationships between marine mammals, cannibalism in fish) [D, >5]
3. Evaluate the effects of oceanographic features on selected species (e.g., concentrations of fish and seabirds at fronts, walrus at ice edge) [M,3-5]
4. Determine effects of coastal development on subsistence activities (e.g., habitat alterations on harvest opportunities) [M, 1-3]
5. Conduct field studies of effects of various human activities or changes in physics on animal populations (e.g., physiological effects of nutritional stress on sea lions and seabirds, trawling effects on fish school structure or benthic communities) [Variable difficulty, study duration depends on particular study]

Food web dynamics

The Bering Sea ecosystem dynamics depend partly on timing and location of nutrient inputs and species responses to physical factors. Varying climate conditions, including those that affect advection, mixing, and stratification, will influence the timing, location, abundance, and species composition of primary producers in the Bering Sea. Areas of upwelling, ocean fronts, and eddies can be regions where well mixed and stratified waters juxtapose to create optimal conditions for enhanced primary production. Species composition may be very important. Regions of high nutrients can lead to production of large phytoplankton cells such as diatoms, whereas regions of low nutrients can lead to small phytoplankton cells such as dinoflagellates. Changes in primary producers can translate into significant shifts in zooplankton distribution, species composition, and production. These production pathways are then translated through the food web to higher trophic levels of interest to commercial fisheries and subsistence users.

There are several ways in which changes in the phytoplankton community can be manifested in major changes in upper trophic levels. For example, communities of large phytoplankton can lead to efficient energy transfer to upper trophic levels and greater fish production due to short food chains, whereas communities of small phytoplankton can lead to long food chains, inefficient energy transfer, and reduced fish populations (Ryther 1969, Mousseau et al. 1998). Such changes can also be manifested in connections between pelagic and benthic food webs, i.e., whether the system is coupled or uncoupled. The PROBES program found that ineffective grazers live inshore of the middle front, thus much of the primary production falls ungrazed to support the bottom community. On the other hand, seaward of the middle front, grazers are effective, so much of the production gets consumed and remains in the pelagic realm. Benthic versus pelagic allocation of the products of primary production is a major factor influencing energy flow to and production of commercially-important pelagic species (salmon, pollock) and benthic species (crabs, flatfish).

At low trophic levels in marine ecosystems, scientists are developing new techniques for sampling micro- and picoplankton. However, the roles of these very small plankton in energy pathways in the Bering Sea ecosystem are unknown. At other trophic levels, much of our knowledge of food web dynamics comes from sampling selected species, such as stomachs of commercially-important groundfish species from assessment surveys in summer on commercial fishing grounds. Little information is available during other seasons, in nearshore areas that serve as nursery areas for many fish and invertebrate species, and from non-commercial species. It is generally thought that fish recruitment is determined during early life; food availability and predation are two of the leading hypotheses about year class formation. Yet, little is known about perhaps some of the most important predators on early life stages of fish and invertebrates in the Bering Sea. Jellyfish and ctenophores are major consumers of larvae, yet virtually nothing is known of their abundance and associated predation mortality. The importance of less sampled forage animals such as squid and mesopelagic fishes to the Bering Sea energy budget is also not well known. Also, enhancement programs contribute to high salmon abundance, but little is known about salmon feeding behavior at sea. Likewise, little is known about other important predators, such as sea stars, sculpins, and others.

It is generally felt that declines of mammals and birds may be related to a reduction in the diversity of available prey species. Historical diet records on at least two species of pinnipeds and three species of marine birds indicate a marked shift in diet that includes an increase in consumption of juvenile walleye pollock and a decrease in consumption of other once predominant forage fishes. In addition, the size of pollock consumed by northern fur seals appears to have decreased since the 1970s. More recent declines in sea otter populations in the southern Bering Sea may reflect cascading effects of earlier mammal declines and further modified trophic interactions among apex predators. The structure of the Bering Sea groundfish community has also shifted in response to what has been termed a pollock-dominated system and a "juvenation" of the pollock resource. Unfortunately, the lack of baseline distribution and abundance data on forage fishes, such as capelin and eulachon, boreal smelt, and cephalopods, such as gonatid squid, limits current interpretation of the full impact of these apparent changes on mammals and birds and the rest of the Bering Sea ecosystem.

Clearly, improved knowledge of food webs and the processes that determine the various routes by which energy is transferred through the ecosystem will be important to developing ecosystem-based management approaches. Knowledge, or its absence, also has major implications on single-species fishery management decisions, as well. For example, area closures and reductions in the pollock fishery have been implemented due to concerns for effects on mammals, and in the yellowfin sole fishery to prevent disturbance of walruses and interference with herring on spawning migrations. However, the benefits of these area closures versus other alternative measures are unknown. A better understanding of food web dynamics will lead to improved fishery management decisions.

<u>Questions</u>:
1. What are the dominant energy pathways in the Bering Sea that lead to managed living marine resources such as fish, crab, marine mammals and birds?
2. How do climate and variability in ocean structure (e.g., stratification, upwelling, cold pool, ice edge) affect prey availability (distribution and abundance) to managed living marine resources?
3. How do human activities (e.g., fishing removals, discards and offal production, salmon enhancement programs, contaminants and other introductions) influence these pathways?
4. How do managed living marine resources respond to changes in prey availability?
5. What are the implications of trophic dynamics on multispecies management and ecosystem-based management?

<u>Possible approaches</u>: The following categories of research approaches (retrospective analysis, monitoring, process studies and modeling) are high priorities. The examples provided are not prioritized nor exhaustive; they merely illustrate the types of research projects envisioned under each approach. Each research approach is identified with respect to feasibility – relatively easy (E), moderately difficult (M), and difficult (D) and with respect to study duration – 1-3 years (1-3), 3-5 years (3-5), and longer (>5).

<u>Retrospective analysis:</u>

1. Provide Native and local communities the resources to collect, preserve, and disseminate traditional and local knowledge. [E, >5]
2. Survey archaeological middens and sediment cores to look at species abundance and changes. [M, 3-5]
3. Analyze ice cover and other environmental factors on predator/prey population dynamics in different regions of the Bering Sea, particularly the northern Bering Sea. [E, 3-5]
4. Analyze seabird colonies (Pribilof Islands and Buldir Is.) and productivity relative to forage. [E, 1-3]
5. Compile and analyze existing data from all sources (literature, unpublished, Native) on marine bird and mammal diets [E, 1-2]

Monitoring:
1. Develop or enhance existing monitoring programs for important physical parameters, phytoplankton, zooplankton, benthos, forage, and predator species and their trophic interactions, at key sites and times throughout the Bering Sea, including critical nearshore areas. [E, >5]
2. Perform systematic harvest monitoring of species linked with observations of long-term trends from hunters. Obtain stomach samples from harvested marine birds. [E, >5]
3. Resume important unfunded or underfunded monitoring efforts, e.g., the multidisciplinary monitoring transects off the Pribilof Islands, slope groundfish surveys. [E, >5]
4. Develop methods and perform baseline research to prepare for monitoring (e.g., develop instruments to measure abundance of less abundant organisms from buoys, perform baseline taxonomic work on benthos, and develop methods to monitor difficult to census species such as Atka mackerel and crevice-nesting birds). [M depends on study, 3-5, depends on study]

Process studies:
1. Conduct process-oriented studies of important trophic interactions to determine predator responses to physical parameters and prey availability. Establish prey density thresholds and form of functional and aggregative response of predators to prey. [M, 3-5]
2. Use telemetry and standard ship transect methods to define (horizontally and vertically) marine mammal, seabird, and apex predator feeding areas both in the Bering Sea during summer and in areas outside the Bering Sea that may be visited seasonally and to define the relationship of feeding areas to principal fishing areas. Identify and quantify food items. [M,3-5]
3. Evaluate the effect of fishing removals on local prey distribution and abundance. [M,1-3]
4. Study the effects of discards on benthic predator-prey dynamics in selected study sites. [M, 3-5]
5. Continue SMMOCI (Seabird, Marine Mammal, and Oceanography Coordinated Investigations) and link it to basin-wide monitoring of forage. [E, >5]
6. Conduct studies to understand the effects of fishing on marine mammal and seabird food webs. [M, depends on study, 3-5]
7. Perform experiments, including adaptive management experiments, involving marine refugia. [M, >5]
8. Study different phytoplankton communities and transfer efficiencies of phytoplankton to zooplankton. [M, >5]

9. Link resulting prey production to recruitment success at critical times in the life history of upper trophic level species. Establish numerical response of predators to prey. [M, >5]
10. Study climate controls of nutrient supply, production, and energy transfer to upper trophic levels. [M, >5]
11. Apply APEX predator studies performed in Cook Inlet and Prince William Sound to the Bering Sea. [E, >5]

<u>Modeling</u>:

1. Design models ranging from minimal realistic models of specific species interactions to multispecies models to ecosystem models. [M-depends on study, 3-5]
2. Develop field and modeling studies to identify the causes of contrasting population trends of several key species with various life history strategies at different trophic levels in the food web. [M, >5]
3. Develop spatial models of predator foraging and energetic models of prey demand. [M, 3-5]
4. Model the effects of a western Bering Sea oil spill on Bering Sea food webs. [M, 3-5]

Contaminants and other introductions

In comparison to shallow seas adjacent to more populated and industrialized parts of the world, the Bering Sea tends to have low levels of toxic contaminants. However, levels have been rising over the last fifty years or more and especially more recently. This is partially due to increases in the release of contaminants related to activities within the region such as mining and fishing. Also, there are instances of local contaminants, such as radioactive wastes in the Aleutian Islands. At least as significant, however, are increases connected to long-range transport of contaminants from more southerly regions. Ocean currents and especially atmospheric air movements can transport contaminants long distances before the contaminants are deposited. Such long-distance transport and deposition of contaminants has been clearly detected in the Bering Sea. A study of Aleutian green-winged teal revealed that 25% of the eggs collected had mercury levels high enough to cause deformities. Other contaminants in the system include PCBs, DDT derivatives, and oil. Oil spills can have devastating effects, particularly on marine mammals and birds. Local ocean circulation may concentrate or conserve contaminants for extended periods.

This build-up of contaminants is of substantial concern because cold region ecosystems such as the Bering system are believed to be more sensitive to the threat of contaminants than are systems in warmer regions. Many of the contaminants tend to be more persistent in colder areas due to slower chemical break-down at lower temperatures and to the tendency of volatile organic contaminants that are transported to the Arctic in the atmosphere and deposited there in the cold oceans to become trapped because low temperatures greatly retard exchange from cold water to air. The benthic nature of the Bering Sea makes it easy for contaminants to become incorporated into benthic animals. In addition, there is a reduced tendency for pollutants to be buried in the sediments because of bioturbation. Thus, they can accumulate in the biota which serve as prey for benthic-feeding birds and marine mammals (e.g. walrus). Furthermore, animals high in the food web and with relatively large amounts of fat, as is true for a number of the important marine mammals and sea birds in the Bering Sea, tend to concentrate organic contaminants, such as pesticides and PCBs, very strongly. Thus, these animals may be at substantial risk from contaminants even at environmental levels that are at or below concentrations that commonly occur in more temperate regions. Finally, there are concerns about human health in the region, particularly for Alaska Natives who rely on marine mammals and seabirds as food sources.

In addition to chemical contaminants, humans introduce other foreign material to the system. These include trash and plastics that may cause problems to animals who consume them or get entangled in them. Discarded or lost fishing nets and pots can entrap and kill animals for years. Introductions may be biological in the form of diseases or exotic species. Introductions of non-native fox populations or invasions of rats on islands negatively impact nesting seabirds primarily due to predation on eggs and young. Bitter crab disease is caused by a dinoflagellate that can be spread by transporting infected crabs from one area to another. Discharge of bilge water or live tanks has been found to introduce exotic species, sometimes with very adverse consequences on the native flora and fauna. Fish reared in hatcheries or enclosures can develop viruses that spread to natural populations when fish escape or are released.

