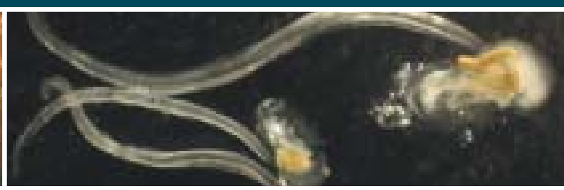
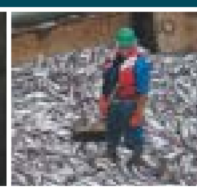
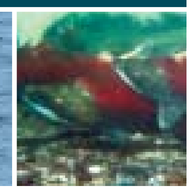
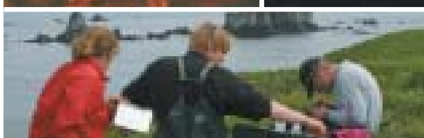
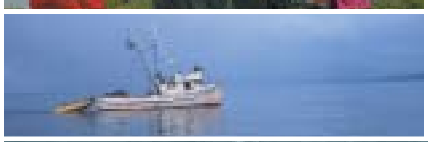
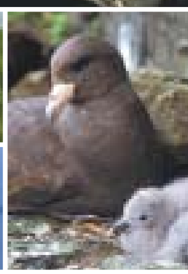
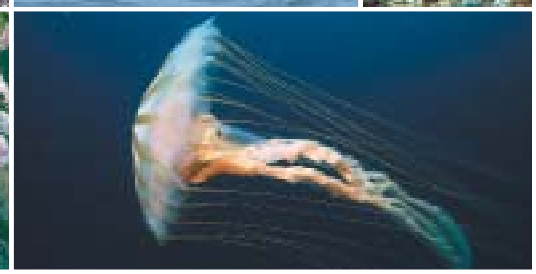
North Pacific
Research Board

Science Plan

Building a clear understanding of the North Pacific, Bering Sea, and Arctic Ocean ecosystems that enables effective management and sustainable use of marine resources.




North Pacific
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Science Plan

The North Pacific Research Board dedicates this first Science Plan to U.S. Senator Ted Stevens of Alaska for his insight and wisdom in creating this enduring legacy of research with the goal of promoting productive fisheries and healthy oceans off Alaska for future generations.

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North Pacific Research Board

Science Plan

Building a clear understanding of the North Pacific, Bering Sea, and Arctic Ocean ecosystems that enables effective management and sustainable use of marine resources.

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Contents

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Research Board

Science Plan

Executive Summary

An Enduring Scientific Legacy - Understanding Alaska's Marine Ecosystems

Alaska's marine ecosystems are some of the most productive regions in the world, supporting vast and varied populations of fish, seabirds, and marine mammals. They provide over 40% of the commercial fish landings in the United States and generate an abundance of resources for subsistence and recreational users. Resource managers and users must have the knowledge necessary to protect these bountiful and biologically diverse ecosystems to ensure their sustained productivity. They must understand how these systems and their components vary over time and how they may be affected by human activities. Gaining this understanding will require an aggressive, effective, and scientifically-sound research program.

The North Pacific Research Board (the Board) was created by Congress in 1997 to develop and implement just such a meritorious science program, focused on the fisheries and marine ecosystems in the North Pacific Ocean, Bering Sea, and Arctic Ocean. Further, Congress directed the Board to be more than a curiosity-based science organization. The enabling legislation directs the Board to address pressing fishery management issues and to be responsive to marine ecosystem information needs. Funding is based on earnings from the Environmental Improvement and Restoration Fund.

The Board has twenty members representing federal, state, and other entities. Upon being organized in 2001, it adopted an ambitious mission to develop a high caliber, comprehensive science program to achieve major goals related to improving our understanding of marine ecosystems off Alaska.

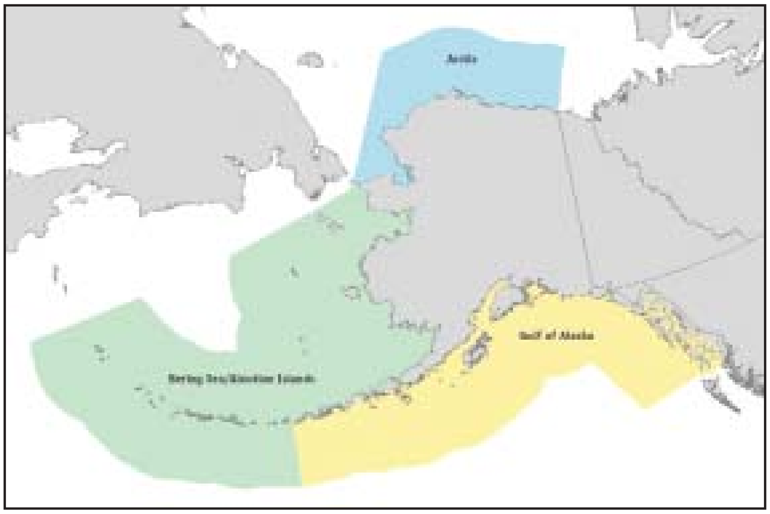
This science plan represents a significant first step in attaining the Board's mission and goals. It was developed with guidance from the National Research Council of the U.S. National Academy of Sciences and will be implemented through annual planning activities and requests for proposals, along with workshops and science symposia. The Board will identify research needs and priorities each year, seeking valuable advice from its science and advisory panels, as well as other stakeholders.