Questions:

1. What are the sources, fates and trends in concentration levels of contaminants in the Bering Sea?
2. What direct and indirect effects do contaminants have on the populations of living marine resources of the Bering Sea?
3. How do contaminants in living marine resources affect the health of individuals and communities reliant on Bering Sea resources?
4. How much foreign material (plastics, trash, fishing gear etc.) is discarded or lost in the Bering Sea?
5. What are the effects of ingestion of or entanglement in these materials on animals?
6. What exotic species have been introduced into the Bering Sea, and what are the risks to native species?
7. How can risk of introduction of exotics and spread of diseases and viruses be minimized?

Possible approaches: The following categories of research approaches (retrospective analysis, monitoring, process studies and modeling) are high priorities. The examples provided are not prioritized nor exhaustive; they merely illustrate the types of research projects envisioned under each approach. Each research approach is identified with respect to feasibility – relatively easy (E), moderately difficult (M), and difficult (D) and with respect to study duration – 1-3 years (1-3), 3-5 years (3-5), and longer (>5).

Retrospective analysis:

1. Perform a literature search on existing information on contaminants studies. [E, 1-3]

Monitoring:

1. Hold a workshop to further develop a coordinated contaminants monitoring program. [E, 1-3]
2. Survey contaminant levels and indicators of contaminants effects in the major components of the Bering ecosystem to assess distribution of contaminant concentrations and the effects they cause (possible indicator species are in Table 1). [E, 1-3]
3. Establish a series of locations where long-term seasonal monitoring of contaminant levels in various media (i.e., air, water, sediment, various types of biota) is conducted on a long-term continuing basis (possible site are in Table 2). [E, 1-3]
4. Assess animal health and condition using local knowledge. [E, 1-3]
5. Augment ongoing monitoring programs for contaminants in subsistence or commercial harvests. [E, >5]
6. Survey lost fishing gear, its condition, and document entangled species. [M, >5]
7. Sample ballast water for exotic species in both the eastern and western Bering Sea regions, and survey the Bering Sea for presence of those species. [M, >5]

Process studies:

1. Conduct controlled field and laboratory experiments to assess the biological consequences of exposure to the levels of contaminant detected in the Bering Sea paying particular attention to evaluating the reproductive and other effects of endocrine disrupting organic contaminants. [M, 3-5]
2. Consider improving current regulations concerning transport of ballast water, and garbage and waste disposal by fishing and merchant vessels. [E, 1-3]

Table 1. Initial list of species and abiotic indicators that are likely to be of interest for contaminants monitoring in the Arctic. These indicators mostly reflect marine species and marine habitats, however a similar list has been developed by AMAP and could be developed for the Bering Sea coast as well.

Draft* AMAP species and abiotic indicators	**Other Bering Sea Species of Potential Interest**
Air, Precipitation, Snowpack	Steller Sea Lion
Sea Water	Northern Fur Seal
Marine Sediment Cores	Bearded Seal
Blue Mussel	Bowhead Whale
Sculpin species (four-horned sculpin)	Sea Otters
Glaucous Gull	Spectacled and/or Steller's eiders
Black Guillemot	Common murres
Kittiwakes	Emperor Geese
Eiders (Common Eider)	Harlequin Ducks
Ringed Seal	Oldsquaw
Walrus	Cormorants
Beluga	Benthic invertebrates
Polar Bear	Zooplankton and/or Phytoplankton
Human Health	

- *AMAP indicators were derived from draft documents developed at the April 1998 AMAP Experts meeting held in Girdwood, AK . A definitive AMAP matrix has not yet been finalized.*

Table 2. List of potential long-term contaminants monitoring sites in or along Bering Sea. These sites represent areas where studies are currently being conducted on species of interest (mainly marine mammals or sea birds). Not all species would be monitored at each site, thus a matrix of sites and species should be developed in the future. Two potential sites in the Chukchi Sea and Arctic Ocean are also included for consideration.

Pribilof Islands
St. Matthew Island
St. Lawrence Island
Barrow (Arctic Ocean)
Point Lay (Chukchi Sea)
Little Diomede Island
Nome
Bluff
Cape Peirce
Round Island
Kasatochi Island and Koniuji Island
Aiktak Island
Buldir Island
Russian sites (western Bering Sea)

** Note: Site-specific studies addressing local contamination issues have been, and will continue to be, conducted within the Bering Sea as well. Several sites such as Adak and Amchitka Islands, will potentially be issues for many years to come.*

Habitat

Habitat is critical to fish, invertebrate, mammal, and bird populations and their productivity. Habitat influences growth, reproduction and survival rates of animals. Depending on the particular species, habitat may include physical characteristics of the bottom or water column and biological characteristics. A certain type of habitat may be necessary for spawning, a different type may be necessary for survival of the early life stages that are most vulnerable to predation, and other types may be needed for juvenile and adult life stages. Thus, identification of habitat requires sufficient knowledge to evaluate all major phases in the life history for each species of interest.

Furthermore, fishing may have direct and indirect effects on habitat and the bottom community of plants and animals that contribute to that habitat. Whether trawling and dredging causes detectable short-term and long-term effects depends on the weight of the gear, the degree of contact with the bottom, depth, ocean currents, bottom type, and the biological community living in the area (Messieh et al. 1991; Jones 1992). Because effects depend so much on these factors, research specific to the Bering Sea fisheries is seriously needed. In some other regions, fishing gear has been shown to scrape and plough the sea bottom, suspend sediment, and damage physical and biological structures (e.g., attached plants, corals, worm tubes, tunicates) important to survival of some species. Damaged and injured benthic species may attract predators, such as sculpins, starfish, flatfish, and crabs (Caddy 1973), thus favoring growth and survival of some species to the detriment of others. In some cases, organic matter becomes buried causing a shift away from aerobic energy pathways at the sediment-water interface that are important to fish production toward anaerobic subsurface respiration by bacteria (Mayer et al. 1991).

In addition, coastal development can adversely affect important habitats located in estuaries, embayments, and shallow and intertidal waters along open coastlines. Changes in economics and human demographics could impact these habitats in the future. Development and fishing activities may disrupt marine mammals and birds through several routes including disruption of nearshore habitat that may be important foraging areas for lactating pinnipeds, nesting birds, or young-of-the-year. Humans may introduce contaminants, remove vegetation that serves important filtering purposes, or disrupt breeding or nesting animals. Habitat research will ultimately improve our ability to develop baseline data to assist in planning future coastal development, predict changes in stock status, provide protection of presently adequate habitat, and make necessary improvements to degraded habitat that will maintain and improve stock status.

Questions:

1. What are the nearshore, benthic, and pelagic habitat characteristics of various life stages of important species?
2. How does fishing and other human activities impact physical and biological habitat attributes, including biodiversity?
3. How does climate variability alter physical and biological habitat attributes, including biodiversity?
4. What marine mammal, seabird, and fish habitats are located in areas likely to be affected by coastal development?

5. How can habitat be protected and restored? What are the economic and political impacts to decisions regarding habitat?

Possible approaches: The following categories of research approaches (retrospective analysis, monitoring, process studies and modeling) are high priorities. The examples provided are not prioritized nor exhaustive; they merely illustrate the types of research projects envisioned under each approach. Each research approach is identified with respect to feasibility – relatively easy (E), moderately difficult (M), and difficult (D) and with respect to study duration – 1-3 years (1-3), 3-5 years (3-5), and longer (>5).

Retrospective analysis:
1. Use geographical information systems to map important habitats, locations of renewable and non-renewable resources, and to evaluate fishery and coastal management options. [E, 3-5]
2. Evaluate current fishing area closures with respect to the location of important habitats. [E, 1-3]
3. Evaluate and define critical habitat for Steller sea lions. [M, 1-3]
4. Use traditional knowledge to get distribution and abundance of a single species, e.g., herring. [M, 1-3]
5. Analyze historical data to determine habitat factors influencing change in distribution, e.g., pollock and the cold pool, Russian-American marine mammal harvest data. [E, 1-3]
6. Analyze historical pelagic seabird database to define foraging habitat for important species [E, 1-2].

Monitoring:
1. Conduct surveys of physical and biological characteristics of habitat for important species and life history stages. [E-M, duration depends on study]
2. Conduct a demonstration project using local communities to monitor a single species. [E, 3-5]
3. Monitor the extent of specific habitats, e.g., spawning habitat for Togiak herring, red king crab and capelin, juvenile red king crab and flatfish habitat, eelgrass areas, walrus feeding areas, selected species important to subsistence, or little-studied species such as steelhead (freshwater habitat only). [E, 3-5 depending on the project]

Process studies:
1. Perform controlled studies of fishing effects on habitat and bottom organisms on different bottom types, and examine short-term and long-term effects on benthic predator and prey populations. [M-D, 3-5]
2. Establish refuges as areas for distinguishing fishing from natural changes in bottom habitats and biological communities. [M, >5]
3. Estimate productivity of the benthos, particularly infauna. [M, >5]

Modeling:
1. Use walrus haulout data to develop a model provides an index of population trend and habitat use. [E, 1-3]
2. Develop spatial models linking habitat characteristics to species population dynamics. [M, 1-3]

Present research needs

The research questions outlined above encompass a wide range of research activities that would be difficult for any one research program to accomplish. Also, some of the questions are already being considered, at least in part, by some presently funded programs. A summary of presently funded cooperative programs is provided in the appendix in order to identify some of the unfunded needs for a cooperative research program relating to the fisheries or marine ecosystems in the Bering Sea. Data needs and research priorities were summarized in the proceedings of the Dec. 4-5, 1997 and June 2-3, 1998 Bering Sea Ecosystem Workshops (Bering Sea Organizing Committee, 1997; 1998) (see the appendix for workshop descriptions). Priorities for pressing fishery management or marine ecosystem information needs from these workshops are summarized below.

<u>Research to address pressing fishery management issues</u>

Some of the most pressing fishery management issues facing the North Pacific Fishery Management Council are those involving pollock and Atka mackerel fishery interactions with Steller sea lions (Figure 1). Other issues presently of importance involve fishery effects on northern fur seal, other marine mammals and seabirds. Human health and safety is also of great concern, so ensuring that contaminants do not become a problem in the Bering Sea is crucial. Also of particular importance are effects of fishing on biodiversity and habitat and the impacts of present waste/discard practices on the ecosystem.

Figure 1.—Pressing fishery management issues of the North Pacific Fishery Management Council. The most pressing issues at present are in the center of the circle. (Source: C. Pautzke, NPFMC).

Research to address marine ecosystem information needs

Lack of long-term time series of many important ecosystem attributes was the most frequently mentioned data need. Conducting planning workshops to design a viable monitoring scheme for various ecosystem components is seen as a next logical step to make advancements in this area. However, a balanced program will require more than just a monitoring effort. Research to address longer-term management concerns, particularly understanding and predicting climate effects will also require retrospective analysis of existing data, process studies consisting of field/lab experiments to elucidate factors influencing key ecosystem rates or mechanisms, and physical and modeling efforts. Advancing our prediction capabilities will require linking our monitoring efforts with predictive models.

Implementation issues

Program products

It is paramount that information collected by researchers be available to stakeholders and other public in a timely manner. This can be accomplished by dissemination of field plans, experimental results, and database links through the world wide web. Real-time biophysical measurements must also be made available via the web to aid in communication and direction of field programs conducted by different research entities and to provide information on the status of the ecosystem to the community. Some long-term monitoring is well suited for real-time dissemination, e.g., data from moored biophysical platforms, satellite-tracked marine mammals and drifting buoys, and ocean color sensors. The on-going results of all monitoring activities must be integrated to provide an annual report on the status of the Bering Sea. Monitoring results also need to be integrated into predictive models that will provide useful information to managers and stakeholders. Community involvement in research is vital and can be accomplished in a variety of ways including use of traditional knowledge in identifying monitoring priorities, identification of scientific questions specific to local communities, participation in data collection and monitoring activities, and entering collected data via interactive web sites.