Major Goals of the North Pacific Research Board

1. Improve understanding of North Pacific marine ecosystem dynamics and use of the resources;
2. Improve ability to manage and protect the healthy, sustainable fish and wildlife populations that comprise the ecologically diverse marine ecosystems of the North Pacific, and provide long-term, sustained benefits to local communities and the nation;
3. Improve ability to forecast and respond to effects of changes, through integration of various research activities, including long-term monitoring;
4. Foster cooperation with other entities conducting research and management in the North Pacific, and work toward common goals for North Pacific marine ecosystems; and
5. Support high quality projects that promise long-term results as well as those with more immediate applicability.

Integrated Ecosystems Research – the Ultimate Challenge

This initial science plan is structured around fundamental ecosystem components. Its long-term success, however, will be realized only if it results in an integrated program that cuts across scientific disciplines and begins to address critical questions regarding ecosystem structure and function and how ecosystem components are influenced by natural variability and human activities. This new comprehensive understanding, integrated at an ecosystem level, will provide one of the most important, long-term legacies of the Board.



Scientific Foundations

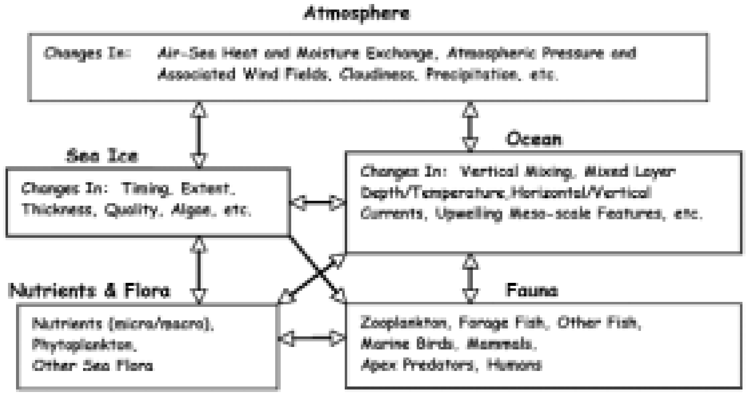
The Board's research program is organized around three large marine ecosystems: the Gulf of Alaska, Bering Sea and Aleutian Islands, and Arctic Ocean (delimited by the Chukchi and Beaufort Seas for purposes of this plan). Each has a suite of atmospheric and oceanographic features within which marine species have adapted strategies for growth and survival. Their features and processes help to define unique research themes, even if regional boundaries remain porous and inexact.

Scientific programs over the past half century have provided a strong foundation for our current understanding of these ecosystems. We know, for example, that climate and surface features such as the El Nino/Southern Oscillation, Pacific Decadal Oscillation, Victoria Pattern, Arctic Oscillation, and Aleutian Low Pressure System, work at time scales from 2-7 years to many decades, thus influencing precipitation, velocity and direction of surface winds, ocean advection and mixing, heat flux and ice formation, nutrient replenishment, and the very productive food webs that depend upon those features.

The food web of the Gulf of Alaska is based largely on a relatively narrow, deep continental shelf that is constantly replenished by nutrients swept onto the shelf from deeper offshore waters by the Alaska Stream and Alaska Coastal Current. Nutrient transport onto the shelf, and downstream onto the Bering and Chukchi/Beaufort Sea shelves, provides the fuel for the high primary and secondary production that supports diverse Alaskan marine ecosystems with extensive marine mammal, bird, fish and shellfish populations.

The Aleutians form a porous boundary between the Gulf of Alaska and the Bering Sea. Much of the nutrient-laden Alaska Stream flows north into the Bering Sea through passes along the Aleutians. Influenced by strong tidal currents, the Alaska Stream provides nutrients to the euphotic zone of the broad, relatively shallow continental shelf of the Bering Sea. This broad shallow expanse helps make the Bering Sea one of the most productive marine ecosystems in the world.

A major feature of the Bering Sea and Arctic Ocean is sea ice. Year-round in much of the Arctic, and seasonal in the Bering Sea, sea ice distribution, thickness, and timing have major impacts on the ecosystem: it provides important substrate for marine mammals, influences primary and secondary production which supplies prey for fish and marine mammals and seabirds, and facilitates access to subsistence foods. Sea ice has diminished over the past 20 years and is projected to continue declining as surface temperatures increase with global warming. This could have far-reaching impacts on the productivity of those marine ecosystems.



The conceptual model presented in this science plan reflects these oceanographic features and the processes that influence energy flow through the ecosystems. A central challenge to furthering our understanding of the dynamics of these ecosystems, is determining how processes that influence energy flow cause changes in the ecosystems. Understanding the importance of temporal and spatial scales is critical to identifying local, regional, and large-scale interactions, integrating single species processes into multiple species models, and up-scaling and downscaling climate effects. For example, the timing of sea ice presence and melt influences the primary and secondary production sequence that is the basis of the food chain. Shifts in timing could disturb availability of prey to predators and influence survival of fish species.