Inclusion of traditional knowledge and local and Native communities in the research effort is an important aspect of the program. Local and traditional knowledge is important to scientists and managers because local people have a long history of observations in the area. The familiarity of local people with an area provides them with a background to recognize out-of-the-ordinary conditions. This kind of information provides scientists and managers with important information they may not be able to obtain otherwise. Many scientific programs in Alaska have developed protocols for including traditional knowledge into the process. Some of the protocols developed for these programs may have utility for the present research program. However, decisions about the nature and scope of the protocols will require direct input from the Native communities involved and will require funding for Native communities to further develop and reach agreement. Several actions need to be taken in order to implement a Bering Sea research program that includes Native and local communities in all aspects of the research effort. First, funding needs to be provided for the Native community to bring together community representatives from around the Bering Sea rim in a Bering Sea summit. Second, research planning, particularly in the monitoring effort, needs to include Native and local communities in the planning process. Finally, evaluation of research proposals that involve traditional knowledge needs to include peer reviewers familiar with that area.

In addition to scientific products, adaptive managerial strategies that allow active management of human use of the ecosystem are essential to the program. To benefit both management and science, the program should support the development of new technologies. Some examples are remote sensing of sea surface salinity and biological populations; moored nutrient sensors; and enhanced methods of sampling and tracking forage fishes, cephalopods, and apex predators. Ecological models can be a valuable tool in support of management and scientific understanding. Sound ecological models require the incorporation of monitoring data and process-oriented research to establish critical rates.

Program management structure and support

Key aspects of implementing research on the Bering Sea ecosystem are: sustained research support, coordination, communication, and involvement of local communities and stakeholders, and other public. Experience has taught us that certain management structures and support will insure the highest degree of success for this interdisciplinary, interagency program. Overall program management will be provided by the North Pacific Research Board. A successful program will also require a staff to handle program administration, including budget management, coordination of field programs, communications, public interactions, and other activities. Design of the management program is beyond the scope of this research plan. However, we envision the establishment of advisory groups as one of the vehicles for industry leaders, members of the environmental community, and other interested public to provide direct advice to the Board about research needs and priorities.

Additionally, a successful science program requires an open and independent peer-review process. A scientific advisory committee should be established to help guide the science program, to coordinate peer review of research proposals, and provide technical advice to the NPRB. The committee should have a representative breadth of scientific expertise, including researchers with expertise in traditional knowledge. There are a number of nationally-recognized peer reviewed granting agencies (e.g., National Science Foundation, Saltonstall-Kennedy Program, Sea Grant, etc.) that could provide templates for the peer review process. Alternatively, the Board might consider the possibility to establish the frameworks for the science plan, but then to turn over administration of the peer-review process to an established body such as the National Science Foundation. Regardless of the particular structure, it is imperative that research is administered by a credible scientific review process. It is also important that traditional knowledge research projects are reviewed by peers in that field.

Communication among researchers and between researchers and other groups is important. An annual science and technology workshop should be held each fall in Anchorage, Alaska, with an agenda including scientific program reports, status of technology developments, synthesis of community input, and field research planning. One product of the workshop could be information to form an annual report to disseminate results more widely and to document program achievements. Other communication methods include the use of NOAA's Bering Sea theme page on the World Wide Web to disseminate research information and the Bering Sea

Ecosystem Project's listserve to distribute local knowledge observations and to initiate informal discussions about important issues.

Research priorities and funding issues

The North Pacific Research Management Board will need to consider several issues with regard to funding. One key issue will be how to allocate funds to support research to answer critical management questions of present concern and research to advance long-term prediction, including long-term monitoring programs. Stability of funding across time is essential to the development and maintenance of multi-year or long-term research projects. Development of mechanisms for multi-year funding will be crucial to the success of the program.

Goals need to be set for assigning priorities to be used in the evaluation and selection of projects to be funded through the program. As outlined before, projects that address pressing fishery management issues are high priority. Also, projects that address important marine ecosystem information needs and advance long-term prediction have precedence. Emphasis should also be placed on cooperative research efforts. Cost-effectiveness should also be a consideration in project selection. Ultimately, projects that fit with our vision of the Bering Sea will be chosen.

Approaches that will receive emphasis are those that:

- respect the importance of traditional knowledge of Native peoples in understanding the Bering Sea
- provide opportunities for local involvement and communication
- foster cooperation among agencies and other stakeholders
- use and acquire information needed for adaptive management
- use a keystone or proxy species approach for monitoring
- provide opportunities for international cooperation and communication
- enhance technology transfer and communication among stakeholders

<u>Key species</u>

Criteria for selecting species for study include:

- special status (e.g., endangered, threatened)
- economic or ecological importance
- subsistence use and interest in the species by local communities
- indicator species for a given trophic level or feeding guild
- access and cost to sample

Impediments

Comprising almost 1 million square miles and surrounded by remote, minimally developed, islands and coastline, the Bering Sea will require both platforms and staging areas to conduct ecosystem specific research. Access to ports for vessels and airports for aircraft are both available, yet limiting, in the area. Competition for pier space during the fishing season, logistics support, and availability of commercial flights all factor into mounting an ecosystem study. Yet, as these issues can be managed, the lack of research vessels appears as the major impediment to a multi-seasonal ecosystem research program.

Historically, research vessels have been involved in the Outer Continental Shelf Enviromental Assessment Program (OSCEAP), the NMFS Fishery Resource Surveys, the Fishery Oceanography Cooperative Investigation, and specific oceanographic or resource oriented studies. Presently, research vessel time has declined to 210 days of Resource Assessment and FOCI on one large federal vessel (MILLER FREEMAN), 130 days on one small federal vessel (TIGLAX) for Maritime Refuge support, and 90 days on one UNOLS regional vessel (ALPHA HELIX) assigned to the University of Alaska (Figure 1). While both federal vessels are fully committed to the management mandates, limited time may be available through the University vessel. However, the limited time available may not be adequate for work planned for the Bering Sea. Alternative vessels, including excess NOAA vessels (CHAPMAN) or limited use UNOLS vessels (ENDEAVOR) may provide interim solutions. To address the crucial scientific issues, adequate research platform time needs to be planned. Whether through dedicated federal vessels, increased funding for University vessels, or through contract of vessels of opportunity, adequate research vessel time remains an impediment to mounting a field program.

Similarly, logistics and staging for an increase in the long term ecosystem research for the Bering Sea will require onshore infra-structure that enables staging and de-staging cruises, gear preparation and storage, and offices for pre- and post-cruise coordination. Improved facilities at Dutch Harbor, Alaska, either through contract or as public assets, should be considered to insure efficient use of vessel time, minimize delays with travel, and allow pre-cruise planning between multiple investigators. The present lack of onshore infra-structure in the research area remains an impediment to multi-agency, multi-disciplinary research cruises.

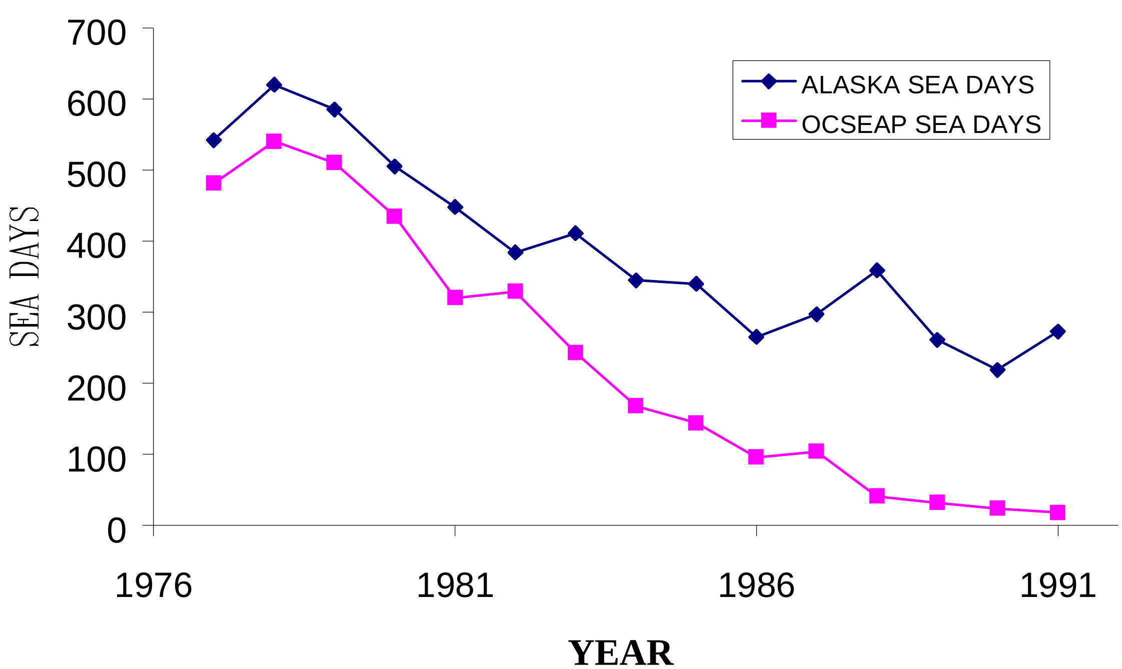


Figure 2.—NOAA ship use for open ocean ecosystem research in Alaska: 1977-1991.

Background reading

ARMRP (Alaska Regional Marine Research Program). 1993. Alaska Regional Marine Research Plan, 1992-1996. University of Alaska Fairbanks.

Arsenev, V.S. Current and water masses of the Bering Sea (in Russian, English summary) *Izd. Nauka*, Moscow. (Transl., 1968, Nat. Mar. Fish. Serv., Northwest Fish. Sci. Center, Seattle, Wash.), 135 pp.

Bakkala, R.G., 1993. Structure and historical changes in the groundfish complex of the Eastern Bering Sea. U.S. Dep. Commer., NOAA Tech. Rep. 114, 91 p.

Bering Sea Organizing Committee, 1997. Report of the Bering Sea Ecosystem Workshop, Dec. 4-5, 1997, Anchorage, AK. Available from U.S. Dep. Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115 USA. 153p.

Bering Sea Organizing Committee, 1998. Report of the Bering Sea Ecosystem Workshop, June 2-3, 1998, Anchorage, AK. Available from U.S. Dep. Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115 USA. ???p.

Brodeur, R.D., M.T. Wilson, G.E. Walters, and I.V. Melnikov, 1998. Forage fishes in the Bering Sea: Distribution, species associations, and trends. In: Loughlin T.R., Ohtani K. (eds.) *The Bering Sea: Physical, Chemical, and Biological Dynamics*. Alaska Sea Grant Pub.

Caddy, J.F. 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. Journal of the Fisheries Research Board of Canada 30:173-180.

Clasby, R.C. 1987. Workshop summary on future rockfish research needs. Pages 385-387 *in* Proceedings of the international rockfish symposium. University of Alaska, Alaska Sea Grant Report 87-2, Fairbanks.

Colebrook, J,M, 1986. Environmental influences on long-term variability in marine plankton. Hydrobiologia 142: 309-325.

Cooney, R.T., 1981. Bering Sea zooplankton and micronekton communities with emphasis on annual production. p.947-974. In: Hood, D.W. and Calder, J.A (eds.) *The eastern Bering Sea shelf: oceanography and resources*, Vol.2. University of Washington Press, Seattle.

Coyle, K.O., and R.T. Cooney, 1993. Water column scattering and hydrography around the Pribilof Islands, Bering Sea. *Cont. Shelf Res. 13*:803-827

Coyle, K.O., V.G. Chavtur, and A.I. Pinchuk, 1996. Zooplankton of the Bering Sea: A review of Russian-language literature. Pages. 97-133. In: Mathisen, O.A. and Coyle, K.O. (eds.) *Ecology of the Bering Sea. A review of Russian literature*. University of Alaska Sea Grant College Program Report No. 96-01. Fairbanks.