Three Overarching Premises

Changes in the ecosystem may have significant impacts on resources and humans. Variability in ecosystem dynamics may be manifested as inter-annual changes in the productivity of component species through variation and trends in rates of production of young, individual growth, mortality, and dispersal. Aggregate changes in species can lead to large shifts in overall ecosystem structure. To provide realistic forecasts of potential changes, we must identify the main factors that shape trophic structure and dynamics and energy flow. It is critical for scientists and managers, on the basis of sound science, to be able to distinguish between natural and human-induced variability, so that both can be addressed to accomplish sustainable management. Three overarching premises emphasize this variability and encompass the broad spectrum of scientific, management and human issues associated with ecosystem change. They will provide an umbrella under which research needs and strategies can be identified and discrete hypotheses formulated and tested.

Four Research Approaches

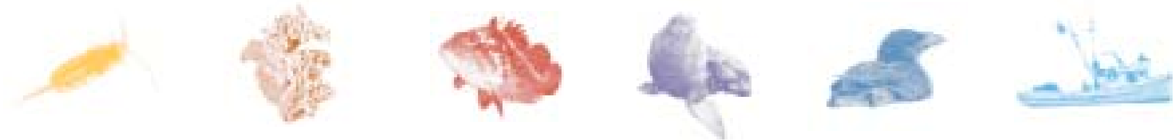
The Board will field an extensive scientific program to discover how the marine ecosystems function and vary over time and space. Four basic research approaches will be applied: (1) monitoring and development of indices to detect changes in ecosystem elements and provide data for modeling and context for process studies; (2) process studies to identify and understand important processes and functional responses; (3) retrospective studies to maximize use of existing long-term observational records, and (4) modeling to synthesize, extrapolate in time/space, test ideas, and forecast future scenarios. Over time, these approaches will evolve toward multidisciplinary efforts and integrated ecosystem research programs.

Three Overarching Premises

1. Natural variability in the physical environment influences trophic structure and overall productivity;

2. Human impacts superimpose additional changes, including increased levels of contaminants, habitat alterations, and increased mortality of certain species that may initiate ecosystem change; and

3. Natural and/or human-induced changes affect people who live and work in the region, forcing adaptation to the changing environment, ecosystem, and management scheme.



Eight Research Themes

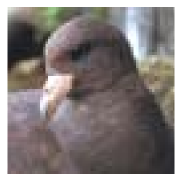
Eight general thematic categories are identified for research: lower trophic level productivity, fish habitat, fish and invertebrates, marine mammals, seabirds, humans, other prominent issues, and integrated ecosystem research programs. The first six represent major components of the marine ecosystem. Other prominent issues include contemporary topics such as contaminants, harmful algal blooms, invasive species, aquaculture, and climate change and ice free Arctic. Integrated ecosystem research, the last but most critical category, provides examples of studies that cut across disciplines and build upon issues raised in other themes. For each thematic category, more specific research needs are arrayed against the Board's two statutory priorities – pressing fishery management issues and marine ecosystem information needs – as summarized in Table ES-1.

Lower Trophic Level Productivity Research needs associated with the base of the food web respond mainly to marine ecosystem information needs. Nutrient flux onto the continental shelves and processes that drive primary and secondary production are key to the highly productive marine ecosystems that exist off Alaska. What mechanisms control nutrient supply to the lower food web? How do they impact phytoplankton and zooplankton community structure and composition? Why do massive blooms of coccolithophorids occur? What factors influence the timing and intensity of zooplankton production which is a major conduit for energy to upper trophic levels? Sea ice is a very significant modifier of the lower food web. How will climate change, manifested in reduction in sea ice, impact the base of the food web? These are just some of the questions that will need to be addressed in examining the nutrient-phytoplankton-zooplankton sequence and comparing and contrasting the three main marine ecosystems off Alaska.

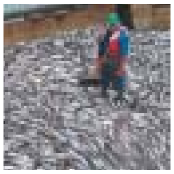
Fish Habitat Fish habitat is everywhere. Broadly defined, it includes the ocean bottom as well as the water column and sea ice where present, and all their components. The Board will focus on the multiplicity of relationships between major fished species and benthic habitat. Some species, such as pollock, are almost entirely independent of benthic habitat, while others, such as rockfish, closely depend on particular bottom structure. Research should elucidate those relationships. How does habitat influence the distribution and abundance of certain species? Are growth, reproduction and survival rates dependent on certain types of habitat? Which habitats are necessary to maintain fish production consistent with sustainable fisheries and a healthy ecosystem? How do fishing and other human activities impact habitat? How resilient is habitat to these impacts? This science plan also recognizes that habitat serves much broader ecosystem functions than just supporting commercially-fished species. For example, deep water corals are unique, highly diverse assemblages that need to be studied. Fishing effects, habitat mapping, ecosystem functions of habitat, and other human-related impacts on habitat, such as contaminants and coastal development, will provide focus for the Board's research program on habitat.

Fish and Invertebrates The vision of the Board is to build a clear understanding of the marine ecosystems off Alaska that enables effective management and sustainable use of marine resources. Knowledge of the rich assemblages of fish and invertebrates and the factors that help shape their distribution and abundance is at the core of the Board's research program. Many fish and invertebrate species support important commercial, recreational, and subsistence fisheries. In addition, other species such as forage species, sharks and skates, are relatively lightly used by humans, but still play significant roles in the ecosystem. A better understanding is needed of the distribution and population dynamics of the fish stocks and how they are influenced by fishing and variability in their surrounding environment. What causes major perturbations in important species? What are the implications of climate change on those species and their management? How can stock assessments be improved? Are there alternative harvesting strategies that should be applied? Which new techniques will help reduce bycatch of unwanted species? How does natural and man-induced variability in fish and invertebrate populations impact humans dependant on those resources? All these research priorities will need to be addressed if the highly productive fisheries off Alaska are to remain sustainable.

Marine Mammals Marine mammals often are considered to be a bellwether of how well a marine ecosystem is functioning. They are one of most visible, charismatic groups of marine organisms and their presence is perceived by the public as signifying a "healthy" ecosystem. Indeed Alaska marine regions support a rich assemblage of marine mammals, including seals, sea lions, walrus, whales, dolphins, porpoises, sea otters, and polar bears. Most species are present throughout the year, while others seasonally migrate into and out of the region. They occupy diverse habitats from nearshore to the continental shelf to deep oceanic waters off the continental slope. Their range often overlaps with major fisheries and other human activities. Several species, such as Steller sea lions and five species of whales, are listed as threatened or endangered under the Endangered Species Act (ESA). Research priorities range from ecosystems information needs such as basic population dynamics and impacts of climate change, to pressing issues such as impacts of major fisheries and other human activities. What is the overlap between species and size of prey consumed by marine mammals and those targeted by commercial fisheries? Is there direct or indirect competition for food? How do fisheries and other human activities impact marine mammal habitat? What techniques will help reduce bycatch, entanglement, and disturbance of marine mammals during fishing operations? What is the role of predation in controlling marine mammal populations? How will environmental and climate change impact marine mammal populations and distributions? Can those effects be distinguished from human-related impacts? All of these issues will need to be addressed to ensure the long-term health and sustainability of this very visible component of the marine ecosystems off Alaska.



Seabirds Alaska is host to millions of seabirds. Major breeding colonies are distributed throughout the Bering Sea, Aleutian Islands, and Gulf of Alaska, and smaller colonies are in the Chukchi and Beaufort seas. Thirty-eight species breed in Alaska and at least five additional species breed elsewhere, but return regularly to feed, typically during summer months. Shearwaters, albatrosses, fulmars, storm-petrels, cormorants, gulls, puffins, murres, auklets, and murrelets are widely representative of the seabird species present. Some populations are listed as *Birds of Conservation Concern* or as threatened or endangered under ESA. Those species in particular will require close observation to shed light on potential impacts of human activities. We need to know how seabird populations vary in time and space and whether humans are having an impact. How will these populations respond to environmental and climate change? What are the direct and indirect impacts of large-scale commercial fisheries on seabird populations and foraging success? What knowledge is needed by resource managers to minimize the risk of their decisions on seabirds? How can bycatch and bird strikes on fishing vessels be reduced? How can human-related impacts on seabird habitat be minimized? How will reduced ice cover change the distribution and availability of prey species that in turn could change nesting and breeding cycles and overall population dynamics of seabird colonies? As with marine mammals, seabirds often are perceived as ecosystem status indicators and will need to be considered closely by the Board in its efforts to field a successful research program that is responsive to the needs of ecosystem-based management.



Humans Research often focuses on the impacts of humans on marine ecosystems. This section of the science plan turns that around and considers the impacts of ecosystems and change on human populations. The NRC noted that one could argue that marine ecosystems and their fluctuations are of interest because of their effect on human societies. Humans interact with marine ecosystems through culture and ways of life, as well as economically. Ecosystems provide for nutrition, subsistence, employment, income, lifestyles, cultural identity, and even spirituality. Natural variability and human-induced variability in marine ecosystems will shape the goods and services provided by the ecosystem to humans. The Board's research program should provide appropriate baseline assessments for detecting the impacts on humans that may result from changing resource populations and climate variability on human populations. In addition, there must be policy studies that help to improve management decisions and institutions. Studies will be needed on the history of the fisheries, the role of international agreements, conflicts among regulatory statutes and rulings, management systems, stakeholder participation, and the use of science in management. Studies also will be needed on human health issues.

Other Prominent Issues Some contemporary issues are not necessarily core research components of the Board's program, but nonetheless may require attention on a case-by-case basis. Five that have been identified include contaminants, harmful algal blooms, invasive species, aquaculture, and climate change. The waters off Alaska are generally perceived as pristine and yet there are concerns with certain contaminants, particularly persistent organic pollutants, and how they move through the food web to humans. The Board will consider studies to determine sources, fates, and trends of contaminants and whether populations are at risk from low, but increasingly detectable concentrations. Harmful algal blooms are of great concern to many resource users, especially as they relate to paralytic shellfish poisoning. Studies may include monitoring environmental variables that influence the presence and intensity of the causal organisms. Invasive species are non-native to Alaska and may cause economic or environmental harm, threaten native species, and impact human health. Atlantic salmon that escape from fish farms are the only marine fish species now considered invasive. They could be a serious threat to native salmonids. Other invasive species could threaten Alaska waters, especially if shipping intensifies with recession of the ice pack in the Arctic under global warming. Alaska aquaculture includes shellfish farming and salmon ranching. Finfish farming is prohibited. A major concern with aquaculture is the introduction of new species that may displace highly productive native stocks. Climate change, discussed throughout this plan, could have significant impacts on marine mammals and seabirds, and the distribution and abundance of major commercial and subsistence fish resources. These changes and their socio-economic consequences will require long-term study.