Decker, M.B., G.L. Hunt, Jr., and G.V. Byrd, 1995. The relationships among sea-surface temperature, the abundance of juvenile walleye pollock (*Theragra chalcogramma*), and the reproductive performance and diet of seabirds at the Pribilof Islands, southeastern Bering Sea. p. 425-437. In: R.J. Beamish (ed.), Climate change and northern fish populations. *Can. Spec. Publ. Fish. Aquat. Sci. 121*.

Favorite, F., A.J. Dodimead and K. Nasu, 1976. Oceanography of the subarctic Pacific region, 1960-71. Int. N. Pac. Fish. Comm. Bull. #33, 187 pp.

Hood, D.W. (ed.), 1986. Process and Resources of the Bering Sea Shelf (PROBES). *Cont. Shelf. Res., 5,* 288 pp.

Hood, D.W. and J. A. Calder (eds.), 1981. The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. 1 and 2. U.S. Government Printing Office, Washington D.C., (distributed by the University of Washington Press, Seattle, WA 98195.), 1339 pp.

Hood, D.W. and E.J. Kelley (eds.), 1974. Oceanography of the Bering Sea. Occ. Pub. #2, Inst. Marine Sci., Univ. of Alaska Fairbanks, Fairbanks, AK 99775, 623 pp.

Hunt, G.L., Jr., and G.V. Byrd, Jr., 1998. Climate change, carrying capacity and marine bird populations of the Eastern Bering Sea. In: T.R. Loughlin and K. Ohtani (eds.), *The Bering Sea: Physical, Chemical and Biological Dynamics*. Alaska Sea Grant College Program Publ.

Jones, J.B. 1992. Environmental impact of trawling on the seabed: a review. New Zealand Journal of Marine and Freshwater Research 26:59-67.

Kruse, G.H. 1996. Crab research in Alaska: an interagency long-term plan. p. 695-705. In: High latitude crabs: biology, management, and economics. University of Alaska Fairbanks, Alaska Sea Grant College Program Report 96-02.

Livingston, P.A., L.-L. Low, and R.J. Marasco, 1998. Eastern Bering Sea ecosystem trends. In: Tang, Q. and K. Sherman (eds), *Large Marine Ecosystems of the Pacific Ocean: Assessment, Sustainability, and Management*. Blackwell Science, Blackwell Press, in press.

Loughlin, T.R., and K. Ohtani (eds.), 1998. *The Bering Sea: Physical, Chemical, and Biological Dynamics*. Alaska Sea Grant Pub., in press.

Mayer, L.M., D.F. Schick, R.H. Findlay, and D.L. Rice. 1991. Effects of commercial dragging on sedimentary organic matter. Marine Environmental Research 31:249-261.

McRoy, C.P., 1993. ISHTAR, the project: an overview of Inner Shelf Transfer And Recycling in the Bering and Chukchi seas. *Continental Shelf Res. 13:* 473-480.

McRoy, C.P., D.W. Hood, L.K. Coachman, J.J. Walsh, and J.J. Goering. 1986. Processes and resources of the Bering Sea shelf (PROBES): the development and accomplishments of the project. Continental Shelf Research 5:5-21.

Merrick, R.L., M.K. Chumbley, and G.V. Byrd, 1997. Diet diversity of Steller sea lions (*Eumetopias jubatus*) and their population decline in Alaska: a potential relationship. *Can. J. Fish. Aquat. Sci. 54:*1342-1348.

Merrick, R.L. and T.R. Loughlin, 1997. Foraging behavior of adult female and young-of-the year Steller sea lions in Alaskan waters. *Can. J. Zool. 75(5):*776-786.

Messieh, S.N., T.W. Rowell, D.L. Peer, and P.J. Cranford. 1991. The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. Continental Shelf Research 11:1237-1263.

MMS (Minerals Management Service). 1997. Alaska Environmental Studies Strategic Plan, FY 1999-2000. Minerals Management Service, Anchorage, AK.

Mousseau, L., L. Fortier, and L. Legendre. 1998. Annual production of fish larvae and their prey in relation to size-fractionated primary production (Scotian Shelf, NW Atlantic). ICES J. Mar. Sci. 55:44-57.

Muench, R.D. (ed.). 1983. Marginal ice zones. *J. Geophys. Res. 88*, 2713-2966.

National Marine Fisheries Service, 1993. Final Conservation Plan for the northern fur seal (*Callorhinus ursinus*). Prepared by the National Marine Mammal Laboratory/Alaska Fisheries Science Center, Seattle, Washington, and the Office of Protected Resources/National Marine Fisheries Service, Silver Spring, Maryland. 80 pp.

Niebauer, H. J., 1988. Effects of El-Nino-Southern Oscillation and North Pacific weather patterns on interannual variability in the subarctic Bering Sea. *J. Geophys. Res., 93* :5051-5068.

Niebauer, H.J., V. Alexander, and S.M. Henrichs, 1995. A time-series study of the spring bloom at the Bering Sea ice edge I: Physical processes, chlorophyll and nutrient chemistry. *Cont. Shelf Res., Vol. 15* : 1859-1878.

Ohtani, K. and T. Azumaya, 1995. Influence of interannual changes in ocean conditions on the abundance of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea. *Can. Sp. Pub. Fish. Aquat. Sci. 121* :87-95.

Paul, A.J. 1996. Summary report of the international workshop on research needs. Pages 675-677 *in* High latitude crabs: biology, management, and economics. University of Alaska Fairbanks, Alaska Sea Grant College Program Report 96-02), and similar lists of research needs identified in Lowell Wakefield Symposia for forage fish, flatfish, and perhaps other species groups.]

Reed, R.K., and P.J. Stabeno, 1996: On the climatological mean circulation over the eastern Bering Sea shelf. *Cont. Shelf Res. 16:* 1297-1305.

Reed, R. K., and P. J. Stabeno, 1998. The Aleutian North Slope Current. In: *The Bering Sea: A Summary of Physical, Chemical and Biological Characteristics and a Synopsis of Research*. (Eds: T.R. Loughlin, K. Ohtani). North Pacific Marine Science Organization, PICES, in press.

Ryther, J.H. 1969. Photosynthesis and fish production in the sea. Science 166: 72-80.

Schell, D.M. 1997. Testing conceptual models of marine mammal trophic dynamics using carbon and nitrogen stable isotope ratios. Pages 119-157 *in* Annual Report 3, University of Alaska Coastal Marine Institute, Fairbanks.

Schumacher, J.D., and P.J. Stabeno, 1998. The continental shelf of the Bering Sea. In: *The Sea*, Vol. XI. The Global Coastal Ocean: Regional Studies and Synthesis. John Wiley, Inc. New York. in press.

Sinclair, E.H., T.R. Loughlin, and W.G. Pearcy, 1994. Prey selection by northern fur seals (*Callorhinus ursinus*) in the eastern Bering Sea. *Fish. Bull. 92(1)*:144-156.

Sinclair, E.H., G.A. Antonelis, B.W. Robson, R.R. Ream, and T.R. Loughlin, 1996. Northern fur seal, *Callorhinus ursinus*, predation on juvenile walleye pollock, *Theragra chalcogramma*, p. 167-178. In U.S. Dep. Commer. NOAA Tech. Rep. NMFS 126.

Sinclair, M. 1988. Marine populations: an essay on population regulation and speciation. University of Washington Press, Seattle.

Smith, R.L. 1995. Future research needs. Pages 631-637 *in* Proceedings of the international symposium on North Pacific flatfish. University of Alaska Fairbanks, Alaska Sea Grant College Program Report 95-04.

Smith, S.L, and J. Vidal, 1984. Spatial and temporal effects of salinity, temperature and chlorophyll on the communities of zooplankton in the southeastern Bering Sea. *J. Mar. Res.42*: 221-257.

Springer, A. M, 1992. A review: Walleye pollock in the North Pacific. How much difference do they really make? *Fish. Oceanogr. 1*:80-96.

Springer, A.M., P.C. McRoy, , and M.V. Flint, 1996. The Bering Sea Green Belt: shelf-edge processes and ecosystem production. *Fish. Oceanogr. 5*:205-223

Stabeno, P.J., 1998. The status of the Bering Sea is the first eight months of 1997. *PICES Press 6, #1:* 8-12.

Stabeno, P.J., J.D. Schumacher, R.F. Davis, and J.M. Napp, 1998. Under-ice observations of water column temperature, salinity and spring phytoplankton dynamics: Eastern Bering Sea shelf, 1995. *J. Mar. Res.*, in press.

Stabeno, P.J., J. D. Schumacher, and K. Ohtani, 1998. Physical oceanography of the Bering Sea. In: *The Bering Sea: Physical, Chemical, and Biological Dynamics*. Loughlin, T. R., and K. Ohtani (eds.), Alaska Sea Grant Press, in press.

Swartzman, G.L. and R.T. Haar, 1983. Interactions between fur seal populations and fisheries in the Bering Sea. *Fish. Bull. 81(1)*:121-132.

Takenouti, Y. and K.Y. Ohtani, 1974. Currents and water masses in the Bering Sea: A review of Japanese work. in Hood, D.W. and E.J. Kelley (eds.), Oceanography of the Bering Sea, Occ. Pub. #2, Inst. Marine Sci., Univ. of Alaska, Fairbanks, AK 99775, 39-58.

Van Meurs, P. and P. Stabeno, 1998. Evidence for episodic on-shelf flow. *J. Geophys. Res.*, in press.

Vidal, J., and S.L. Smith, 1986. Biomass, growth and development of populations of herbivorous zooplankton in the southeastern Bering Sea during spring. *Deep-Sea Res.33*: 523-556.

Wyllie-Echeverria, T., 1995. Sea-ice conditions and the distribution of walleye pollock and the Bering And Chukchi Sea shelf. In: R.J. Beamish (editor), Climate Change and Northern Fish Populations, *Can. Spec. Publ. Fish. Aquat. Sci. 121:* 87-95.

Wyllie-Echeverria, T. 1995. Seasonal sea ice, the cold pool and gadid distribution on the Bering Sea shelf. Ph.D. Thesis, Univ. Alaska, Fairbanks, 281 pp.

Appendix 1: Review of recent research plans, workshops, and cooperative studies

There are many previous and ongoing programs that provide guidance for identifying important research questions, issues and information needs for planning research in the Bering Sea. Below is a summary of some of the most important documents and programs that have been integrated into this science plan. A more detailed overview of agency and other sources of information about the Bering Sea can be found in the report of the Bering Sea Ecosystem Workshop held on Dec. 4-5, 1997 (Bering Sea Organizing Committee, 1997).

National Research Council

As a result of concerns about how living resources in the Bering Sea have been and should be managed, the NRC was asked to assess the current scientific understanding of the Bering Sea. The NRC appointed the Committee on the Bering Sea Ecosystem to study population dynamics and changes in marine mammals, birds, and commercially-important species in the ecosystem, and to ascertain the probable causes of the changes, gaps in knowledge, and research needs. The committee published its report in 1996.

Fish populations and other components of the ecosystem appear to react to many different environmental variables in the atmosphere and ocean. Overall, the committee concluded that climate-driven variability in the Bering Sea ecosystem is significant, occurs at many different time scales, and appears to affect many ecosystem components. It appears that climate has caused relatively rapid shifts in the organization of this marine ecosystem, and that changes over periods of decades may have larger effects than those over yearly periods.

Fishing and hunting of marine mammals by Aleuts and Eskimos have occurred for hundreds of years or more. Exploitation by indigenous peoples affected the abundance and community structures of marine resources, especially close to shore. Intensive exploitation of Bering Sea marine resources by the United States, Russia, Japan, and other nations began in the eighteenth century and increased in the nineteenth and twentieth centuries. This exploitation led to more severe local food shortages and even starvation among the indigenous peoples. Large-scale intensive exploitation of whales occurred during the 1950s, 1960s, and early 1970s. During this period, trawl fisheries severely reduced populations of eastern Bering Sea shelf flatfishes and slope rockfishes. The committee concluded that the most likely explanation of events over the past few decades in the Bering Sea ecosystem is that a combination of changes in the physical environment acted in concert with human exploitation of predators (whales, fish) to cause pollock to dominate the ecosystem - The Cascade Hypothesis.