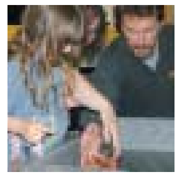
Integrated Ecosystem Research Programs As stated earlier, encouraging multidisciplinary, ecosystem-wide research may provide the most important, long-term legacy of the Board. This science plan provides opportunities for and examples of programs that cut across scientific disciplines and begin to address critical questions regarding ecosystem structure and function and how they might be influenced by natural variability and human use of resources. Examples are provided for a selection of marine regions within the three large marine ecosystems off Alaska. These examples must be developed further using synthesis teams and workshops. They are meant to be responsive to the NRC study committee's strong recommendations to support well-integrated regional investigations and fundamental science on ecosystems and the populations they support. First and foremost will be the development of an integrated ecosystem research plan to address the response of the Bering Sea ecosystem to climate change, especially as it is mediated through a reduction in sea ice cover. This approach to integrated research will provide resource managers and users with the information they need to react responsibly to far reaching changes in the ecosystem and its highly productive resources.

Other Research Approaches and Partnerships

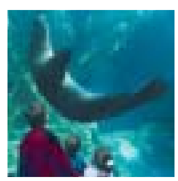
Coordination of Research Board members represent a broad array of federal, state, and other entities involved in research off Alaska; by its very composition and nature, the Board is in a position to provide coordination among research programs and entities. The Board will encourage partnerships and other approaches to research and provide leadership in working with other agencies and entities to identify science, management, and monitoring needs. It intends for its science program to be viewed as a source of unbiased, high quality, information.

Local and Traditional Knowledge Local and traditional knowledge (LTK) refers to an array of information, understanding, and wisdom accumulated over time based on experience and often shared within a group or community. This knowledge may be the product of an individual's time on the land or sea (local knowledge) or it may be accumulated over generations and perpetuated within a culture (traditional knowledge). It may offer new perspectives and paradigms for understanding the marine ecosystem, and greater involvement of those who live and work in the area. The Board will explore ways to use LTK, including the formulation of research hypotheses, documenting existing LTK, recording observations, fostering collaborative analysis, collaborating on specific projects, and exploratory research. The LTK effort must meet standards as high as those applied to the rest of the scientific program.

Cooperative Research Another promising research approach and partnership is working with industry, including commercial fishermen, the oil and gas industry, and others. Fishermen provide the most realistic opportunity for cooperative research. In general they are very knowledgeable of fishing gear, fishing grounds, and fish behavior. This knowledge can be incorporated into most forms of research and provide the basis for formulating hypotheses to be tested. They offer a significant opportunity to collect scientific information on the fisheries and marine ecosystem. They provide field experience, practical knowledge, and platforms for collecting data. They are expert at deploying their gear and have the knowledge to increase their efficiencies and lessen their impact on non-target fish stocks. Their expertise can help to ensure that survey fishing gear is operated as efficiently as designed and that the survey range is consistent with the geographic range of the fish. Use of fishing gear in research helps scientists better understand the impacts of that gear, not only on the fished population, but also on the surrounding habitat. It also allows inter-calibration of gears used by scientists and fishermen.



Education and Outreach The Board aims to support research that is useful to those who live and work in the region. Education, outreach, and community involvement are thus crucial elements of an effective science plan. Each project is required to have an education and outreach component which should include efforts to disseminate research findings and other information to various groups and individuals. These efforts may be general, for example, through a web site or other broadly distributed media, or they may be specific, such as presentations in schools or meetings of stakeholders such as fishermen. Education and outreach also provide opportunities for stakeholders to give feedback to the Board, but the emphasis will be on the dissemination of information generated by the Board's research program.



Community Involvement Effective community involvement is broader than the transfer of information through education and outreach. It includes those activities, but also provides a substantive role for communities to help shape Board activities, from research to education to program guidance. The underlying principle is that communities should be aware of what the Board is doing and why, and have their voices heard in determining program direction. The Board should be responsive to community interests and provide additional information about research being planned or underway in specific areas. Researchers should advise communities and people involved or affected by the studies of the purpose and time-frame of the research and any potential implications. And finally, communities and their members may want to participate in research and the Board may help develop the capacity for them to do so.

Scientific Excellence and Sharing of Information

The Board's science program must be of the highest quality, with results viewed as unbiased, based on sound science, and useful to resource managers. To maintain high quality research, the Board will implement strict procedures for reviewing proposals, avoiding conflicts of interest, and protecting confidential information. When the research is completed, the Board expects significant findings to be promptly submitted for publication, with authorship accurately reflecting contributions of those involved.

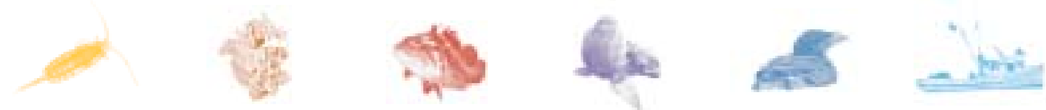
Investigators will be encouraged to share with other researchers, within a reasonable time, the data, samples, genetic baseline data, physical collections and other supporting materials created or gathered. Principal investigators will be required to submit data to the Board's database and to designated national data centers as soon as possible, but no later than two years after the projects are completed. For continuing observations, or for long-term (multi-year) projects, data should be made public annually. Annual reports, required for all projects, should address progress on the sharing of data and research findings.

The Board will seek to establish local, regional, and national partnerships for archiving tissues, specimens, and other types of samples, to ensure proper curation and preservation. The Board will comply with federal requirements for protection of intellectual property, including patents, inventions, and copyrights. And finally, the Board, as feasible and appropriate, will expedite access to and sharing of its facilities and equipment to reduce costs, increase efficiency and avoid duplication of effort.

The Promise of Improved Understanding

The future holds promise for many exciting and significant gains in understanding the marine ecosystems off Alaska and why they remain some of the most productive in the world. This science plan will be the basis for implementation plans and annual requests for proposals. Over time, the North Pacific Research Board's program will grow to encompass several hundred projects of varying scope and duration. Some will focus on individual ecosystem components, while others will contribute to integrated ecosystems programs in the major marine regions. Some will be intended to resolve pressing fishery management issues, while others will address marine ecosystems information needs. All must meet high scientific standards for meritorious research.

This science plan and its research program will provide a firm foundation for building a comprehensive understanding of the many complex processes that influence Alaska's marine ecosystems and contribute to their inherent natural variability. It will help assess the effects of humans on those ecosystems, and in turn, how humans are impacted by them. As knowledge and understanding of those ecosystems grow, theories will evolve and new hypotheses will be generated. This current plan is intended to have a useful life of about five to seven years and then will be revised to incorporate new knowledge of the marine ecosystems off Alaska. The North Pacific Research Board believes that its science program will be a significant contribution to improved understanding of northern marine ecosystems.



	Lower Trophic Level Productivity	Fish Habitat	Fish & Invertebrates	Marine Mammals	Seabirds	Humans
Pressing Fishery Management Issues		Other Human-Related Impacts	Stock Assessment Research & Development	Other Human-Related Impacts	Other Human-Related Impacts	Fishery Management & Policy
						Baseline Assessment Issues
			Alternative Harvest Strategies	Fisheries Interactions	Fisheries Interactions	
		Fishing Effects				Human Health and Marine Resources
			Socio-economic Considerations			
↕				Marine Habitat Use	Marine Habitat Use	Human Values and Resource Protection
			Reducing Catch of Unwanted Species			
				Foraging Success	Foraging Success	
		Habitat Mapping				
			Causes of Perturbations of Major Species	Population Dynamics	Population Dynamics	
	Nutrient Dynamics					
	Phytoplankton Ecology	Ecosystem Functions of Habitat	Ecosystem Change Implications on Fisheries Management	Long-term Climate Change	Long-term Climate Change	Climate Variability and Change
	Phytoplankton – Sea Ice Dynamics					
Marine Ecosystem Information Needs	Zooplankton Ecology					

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Chapter 1
Introduction

Overview

The marine ecosystems off Alaska are some of the most productive regions in the world, supporting abundant populations of fish, seabirds, and marine mammals, and providing over 40% of U.S. commercial fish landings. Resource managers must have the knowledge necessary to protect and conserve these rich and biologically diverse ecosystems over the long term. This will require a comprehensive understanding of their components and natural variability, and how they are affected by human activities, especially commercial fisheries.

Toward that end, the North Pacific Research Board (NPRB or Board) was created by Congress in 1997 to recommend marine research activities to the Secretary of Commerce, supported by interest earned from the Environmental Improvement and Restoration Fund (EIRF). The enabling legislation (available at www.nprb.org) requires the funds to be used to conduct research 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). The NPRB must strive to avoid duplicating other research and must emphasize research designed to address pressing fishery management issues or marine ecosystem information needs.

The NPRB has twenty members representing federal, state and other entities (see Appendix D). Of the twenty members, five are nominated by the Governor of Alaska, three by the Governor of Washington, and one by the Governor of Oregon, and appointed by the Secretary of Commerce. The other members represent the U.S. Secretaries of Commerce, State, and Interior, the U.S. Coast Guard, the Office of Naval Research, U.S. Arctic Research Commission, Alaska Department of Fish and Game, North Pacific Fishery Management Council, Alaska SeaLife Center, and Oil Spill Recovery Institute. One member representing fishing interests, is nominated by the Board, and appointed by the Secretary of Commerce. The staff of NPRB is located in Anchorage, Alaska.

The NPRB receives advice from an Advisory Panel of up to 10 members, and from a Science Panel of up to 16 members (Figure 1-1). The Advisory Panel provides a mechanism for meaningful stakeholder involvement in science planning, oversight, and review. It has an active role in setting research priorities, defining questions, and helping NPRB to field an effective and meaningful education and outreach program. The Science Panel also helps shape the research program, advises NPRB on science planning and identification of research priorities, helps draft the annual requests for proposals, and then reviews proposals and develops recommendations for Board consideration. The NPRB may appoint other standing and ad hoc committees and advisory groups as deemed necessary. The Board's recommendations on research proposals are subject to approval by the U.S. Secretary of Commerce, whose authority is delegated to the Alaska Regional Administrator for the National Marine Fisheries Service.