Scientific questions posed by the NRC Committee on the Bering Sea Ecosystem are:

1. What are the nature and causes of the dynamics of pollock in the northeastern Pacific and Bering Sea over the past 50 years? Examine the plausibility of the Cascade Hypothesis as a scenario for ecosystem dynamics using models; examine short and long-term effects of commercial fishing through adaptive management and modeling, respectively; examine roles of top-down and bottom-up forcing; examine relationships between pollock and other forage fishes; examine at-sea ecology of mammals and birds and how that ecology is influenced by pollock and other forage fishes.

2. What is the role of ice in structuring the Bering Sea ecosystem? What are habitat requirements of invertebrates; effects of seasonal and interannual dynamics of ice on invertebrates?
3. What are the periodicities of ecosystem changes? Consider physical attributes, i.e., position of the Aleutian Low, ocean circulation changes, and sea surface temperature; and ecological attributes, i.e., distribution and abundance of marine mammals, seabirds, fish, benthic invertebrates, and plankton.
4. How do lower trophic levels of the ecosystem interact? Planktivorous birds (and fishes, if their place and time of collection are carefully documented) can be used as samplers of planktonic species.
5. What are the structure and functioning of the "green belt?" To what degree does it support productivity of various parts of the Bering Sea ecosystem? What physical and biological features make it so productive relative to other areas in the Bering Sea? Do changes in the green belt affect the various areas in a related way?

Bering Sea Impacts Study

The Bering Sea Impacts Study (BESIS) project, initiated by the International Arctic Science Committee (1997) and now supported by NSF and USDOI through the regional assessment program of the US Global Change Research Program, has begun to synthesize data and information from all regional sources, including the research programs described above. Its goal is to assess the nature and magnitude of changes in the Western Arctic/Bering Sea region as a consequence of global change; predict/assess the consequences of these changes on the physical, biological and socio-economic systems in the region; determine the cumulative impacts of these changes on the region, including assessment of past impacts; and investigate possible policy options to mitigate these cumulative impacts.

Participants from the U.S., Russia, Japan, Canada and China provided some insight into impact assessment during a workshop held in September 1996. The approach and a list of highly condensed scientific questions follow. After listening to a series of presentations regarding the status of knowledge in the Bering Sea with respect to climate change, workshop attendees were divided into four groups. These groups: Climate, Snow and Ice; Coastal and Marine Ecosystems; Economic Effects; Native Culture and Subsistence, then convened to deliberate on future research. The first three groups established 60 research recommendations or questions. The fourth group determined that "the trust of Native knowledge work must eventually be more thoroughly discussed by the other groups" and did not provide a list of research priorities.

Three general topics which require further research appeared in at least two of the BESIS groups. These can be integrated into the following general questions:

1. How will global climate change affect the flux of nutrients onto the shelf? What are the implications of a reduced flux on nutrient-phytoplankton-zooplankton dynamics [including species composition and changing population dynamics] and transfer to higher trophic levels? Will the carrying capacity of the eastern Bering Sea shelf decrease under a warming scenario?
2. How will global climate change affect seasonal sea ice? How will decreases in extent, thickness, and timing of advance/retreat influence biophysical processes throughout the food web and distributions of fish, birds and mammals?

3. How will global climate change affect sea level? Will the expected rise in sea level significantly alter coastal habitats? Will the steric level increase in the Arctic exceed that in the North Pacific so that transport through Bering Strait diminishes? Will this markedly impact the flux of water/nutrients onto the shelf, thereby diminishing carrying capacity?

The most recent workshop, conducted at the University of Alaska in June 1997 examined and documented climate change in the region, and present and future impacts due to climate change on forests, tundra, wildlife and fisheries, the coastal zone, permafrost regimes, social and cultural systems and lifestyles, resources, and man-made infrastructure (BESIS, 1998). It listed and discussed major impacts already experienced, both positive and negative in relation to human activities, and projected future changes if present climate trends continue. The observed impacts (positive +, or negative -) include:

- Major changes in fisheries catches in recent years, due to both longer-term climate change and El Nino conditions (+ and -).
- Accelerated permafrost thawing, leading to costly increases in road damage and road maintenance (-).
- Major landscape changes from forest to bogs, grasslands and wetland ecosystems, due to permafrost thawing, affecting land use (-).
- Increased forest fire frequency and insect outbreaks with reduced economic forest yields (-).
- A lengthening of the growing season for agriculture and forestry by up to 20%, producing higher yields (+).
- Increased coastal erosion and inundation, due to less sea ice in the Bering Sea and more severe storm surges, causing threats to structures (-).
- Impacts on Native subsistence lifestyles as snow and sea ice changes affect land and marine animals used in hunting/fishing (-).

The workshop included representatives from Russia, Japan, Canada and China and future annual workshops are planned to update and improve these impact assessments.

Arctic Monitoring and Assessment Program (AMAP)

AMAP has a goal to monitor the levels and assess the effects of selected anthropogenic pollutants in the Arctic (Stone 1997). In comparison with most of other areas of the world, the Arctic remains a clean environment. However, potential impacts in the Arctic may be great because of vulnerability of species to stress and relatively greater exposure of animals high in the food webs. The major concern at present is PCBs and pesticides. The Bering Sea was not selected as a major geographic area of concern.

AMAP's recommendations are to:

1. Better quantify the input to, and significance of, the different pollutant pathways to the Arctic.
2. Promote the design and establishment of a coordinated circumpolar network of long-term reference monitoring sites for contaminants and pollutants.

Global Ecosystem Dynamics

U.S. GLOBEC was developed to study the effects of climate variability and change on marine ecosystems. It has ongoing studies on the Antarctic, Georges Bank and North Pacific (U.S. GLOBEC 1996a, 1996c) ecosystems. GLOBEC's science plan (U.S. GLOBEC 1996b), proposed a research program in the eastern Bering Sea, which was not approved for funding. However, the plan did highlight some reasons that a GLOBEC study of the Bering Sea would be important: it would build on NOAA Coastal Ocean Program's Southeast Bering Sea Carrying Capacity and compliment the other U.S. GLOBEC regional studies; the impact of climate change will be strongest in northern latitudes; the Bering Sea supports large fisheries which are sensitive to climate variability; and major shifts in the Bering Sea ecosystem are presently occurring. The overall goal of a GLOBEC study of the Bering Sea would be to understand the effects of climate variability and change on the distribution, abundance and production of marine animals in the Bering Sea. The program was designed to address the top down and bottom up controls in the ecosystem with zooplankton production as a focal point. The proposed approach is to study the effect of past and present climate variability on the ecosystem and use this information as a proxy for how the system may respond to future climate change. Key taxa proposed for investigation are copepods and euphausiids, their pelagic prey and predators. Retrospective, modeling, process-oriented, and monitoring approaches would be used. New technology would also be developed.

Key GLOBEC issues for the Bering Sea are:

1. Is zooplankton production controlled by physical processes (advection, stratification, sea ice coverage and water temperature [extent of cold pool]) and/or is it controlled by biological processes related to the distribution and abundance of predators?
2. Is production in the Bering Sea coupled to that in the Gulf of Alaska through physical forcing?
3. Do interannual and interdecadal changes in physical forcing impact top level predators by altering survival of prey species?
4. Are mesoscale circulation and sea ice formation the dominant physical factors controlling zooplankton dynamics on the shelf?

North Pacific Marine Science Organization

PICES hosts an international GLOBEC program on Climate Change and Carrying Capacity (CCCC: North Pacific Marine Science Organization 1996). The main purpose of the CCCC program is to integrate and stimulate national activities on the effects of climate variations on the marine ecosystems of the subarctic North Pacific. This program has developed a science and implementation plan to address how climate change affects ecosystem structure, and the productivity of key biological species at all trophic levels in the open ocean and coastal North Pacific ecosystems. There is a strong emphasis on the coupling between atmospheric and oceanic processes, their impacts on the production of major living marine resources, and how they respond to climate change on time scales of seasons to centuries. The implementation plan has outlined several central scientific issues around physical forcing, lower trophic level response, higher trophic level response, and ecosystem interactions. It has been recognized that the comparative approach would be a key ingredient to the study of the central scientific issues. The eastern and western Bering Sea regions are two of the ten regional ecosystem components considered by the CCCC program and a recent workshop held by the REX (Regional Experiment) task team of the CCCC program identified several comparative studies that could be performed, including several focusing on comparisons between the eastern and western Bering Sea regions.

Important scientific questions identified by PICES - CCCC include:

1. What are the characteristics of climate variability, can interdecadal patterns be identified, how and when do they arise?
2. How do primary and secondary producers respond in productivity, and in species and size composition to climate variability in different ecosystems of the subarctic Pacific?
3. How do life history patterns, distributions, vital rates, and population dynamics of higher trophic level species respond directly and indirectly to climate variability?
4. How are subarctic Pacific ecosystems structured? Do higher trophic levels respond to climate variability solely as a consequence of bottom up forcing? Are there significant intra-trophic level and top down effects on lower trophic level production and on energy transfer efficiencies?

PICES established a Bering Sea Working Group (WG) from 1993 through 1996 to provide a focus for cooperative, international research in the region. The WG noted that advances in understanding the Bering Sea as a system would primarily develop through recognition of the complexity of the ecosystem as a whole. The consensus of the group noted that the abundance of species fluctuated widely and that integrated physical and biotic studies are required to understand the nature and reasons for such fluctuations (North Pacific Marine Science Organization 1997).

To stimulate international, cooperative research, the PICES WG recommended five areas for study:

1. Understand the mechanisms behind decadal scale change and possible amplified effects in the biological response. For example, could there be an alternation in dominance of shelf production between benthic versus pelagic components of the ecosystem? What is the future role of pollock?
2. Improve understanding of the interchange between the North Pacific Ocean and the Bering Sea and the role of the deep basin as a repository for global deep water.
3. What are the mechanisms for biophysical exchange between the deep basin and shelf waters?
4. How does the presence of sea ice increase biological productivity?
5. What is the biology of predator-prey relationships? For example, are there seasonal changes? What are key nodal species in the benthic and pelagic food webs? Will fishing have the potential to substantially alter natural food webs?

Alaska Research Plan, Alaska Regional Marine Research Board, 1993

In 1991 Congress enacted the Regional Marine Research Act which established nine Regional Marine Research Programs around the country. The purpose was to “(1) set priorities for regional marine and coastal research in support of efforts to safeguard the water quality and ecosystem health of each region; and (2) carry out such research through grants and improved coordination.” Subsequent to a science planning workshop held in Fairbanks, Alaska, during March 10-11, 1993, a research plan was developed (ARMRP 1993). Unfortunately, beyond receipt of a $50,000 planning fund, the Alaska Regional Marine Research Program was not funded by Congress.

The plan covered five major sections: (1) an overview of the marine environmental quality in the region; (2) an inventory of current research activities; (3) a statement of the research needs and priorities within the context of a 10-year goal; (4) an assessment of how the plan will incorporate existing research and management in the region; and (5) a description and schedule of the research objectives for the region during the 4-year period covered by the plan.

The Board identified the following four program goals and examples of specific research objectives:

1. Distinguish between natural and human-induced changes in the marine ecosystem of the Alaska region.
    - Investigate physical and biological factors that affect recruitment, growth, and survival of key marine species.
    - Investigate linkages between pelagic and benthic food chains
    - Determine the effect of human-induced factors such as fishery harvest (predator or prey removal), damage to the environment (e.g., trawling, habitat alteration), enhanced competition (through hatchery stocks), or water quality (pollution) on recruitment, growth, and survival of key species.

2. Distinguish between natural and human-induced changes in water quality of the Alaska region.
    - Develop techniques, tools, and indicators which will enable scientists in the region to determine when water quality has been degraded such that it affects the health of the marine ecosystem.
    - Determine whether increasing incidences of biotoxins in fish and shellfish are related to natural change, human-induced change, or increased analytical capabilities.