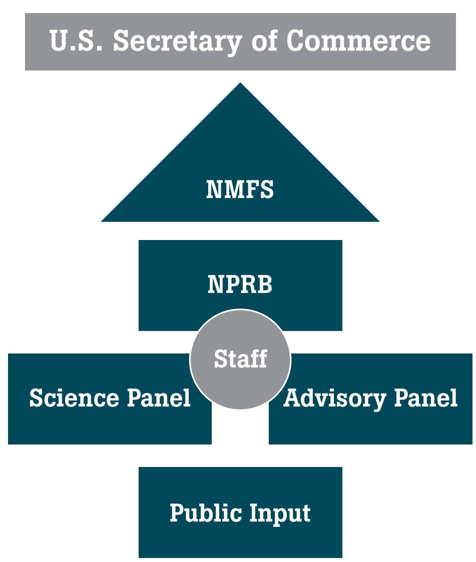
The NPRB held its first two organizational meetings in April and May 2001 and began to develop a common vision of a potential long-term research program in the North Pacific. After hiring staff in early 2002, NPRB further refined its research priorities and launched its inaugural request for proposals (RFP). In subsequent meetings in 2002-2005, NPRB adopted operating procedures and budgets, and developed this science plan, as well as a rolling, four-year implementation plan covering the current and three future years, and three additional RFPs. As will be explained further below, this science plan serves as the Board's overall, longer-term planning document for research off Alaska. Additional details on potential activities and funding allocations spanning four years are presented in the implementation plan. The greatest detail on immediate research needs may be found in the annual RFP released each October. That is where the longer-term planning and priorities of the science and implementation plans achieve traction, culminating in actual field research.

As a result of the four RFPs released from early 2002 through mid-2005, the period when this science plan was developed, the Board funded 92 projects of 1-4 years duration for just over $17 million. While the research priorities in the first three RFPs were based mainly on the Bering Sea research plan from 1998 (BSERP 1998), the penultimate draft of this science plan was available to inform the development of research priorities for the 2005 RFP in September 2004. The 92 projects fall into seven broad categories of research and will be referenced in discussions of implementation strategies in Chapter 3 (please see http://www.nprb.org for details on all NPRB-funded projects).

Categories of Research

Category	# of Projects	Total Funding	Percent
Oceanic and Estuarine Salmon	9	$2.29 million	13
Other Fisheries-Related Research	22	$2.66 million	15
Fish Habitat	12	$3.14 million	18
Marine Mammals	16	$2.78 million	16
Seabirds	9	$1.97 million	11
General Ocean and Ecosystem Studies	19	$3.70 million	22
Education and Outreach and Synthesis	5	$0.67 million	4

Fig. 1-1 Organization chart for the NPRB and flow of recommendations.



NPRB Vision, Mission, and Goals

Prominent guidance in shaping the Board's research program is provided in its enabling legislation which states that funds are to be used to conduct research on or relating to the fisheries or marine ecosystems and that the Board must emphasize research designed to address pressing fishery management issues or marine ecosystem information needs. In effect, the legislation characterizes the NPRB as having an emphasis on applied science and research, rather than just being a curiosity-based science organization. On the basis of these legislative mandates, the Board adopted the following vision, mission, and goals:

Vision Statement

Building a clear understanding of the North Pacific, Bering Sea, and Arctic Ocean ecosystems that enables effective management and sustainable use of marine resources.

Mission Statement

To develop a comprehensive science program of the highest caliber that provides a better understanding of the North Pacific, Bering Sea, and Arctic Ocean ecosystems and their fisheries. The work of the NPRB will be conducted through science planning, prioritization of pressing fishery management and ecosystem information needs, coordination and cooperation among research programs, competitive selection of research projects, enhanced information availability, and public involvement.

Supporting Goals

1. Improve understanding of North Pacific marine ecosystem dynamics and use of the resources.

2. Improve ability to manage and protect the healthy, sustainable fish and wildlife populations that comprise the ecologically diverse marine ecosystems of the North Pacific, and provide long-term, sustained benefits to local communities and the nation.

3. Improve ability to forecast and respond to effects of changes, through integration of various research activities, including long-term monitoring.

4. Foster cooperation with other entities conducting research and management in the North Pacific, and work toward common goals for North Pacific marine ecosystems.

5. Support high quality projects that promise long-term results as well as those with more immediate applicability.

Science Plan Development

The NPRB commenced developing this science plan in 2002. First, the NPRB requested the National Research Council (NRC) to provide advice on the components of a sound science plan. The NPRB envisioned that the eventual plan would be: (1) consistent with the enabling legislation, (2) responsive to the mission and goals of NPRB, (3) comprehensive and long term in nature, (4) composed of major research themes, with particular emphasis on critical living resource management issues and sustainability, (5) built upon past and ongoing research programs of the Federal government, the State of Alaska, universities, and other entities, and (6) sufficiently flexible to adapt to new research and monitoring findings. The NPRB indicated its desire to not be viewed simply as a granting agency, but rather to play a leadership role in identifying science, management, and monitoring needs and conduct a dynamic and scientifically sound research and monitoring program. The NPRB intends to have a coordination role as well. It will strive to be independent and viewed as a source of unbiased, high quality scientific information.

The NRC established a study committee in early 2003 and held field hearings in several resource-based communities to identify research needs. In early 2004, the NRC provided the Board with an interim report titled: Elements of a Science Plan for the North Pacific Research Board (NRC 2004a). A writing team then was established by the Board to draft a plan, which went through several reviews by the Board and its science and advisory panels and finally was forwarded in October 2004 to the NRC for comment. The NPRB received final comments from the NRC in mid-February 2005 and proceeded to finalize the plan.