3. Stimulate the development of a data gathering and sharing system which will serve scientists from government, academia, and the private sector in dealing with water quality and ecosystem health issues in the region.

4. Provide a forum for maintaining and enhancing communication between the marine scientific and management communities on issues related to maintaining the region’s water quality and ecosystem health.

Minerals Management Service (MMS) Alaska Environmental Studies Strategic Plan

The MMS Environmental Studies Program was initiated by the U.S. Department of the Interior in 1974 in response to the Federal Government’s decision to propose areas of Alaska for offshore gas and oil development. The purpose of the program is to define information needs and implement studies to assist in predicting, assessing, and managing potential effects on the human, marine, and coastal environments of the outer continental shelf and coastal areas that may be affected by gas and oil development. Lease-management decisions are enhanced when current, pertinent, and timely information is available. The Environmental Studies Program then monitors any effects during and after oil exploration and development. Since program inception, more than $250 million have been spent on Alaskan studies in the Arctic, Bering Sea, and Gulf of Alaska. The MMS environmental studies effort has been significantly reduced in the Bering

Sea. MMS remains interested in cooperative opportunities to obtain information useful to decision making and useful to improved management of the valuable resources of the Alaska outer continental shelf.

Early in the development of the program, the focus was on obtaining information on the vast biological resources and physical characteristics of the Alaskan environment for pre-lease decision-making. As a broader base of information was established, it became possible to focus on more topical studies in smaller areas to answer specific questions and fill identified information needs. As more disciplinary data were collected and analyzed, the importance of taking an integrated, interdisciplinary look at complete ecosystems in sensitive areas became apparent. The Minerals Management Service (MMS) has involved Alaskans and others in research planning and execution in a number of ways. In all MMS field-oriented studies, researchers coordinate directly with local communities, and traditional knowledge has been incorporated into specific study planning, field work, and interpretation of results.

Areas covered by the Alaska Environmental Studies Program include: (1) physical oceanography; (2) fate and weathering of spilled oil and the effects that oil spills may have on marine habitats and biota; (3) life history, food habits, and abundance and distribution of seabirds, fish, and invertebrates, as well as their interaction with oil and gas activities; (4) protected species of marine mammals; and (5) social and economic studies, including subsistence, on the effects of oil and gas exploration and development. In the most recent strategic plan for FY1999-2000 (MMS 1997), MMS identified the long-range information needs for the Beaufort Sea: potential disturbance of bowhead whales and other wildlife; effects of petroleum activity on native culture; and pollutants as potential contaminants of food supply. For Cook Inlet, long-range needs include water and sediment quality; the effects of oil spills, discharged pollutants, and construction activity on lower trophic level organisms; effects of oil spills on fisheries resources; socioeconomic concerns about oil and gas activities, and cumulative effects on resources. For both regions, there is a long-range need to develop an environmental database. The plan also lists specific topical areas for proposed future research.

Long-term Plan for Crab Research in Alaska, 1995

Staffs from the Alaska Department of Fish and Game, National Marine Fisheries Service, University of Alaska Fairbanks, and University of Washington have met annually since 1992 to discuss ongoing crab research and future research planning. Research plans have been developed and revised periodically. The most recent long-term research plan (Kruse 1996) prioritizes crab research into four broad areas: (1) stock structure; (2) population estimation; (3) stock productivity; and (4) harvest strategies.

Specific research topics addressing stock structure include attempts to distinguish stocks of geographically-close areas such as king crabs within the Kodiak and Alexander Archipelagos, Tanner crabs in Bristol Bay versus Pribilof Islands and in Kachemak versus Kamishak Bays of lower Cook Inlet, and hybridization among snow and Tanner crabs. *Population estimation* research topics include application of new length-based analyses to assess Alaskan crab stocks; development of fishery-based assessment methods using onboard observer data; and development and application of laser line scanning systems for assessment of trawl and pot catchability, crab associations with their habitats, and other topics.

Much crab research is needed on stock productivity, including: estimation of natural mortality such as predation; development of a retainable tag to study growth of brachyuran crabs; growth studies of Tanner crabs, snow crabs, and blue and golden king crabs; studies of reproductive biology; crab recruitment processes as related to spawning stocks, predation, competition, and oceanographic conditions; red king crab habitat as defined by biological communities and effects of fishing on these habitats; and additional fishing-related studies on handling mortality, ghost fishing by lost gear, and others. Needed research on harvest strategies include modification of fishing gear to reduce bycatch, and experimental management and population simulation models to evaluate radically different harvest strategies.

Workshops

A. Proceedings of the workshop on biological interactions among marine mammals and commercial fisheries in the southeastern Bering Sea, October 18-21, 1983, Anchorage, AK. Alaska Sea Grant Report 84-1, University of Alaska, Fairbanks, Alaska 99775, April 1984.

This report documents the discussion of workshop participants, convened by Alaska Sea Grant, on the interactions between marine mammals and four types of fisheries in the southeastern Bering Sea: groundfish, herring, salmon, and shellfish. The objectives of each group were to: 1) identify marine mammal species that are known to be or could be affected by the fishery; 2) indicate the nature and probable significance of the interactions; 3) determine whether existing data, models and research/monitoring programs were sufficient to predict, detect, and mitigate any possible adverse effects of interactions on marine mammals, the exploited species, or the fishery; 4) identify any critical data needs; 5) suggest how critical data needs could be filled; and 6) rank research needs in order of priority. High priority research needs of each of the groups were: feeding ecology of marine mammals; distribution (both geographically and with depth) and diet of marine mammals by area, season, age and sex; and population dynamics and factors affecting recruitment and distribution (seasonal and geographic) of both exploited and non-commercial prey species. Recommended methods of obtaining data on feeding ecology of marine mammals included tagging/tracking studies and analyses of stomach contents, scats and teeth to determine what is being eaten where and by whom, and oceanographic and biological surveys to determine the abundance, distribution and species composition of the prey available to marine mammals at the same times and locations.

B. National Marine Fisheries Service program development plan for ecosystems monitoring and fisheries management, NMFS, Washington, DC, September 14, 1987.

This plan provides a discussion of the general considerations involved in the development and implementation of broad-scale ecosystem programs. Although written from a national perspective, the contents are relevant to a program tailored specifically for the Bering Sea. The plan includes descriptions of the underlying justifications for such programs, a template for program structure, and program management considerations. An appendix includes an outline of ecosystem research topics and data needs, which was used as a framework for the construction of the Bering Sea Ecosystem Study Components section of the present document. Much of the step-down outline below was adapted from the NMFS Plan.

C. Uncertainties and research needs regarding the Bering Sea and Antarctic marine ecosystems, December 12-13, 1990, Seattle, WA. U.S. Dept. Commerce., Natl. Tech. Info. Serv. PB91-201731 (Swartzman, G. L., and R. J. Hofman), Springfield, VA 22161, July 1991.

This workshop was convened by the Marine Mammal Commission (MMC), in consultation with NMFS and Alaska Sea Grant, to: (1) identify critical uncertainties concerning the causes and possible relationships among the observed declines in various marine mammal and seabird populations in the Bering Sea over the previous 20 years, (2) identify the research that would be required to resolve the uncertainties; and (3) determine how experience in the Bering Sea/Gulf of Alaska and the Antarctic might be used to improve research planning and resource management in both area. Uncertainties in understanding and recommendations for research were listed for marine mammals, seabirds, fish and fisheries, and oceanography and primary production. Principal research recommendations for the first three biological components were improvements in techniques for estimating vital rates (e.g., size, mortality, births, energy flow) of populations (particularly for cetaceans, seabirds and some fish stocks, and in areas outside the Bering Sea for seasonal migrants), greater understanding of their seasonal distributions, and studies specifically designed to investigate the specific effects of fisheries on prey availability and population dynamics of fish and other species in upper trophic levels (including non-commercial species). With regard to Bering Sea oceanography and primary production, workshop participants recommended the establishment of a long-term monitoring program of primary, secondary and benthic production, as well as environmental parameters at a series of stations located on cross-shelf and slope transects in at least the western and northern Bering Sea. Participants also recommended that a formal or *ad hoc* working group, like CCAMLR (Convention for the Conservation of Antarctic Marine Living Resources) in the Antarctic, be established to plan and coordinate results of resource-related research in the Bering Sea and Gulf of Alaska.

D. Is it food? Addressing marine mammal and seabird declines, March 11-14, 1991, Fairbanks, AK. Alaska Sea Grant College Program Report AK-SG-93-01, University of Alaska, Fairbanks, AK, 99775, 1993.

The emphasis of this workshop organized by Alaska Sea Grant was to attempt to answer the dual questions of: Is food availability the key to declining marine mammal and seabird populations in the northern Gulf of Alaska and Bering sea?; and if so, What are the causes of reduced food availability (oceanographic/environmental changes, or human activities, principally fishing)? While workshop participants agreed that changes in quality and quantity of prey were most likely major contributors to observed declines in marine mammal and seabird population sizes, no consensus was reached on the factor(s) responsible for such changes. Structured similarly to the workshop summarized in D above, the workshop subgroups recommended research in feeding ecology of marine mammals and seabirds, with specific attempts to ensure the availability of small or young fish as prey, improvements in methods and funding for studies to monitor species demographics (e.g., population size, age structure, vital rates), initiation of studies on distribution, population dynamics and nutritional value of non-commercial prey species, and expansion (seasonally and geographically) of pre-recruit surveys of commercial species (e.g. pollock).

E. Report on the Workshop on Enhancing Methods for Locating, Accessing and Integrating Population and Environmental Data Related to Marine Resources in Alaska.

The primary goals of this workshop were to:

Identify the data types critical to the conservation of marine mammals and other marine resources in Alaska, and the organization collecting and maintaining those data.

Determine how these data can be made available to other individuals and agencies.

Describe current geographic information systems (GIS) used by different groups.

Determine and recommend actions to develop a common or coordinated GIS or other data networks.

The workshop was held as a result of the findings of a 1992 study contracted by the Marine Mammal Commission entitled "Assessment and possible use of a cooperative/coordinated GIS to facilitate access to, and integration and analysis of, data bearing upon the conservation of marine mammals in Alaska." The study results suggested that the development of a coordinated GIS would enhance the efficiency and utility of existing databases presently maintained independently by various agencies and organizations.

F. International Workshop on Future Crab Research Needs, 1995

In 1995, the Lowell Wakefield Fisheries Series included an International Symposium on Biology, Management, and Economics of Crabs from High Latitude Habitats. As part of the symposium, a workshop on crab research needs was convened (Paul 1996). Workshop participants identified a list of 39 research needs. Some topics overlap with other research lists (Kruse 1996); others included: role of climate in modifying food web structure; location of spawning, incubation, and nursery areas relative to recruitment; role of ocean currents in recruitment; improved understanding of population dynamics including stock-recruitment relationships; life history studies on lightly-exploited deepwater species and others using cost-effective remotely operated vehicles; fate of bycatch discards on the benthic environment; consequences of fishery alterations of size and sex structure of populations; socioeconomic tradeoffs of pulse fishing versus harvesting at lower, more constant levels; and use of refuges to propagate crab populations.

G. International Workshop on Future Rockfish Research Needs, 1986

A fisheries science symposium has been convened annually in Alaska since 1982 in honor of Lowell Wakefield who is recognized as the founder of the Alaskan king crab industry among other achievements. These meetings are organized by the Alaska Sea Grant College Program, and other sponsors include the Alaska Department of Fish and Game, National Marine Fisheries Service, North Pacific Fishery Management Council, and occasionally other organizations depending on the symposium topic. Often these symposia conclude with a workshop on research needs.

In 1986, the Lowell Wakefield Fisheries Series included an International Rockfish Symposium, and a workshop was conducted on rockfish research (Clasby 1987). Workshop participants identified a number of needs, including: (1) lack of knowledge of the life histories of many rockfish species; (2) inability to forecast recruitment; (3) unknown accuracy and precision of biomass assessments; (4) multispecies fishery management; (5) bycatch of birds, mammals, and prohibited or fully-utilized fish species; (6) conflicts among user groups; (7) overlapping regulatory jurisdictions; (8) intra- and intersite variability of assessments; (9) accuracy of assessment models and surveys at low stock size; (10) incorporation of new biological and physical data into assessment models; (11) investigation of climatic effects on stocks; (12) use of experimental fisheries to test hypotheses; and (13) evaluation of costs and benefits of stock rebuilding.

H. International Workshop on Future Research Needs for North Pacific Flatfish, 1994

In 1994, the Lowell Wakefield Fisheries Series included an International Symposium on North Pacific Flatfish, and a workshop on future research needs was convened (Smith 1995). Workshop participants identified the following non-prioritized list of 13 research needs: (1) spatial analysis of catch per unit effort for Pacific halibut; (2) additional survey data to be correlated with commercial catch data; (3) potential conflict between commercial and sport halibut fisheries and its resolution; (4) bycatch and relationship with regulatory and economic discards; (5) cooperative research on Greenland halibut; (6) potential for arrowtooth harvest in Gulf of Alaska with acceptable bycatches; (7) does reproductive biology of flatfish drive abundance?; (8) age validation of flatfishes; (9) multispecies interactions of flatfishes with their prey, competitors, and predators; (10) assessment of archived data on flatfishes; (11) myxosporidean parasite as a cause of arrowtooth soft flesh; (12) genetic analysis of Pacific halibut; (13) human perturbations such as pollution and introduction of alien species.

I. International Workshop Future Research Needs for Forage Fishes, 1996

In 1996, the Lowell Wakefield Fisheries Series included an International Symposium on the Role of Forage Fishes in Marine Ecosystems, and a workshop discussion on future research needs was convened (Hay 1997). The chair of the workshop concluded with the following non-prioritized list of 8 research needs: (1) need for better ecosystem modelers; (2) bioeconomic models with long-term perspectives; (3) forage species-fish predator interactions; (4) improved communication of our science to public and government; (5) retrospective ecosystem analysis; (6) improved understanding of natural mortality processes; (7) distinguish between fishery and environmental changes; and (8) better data on lower trophic levels.

J. Bering Sea Ecosystem Workshop Report , NMFS, USDOI, ADF&G, 1997

This workshop was held on December 4-5, 1997 in Anchorage to promote research coordination and data sharing among organizations that study and utilize resources of the Bering Sea (Bering Sea Organizing Committee, 1997). Organizations including NOAA, Department of Interior, Alaska Department of Fish and Game, EPA, University of Alaska, and Alaska Native groups presented their research projects, data bases, and data needs. Following the workshop, an interagency Bering Sea Organizing Committee, consisting of representatives from NOAA, Dept. of Int., and the State of Alaska, was formed to review issues raised and the workshop and to plan for further coordination of ecosystem research in the Bering Sea. Topics the organizing committee are discussing include: coordination of field sampling plans, sharing of databases, traditional local knowledge, and the development of a Bering Sea Ecosystem Research Plan.

K. Bering Sea Ecosystem Workshop Report, NMFS, USDOI, ADF&G, 1998

This workshop was held June 2-3, 1998 in Anchorage to bring together scientists from major agencies and institutions and other Bering Sea stakeholders such as environmental groups, local, Native, and fishing communities (Bering Sea Organizing Committee, 1998). The main purpose of the workshop was to receive input from these groups on how to further develop and refine an integrated Bering Sea Ecosystem Research Plan. Prior to the workshop, an initial draft plan had been developed by NOAA, USDOI, and ADF&G scientists, based on the recommendations from the Dec. 4-5, 1997 Bering Sea ecosystem workshop. The draft plan was commented on, research priorities were discussed, and the next step for Native community involvement in the research process was outlined.

National Oceanic and Atmospheric Administration- Cooperative Projects

NOAA has conducted Bering Sea fisheries surveys and research for many years. NOAA managed OCSEAP during the 1970s and 1980s. Recently NOAA has funded several cooperative projects that focus on the Bering Sea ecosystem.

<u>Arctic Research Initiative (ARI) (FY98 Funding level $1,500K)</u>

A major new research program in the region, an Arctic Research Initiative called "Health of the Bering Sea Ecosystem" (Cooperative Institute for Arctic Research 1997) was first funded by NOAA in 1997. One of the highlights of this research in 1997 was a major interdisciplinary cruise along the Bering Sea shelf break on the NOAA ship "Miller Freeman." Seven oceanographic transects were conducted across this highly productive region, labelled the "green belt", collecting data on the Bering Slope Current's location and strength, on photosynthetic activity, and on other oceanographic parameters.

Following 15 initial studies funded in 1997, including the projects on the "Miller Freeman", 22 research projects will be conducted in 1998. About half of the projects are concerned with the natural variability of the Bering Sea ecosystem and the atmosphere-ice-ocean interactions that control this variability. The other half deal with anthropogenic influences, including atmospheric and marine contaminant studies and their effects on biota and eventually on humans. The four major research thrusts are:

Natural variability of the Western Arctic/Bering Sea ecosystem

- The Bering Sea Green Belt: processes and ecosystem production.
- Atmosphere-ice-ocean processes that influence ecosystem variability.

Anthropogenic influences on the Western Arctic/Bering Sea ecosystem

- Arctic haze, ozone and UV flux and their potential impacts
- Contaminant inputs, fate and effects on the ecosystem.

With this new funding NOAA is strengthening US marine ecosystem and meteorological/oceanographic research in the Bering Sea, as well as continuing major contributions to the study of atmospheric pollutants such as Arctic Haze. Studies of the "green belt", meteorological processes associated with the Aleutian Low, and the oceanographic processes in the Bering Strait are emphasized. Inter-decadal variations in atmosphere-ice-ocean interactions are beginning to shed new light on climate change. Studies of marine contaminants and their effects, for example mercury, begun modestly in 1997, have been strengthened and there is a new emphasis on contributions to AMAP, the international Arctic Monitoring and Assessment Program. Also, the studies of contaminants effects are establishing new and much closer links with Native communities and individuals than in the past. The program is managed for NOAA by the Cooperative Institute for Arctic Research (CIFAR) at the University of Alaska Fairbanks.

<u>Fisheries-Oceanography Coordinated Investigations (Supports NOAA investigator salaries.)</u>

FOCI was established by NOAA in 1986 to examine the physical and biological factors that affect commercial fisheries in Alaskan waters and to provide information to resource management (Schumacher and Kendall 1995). Research is conducted mainly by personnel at two NOAA laboratories in Seattle, Washington: the National Marine Fisheries Service's Alaska Fisheries Science Center (AFSC) and the Office of Oceanic and Atmospheric Research's (OAR's) Pacific Marine Environmental Laboratory (PMEL), with assistance from scientists at several joint NOAA/university institutes, including those at the Universities of Alaska, Washington and Oregon State. Researchers from other academic and research institutes from across the nation have been part of the FOCI effort. The goal of FOCI is to understand the influence of changes in the environment on the abundance of various commercially valuable fish and shellfish stocks in Alaskan waters and to examine the role of these animals in the ecosystem. Presently, FOCI research focuses on factors influencing recruitment to stocks of pollock, with emphasis on early life stages (egg through young of the year), and their associated ecology. Among FOCI's legacy is the development and implementation of models to integrate biophysical observations, the evolution of technologies to measure biophysical conditions and to access condition factors of larval pollock, and the development of methods to apply research results to fisheries management.

<u>Southeast Bering Sea Carrying Capacity (FY98 funding level $950K)</u>

SEBSCC is a NOAA Coastal Ocean Program Regional Ecosystem Study begun in 1996 that is administered by the University of Alaska, AFSC, and PMEL. SEBSCC followed Bering Sea FOCI, a project that evaluated stock structure of pollock in the Bering Sea and examined their recruitment dynamics. SEBSCC's goal is to increase understanding of the southeastern Bering Sea ecosystem, to document the role of juvenile pollock and factors that affect their survival, and to develop and test annual indices of pre-recruit (age-1) pollock abundance.

SEBSCC scientific questions (NOAA Coastal Ocean Program 1995) address productivity of the region and climatic and anthropogenic effects on the ecosystem:

1. How does climate variability influence the Bering Sea ecosystem? How does climate variability affect the physical regimes of the southeastern Bering Sea? Is there historical evidence for a regime shift in the Bering Sea, and how is this reflected in ecological relationships? What information will we need to further clarify this? How have past changes in the species mix in the region related to climatic and oceanographic variability?
2. What limits population growth in the Bering Sea? Is there evidence of a carrying capacity, e.g., for pollock? What is the role of cannibalism in controlling pollock populations? What is the feeding and switching behavior of juvenile pollock and their predators? What is the ecological role of pollock in the Bering Sea, and what energetic links exist among pollock and apex species?
3. How do oceanographic conditions influence biological distributions? How do oceanic conditions influence overlap or separation between predators and prey? Do ocean conditions create discrete aggregations of pollock, and do life histories differ in separate aggregations? Does sea ice influence the distribution of pollock, and if so, how? What maintains separations between biophysical domains?

4. What influences primary and secondary production regimes? How do primary and secondary production respond to climatic variability? What are the sources of nutrients to the southeastern Bering Sea shelf, and what processes affect their availability?

Marine Mammal Protection Act – Bering Sea Ecosystem Study Plan (Not funded)

The 1994 amendments to the MMPA included a provision that the Secretary of Commerce develop a research program to monitor the health and stability of the Bering Sea ecosystem. The research program was to resolve uncertainties concerning the causes of population declines in marine mammals, sea birds, and other living resources of that marine ecosystem. The amendments further required that the program address research recommendations developed by previous workshops on the Bering Sea, and that it include research on subsistence uses of such resources and ways to provide for the continued opportunity for such uses. The Secretary was directed to utilize, where appropriate, traditional local knowledge in the conduct of the research. In early 1995, the National Marine Fisheries Service developed a draft study plan that was refined at a workshop to discuss habitat, ecosystems, marine mammals, sea birds, and fisheries and trophic interactions (National Marine Fisheries Service 1995).

Important scientific questions identified by the MMPA Bering Sea Ecosystem Study Plan include:

1. Do climate fluctuations affect the transfer of nutrients from the basin to the shelf? What is the impact of those fluctuations to the food chain, marine mammals and seabirds.
2. Climate variability affects the seasonal production and extent of sea ice. How does sea ice affect the top down and bottom up processes that influence seabird and marine mammal demography?
3. What are the effects of commercial fishing activities (such as removal of fish biomass, return of discards and offal to the sea, pulse fishing, trawl exclusion zones, and gear impacts on the bottom) on the ecosystem? In particular, what are the effects on those components that are trophically linked to the targeted populations?
4. Is the effect of contaminants (heavy metals, organics, and offal) limited to the proximity of contaminated sites/ sources or can it be traced through the ecosystem via biological and physical pathways?
5. Climate variability influences the basic circulation and heat content of the Bering Sea. How would major perturbations or secular trends in circulation, vertical structure, and heat content affect habitat quality for Bering Sea marine mammals and seabirds.

NOAA’s Bering Sea Ecosystem Management Project (BSEMP) (FY99 funding level $125K)

The Office of the Governor for the State of Alaska, Division of Governmental Coordination and the St. Paul Coastal district received funding from NOAA for FY98 for this project. Its overall purpose is to increase coordination and communication among those interested in Bering Sea ecosystem management. The project proposes to promote interagency cooperation, investigate the feasibility of developing an ocean management plan for the Bering Sea, and develop annotated bibliographies about ecosystem management and local knowledge.

Interorganizational Projects

Seabird, Marine Mammal and Oceanography Coordinated Investigations (SMMOCI)

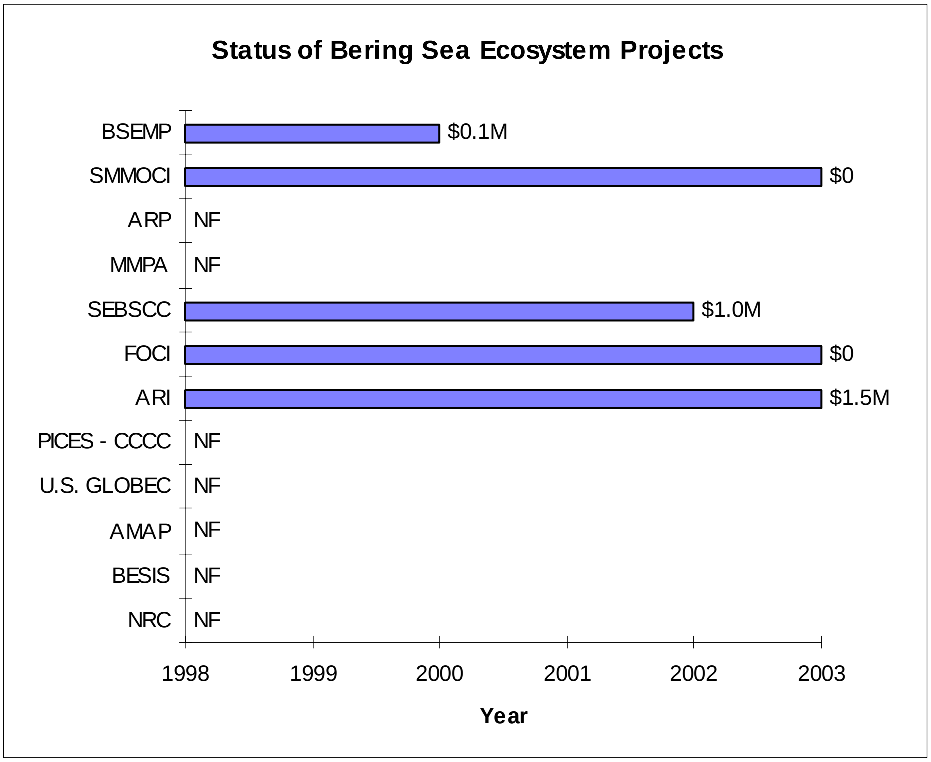
Forage fishes comprise the primary prey base for several species of marine birds and mammals that have been monitored in Alaska over the past 20 years. Knowledge of the marine ecosystem is important for understanding causes of changes. Four organizations (U.S. Fish and Wildlife Service, National Marine Fisheries Service, U.S. Geological Survey, and University of Alaska Fairbanks) have agreed to cooperate in an effort to characterize foraging habitat for seabirds and Steller sea lions at six locations in the Gulf of Alaska and Bering Sea where background monitoring data are available. We began the nearshore marine habitat characterization in 1995 at Unimak Pass in the eastern Aleutian Islands where seabirds and sea lions have been monitored on two nearby islands: Aiktak and Ugamak. Hydroacoustic data were collected along a series of transects within a 50-km radius of the islands to describe the distribution and biomass of potential prey. Midwater and bottom trawls were conducted to support the hydroacoustic surveys, and longline sets were made to help characterize the bottom fish fauna. Marine bird and mammal observations were made during all daylight transects, and adult seabirds were collected to characterize diet composition. Preliminary results suggest such studies can adequately describe ecosystem components and may ultimately help reveal patterns that demonstrate the response of top-level predators to fluctuations in the prey base.

Presently funded cooperative programs

Although many research plans have been developed for the Bering Sea, very few cooperative programs have actually been funded (Appendix Table 1, Appendix Figure 1).

Appendix Table 1.— Bering Sea ecosystem-related plans or projects and research foci.

Plan or Project Name	Research Focus
NRC - National Research Council Report on the Bering Sea	Ecosystem dynamics - climate and human-induced change
BESIS - Bering Sea Impacts Study	Regional impacts of global change - from climate to all trophic levels
AMAP	Amount and effects of pollutants
U.S. GLOBEC	Effects of climate variability on marine animals
PICES Bering Sea Working Group and Climate Change and Carrying Capacity Program	Effects of climate variability and fishing on ecosystems
ARI - NOAA - Arctic Research Initiative	Natural variability of the ecosystem and contaminant inputs, fate, and effects. Themes include: Green belt biology, air-ice-ocean interactions, Boundary layer, arctic haze and UVB, and contaminants
FOCI - NOAA- Fisheries Oceanography Coordinated Investigations	Physical and biological factors affecting commercial fisheries
SEBSCC - NOAA-Southeast Bering Sea Carrying Capacity	Effects of climate variability on the ecosystem - FY99-00 emphases: availability of nutrients on the Bering Sea shelf and relation of juvenile walleye pollock to top predators
MMPA - Bering Sea Ecosystem Study Plan	Monitor the health and stability of the Bering Sea ecosystem - marine mammal and seabird emphasis
ARMRP - Alaska Regional Marine Research Program - Alaska Research Plan	Safeguarding water quality and ecosystem health - effects of natural and human factors
SMMOCI - Seabird , Marine Mammal and Oceanography Coordinated Investigations	Characterize foraging habitat for seabirds and Steller sea lions at specific locations in the Gulf of Alaska and Bering Sea to understand the response of top-level predators to fluctuations in prey base
BSEMP - NOAA Bering Sea Ecosystem Management Project	Increase coordination and communication among those interested in Bering Sea ecosystem management.



Appendix Figure 1. Funding status and timeline for various Bering Sea cooperative programs. (NF = not funded).

There are four programs that presently support cooperative research in the Bering Sea. Two of the programs (FOCI and SMMOCI) are not fully funded with base agency funds. At present, FOCI investigators in NOAA have support for salary but not for shiptime and other resources needed to carry out research. Salary support is part of NOAA base funding and should continue into the future. SMMOCI investigators bring their own resources from their respective organizations to carry out the research so the program is not officially funded. The other two funded programs have limited funding horizons. NOAA's Arctic Research Initiative will be funding projects through FY99. This program has been funded as a congressional add-on in previous years and funding status beyond FY99 is very uncertain. The funding for NOAA's Southeast Bering Sea Carrying Capacity Program will be around $1,000K through FY00 and will then be phased out in the final two years of the program (FY01-02) with funding levels of $700K and $292K, respectively. NOAA's BSEMP project will be funded for FY99 at $125K and funding level for FY00 is presently unknown.

References

Bering Sea Organizing Committee, 1997. Report of the Bering Sea Ecosystem Workshop, Dec. 4-5, 1997, Anchorage, AK. Available from U.S. Dep. Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115 USA. 153p.

Bering Sea Organizing Committee, 1998. Report of the Bering Sea Ecosystem Workshop, June 2-3, 1998, Anchorage, AK. Available from U.S. Dep. Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115 USA. ???p.

BESIS, 1998. Bering Sea Impacts Study - Implications of Global Change in Alaska and the Bering Sea Region. Eds. Gunter Weller and Patricia Anderson. Center for Global Change and Arctic System Research, University of Alaska, 160pp.

Byrd, G.V., R.L. Merrick, J.F. Piatt, B.L. Norcross. 1997. Seabird, marine mammals, and oceanography coordinated investigations (SMMOCI) near Unimak Pass, Alaska. Forage Fishes in Marine Ecosystems. Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program Report No. 97-01. University of Alaska Fairbanks.

Cooperative Institute for Arctic Research, 1997. FY 1998 Arctic Research Initiative: Announcement of Opportunity. Center for Global Change and Arctic System Research, University of Alaska Fairbanks, Fairbanks, AK 99775.

Hay, D.E., 1997. Workshop discussion. Pages 751-771 in Proceedings of the International Symposium on the role of forage fishes in marine ecosystems. University of Alaska Sea Grant College Program Report 97-01, Fairbanks.

International Arctic Science Committee, 1997. The Impacts of Global Climate Change in the Bering Sea Region. Bering Sea Impacts Study Project Office, Campus Box 7740, University of Alaska Fairbanks, Fairbanks, AK, 99775-7740, 42 pp.

National Marine Fisheries Service, 1995. Bering Sea Ecosystem Study: Workshop Report. NMFS/AFSC, 7600 Sand Point Way N.E., Seattle, WA, 98115-0070, 20 pp.

National Research Council, 1996. The Bering Sea Ecosystem. National Academy Press, Washington, D.C., 307 pp.

NOAA Coastal Ocean Program, 1995. Planning Workshop for Southeast Bering Sea Carrying Capacity. NOAA/PMEL, 7600 Sand Point Way N.E., Seattle, WA 98115-0070, 51 pp.

North Pacific Marine Science Organization, 1996. Science Plan and Implementation Plan: A Report of the PICES-GLOBEC International Program on Climate Change and Carrying Capacity. PICES Scientific Rep. No. 4., Institute of Ocean Sciences, P.O. Box 6000, Sidney, B.C., Canada. V8L 4B2, 64 pp.

North Pacific Marine Science Organization, 1997. PICES Annual Report. Fifth Annual Meeting, Institute of Ocean Sciences, P.O. Box 6000, Sidney, B.C., Canada V8L 4B2, 34-44.

Schumacher, J.D. and A.W. Kendall, Jr., 1995. An example of fisheries oceanography: walleye pollock in Alaskan waters. Amer. Geophys. Union U.S. National Report 1991-1994, 1153-1163.Stone, David, 1997. Arctic Pollution Issues, A State of the Arctic Environment. Arctic Monitoring and Assessment Program (AMAP). Oslo, Norway, 188 pp.

U.S. Global Ecosystems Dynamics, 1996. Report on Climate Change and Carrying Capacity of the North Pacific Ecosystem. U.S. GLOBEC Report Number 15, Department of Integrative Biology, University of California, Berkeley, CA 94720-3140, 95 pp.
U.S. Global Ecosystems Dynamics, 1996. North Pacific Climate Change and Carrying Capacity (CCCC) Science Plan. U.S. GLOBEC Report Number 16, Department of Integrative Biology, University of California, Berkeley, CA 94720-3140.
U.S. Global Ecosystems Dynamics, 1997. U.S. GLOBEC Northeast Pacific Implementation Plan. U.S. GLOBEC Report Number 17, Department of Integrative Biology, University of California, Berkeley, CA 94720-3140.

Appendix Table 2.—List of acronyms, Bering Sea Ecosystem Research Plan.

ADF&G	Alaska Department of Fish and Game
AFSC	Alaska Fisheries Science Center
AMAP	Arctic Monitoring and Assessment Program
ARI	Arctic Research Initiative
ARMRP	Alaska Regional Marine Research Board's Alaska Research Plan
BESIS	Bering Sea Impacts Study
BSEMP	Bering Sea Ecosystem Management Project
BSMIZEX	Bering Sea Marginal Ice Zone Experiment
CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CCCC	Climate Change and Carrying Capacity Program of PICES
CIFAR	Cooperative Institute for Arctic Research
DDT	Dichloro-diphenyl-trichloro-ethane
EPA	Environmental Protection Agency
FOCI	Fisheries-Oceanography Coordinated Investigations
GIS	Geographic Information Systems
GLOBEC	Global Ecosystem Dynamics
ISHTAR	Inner Shelf Transfer and Recycling in the Bering and Chukchi Seas
MMC	Marine Mammal Commission
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
NMFS	National Marine Fisheries Service
NOAA	National Oceanic Atmospheric Administration
NPRB	North Pacific Research Board
NPZ	Nutrient-phytoplankton-zooplankton
NRC	National Research Council
OAR	Oceanic and Atmospheric Research
OCSEAP	Outer Continental Shelf Environmental Assessment Program
PCB	Polychlorinated biphenyl
PICES	North Pacific Marine Science Organization
PMEL	Pacific Marine Environmental Laboratory
PROBES	Processes and Resources of the Bering Sea
REX	Regional Experiment Task Team of PICES-CCCC Program
SEBSCC	Southeast Bering Sea Carrying Capacity
SMMOCI	Seabird, Marine Mammal and Oceanography Coordinated Investigations
TK	Traditional or local knowledge
USDOI	U.S. Department of the Interior
UV	Ultraviolet