Science Plan Philosophy and Overarching Premises

This science plan is intended to provide the basis for an integrated program to monitor ecosystem state, develop a more comprehensive understanding of processes that connect elements of the ecosystem, and forecast ecosystem and fisheries dynamics of the Gulf of Alaska, Bering Sea and Aleutian Islands, and Arctic Ocean (limited to Chukchi and Beaufort seas for purposes of this plan), representing three large marine ecosystems (LMEs) that comprise the vast marine region off Alaska. The philosophy of the plan is to explicitly acknowledge that changes in the ecosystem can and will have impacts on humans and resources, and that our present knowledge about these changes and their impacts is far greater in some regions (e.g., the southeast Bering Sea) than in others (e.g., the Arctic or Southeast Alaska). Variability in ecosystem dynamics is manifested as inter-annual changes in the productivity of component species through variation and trends in rates of production of young, individual growth, mortality, and dispersal. Resulting aggregate changes in species can lead to large shifts in overall ecosystem structure. To provide realistic forecasts of future changes, we must identify phenomena and mechanisms that impact trophic structure and dynamics and energy flow through the ecosystem. This will require distinguishing the interconnected roles of human-induced and natural climate forcing, both of which operate at various spatial and temporal scales.

Three overarching premises encompass the broad spectrum of scientific, management and human issues associated with ecosystem change:

1. ***Natural variability in the physical environment influences trophic structure and overall productivity.***

2. ***Human impacts superimpose additional changes, including increased levels of contaminants, habitat alterations, and increased mortality of certain species that may initiate ecosystem changes.***

3. ***Natural and/or human-induced changes affect people who live and work in the region, forcing adaptation to the changing environment, ecosystem, and management schemes.***

These three premises provide an umbrella under which research needs and strategies can be identified and discrete hypotheses formulated and tested. They are intentionally general and of a nature that will require decades to fully address, while allowing shorter-term studies to be undertaken on specific issues. Further, they encompass the four research themes recommended by the NRC (2004a): Ecosystem states and variability; human-induced impacts; economic, social, and management research; and forecasting and responding to change. This plan embraces the reality that ecosystems are complex, and acknowledges that ecosystem changes may have multiple causes and responses and that stable ecosystem states and reversible processes may not exist.

Integrated Ecosystem Research - the Ultimate Challenge

The ultimate challenge of the Board is to field a successful integrated ecosystem research program (IERP) to achieve its vision of building a clear understanding of the North Pacific, Bering Sea, and Arctic Ocean ecosystems that enables effective management and sustainable use of marine resources. This will require interdisciplinary research teams performing well-integrated regional and large-scale investigations on the fundamental structure and function of ecosystems in order to understand the populations they support (NRC 2004a). With its longer term funding, the Board has this unique opportunity to establish an integrated program that cuts across scientific disciplines and begins to address critical questions regarding marine ecosystems and how they are influenced by human use of resources and natural variability, including climate change.

Over the longer term, the Board should not encourage single factor hypotheses. Rather, the entire ecosystem needs to be considered, as well as interactions of the spatial-temporally heterogeneous components. Thus, an IERP should include some aspects of each of the ecosystem elements (atmospheric features through apex predators and humans) of the conceptual model that will be described in Chapter 2, though there may be a primary focus on a particular component, such as invertebrates, groundfish, salmon, marine mammals or birds, or even one or two species, such as red king crab or Steller sea lions or northern fur seals.

Once an interdisciplinary research team is established, it should be assured of substantial funding (millions of dollars per year) over an extended period (e.g., 10 years, with a one-year start-up, seven years with field operations, and two years for synthesis and reporting). In order to develop an IERP, input is required not only from the researchers who would conduct the program, but also from those who may use the ensuing information (e.g., managers of ecosystem resources) and/or have a direct interest such as the Science Panel, Advisory Panel, and other stakeholders. More than one IERP may be appropriate for a large marine ecosystem, though it should be recognized that funds may not be sufficient to support more than a single IERP in each region.

Over time, the IERPs should lead to validation of or changes in the basic conceptual foundation and refinement of the overarching research premises. They should provide the types of information needed for ecosystem-based management, and their results should appear not only in the scientific literature, but in resource assessment documents provided to resource managers such as NPFMC, NMFS, FWS, ADFG, and the Alaska Board of Fisheries. Encouraging multidisciplinary, ecosystem-wide research may provide one of the most important, long-term legacies of the Board.

Components of the Science Plan

This first chapter has explored the legislative foundation for the Board, as well as its organization, vision, mission and goals. It has summarized the early activities of the Board and development of the science plan with guidance from the NRC. The overriding philosophy and premises that will guide future research programs also are described. Clearly, the Board must be responsive to the strong recommendations of the NRC to move away from traditional approaches of research on individual components of the ecosystem, toward a more integrated ecosystem research program that cuts across disciplines.

Chapter 2 presents the scientific foundations for the science plan. They reflect our current understanding of the three LMEs off Alaska based on the many past and ongoing science programs reviewed in that chapter, and provide a conceptual foundation based on knowledge of the atmospheric, oceanographic, and biological features. Chapter 2 ends with a brief description of the research approaches that the Board may use to address the research needs identified in Chapter 3 and a discussion of how research results may be synthesized into a suite of ecosystems indicators for each LME.

Chapter 3 explores major research themes based on the overarching premises presented in this first chapter and the conceptual model and scientific foundations presented in Chapter 2. The NPRB has identified eight general thematic categories: lower trophic level productivity, fish habitat, fish and invertebrates, marine mammals, seabirds, humans, other prominent issues, and integrated ecosystem research programs. The first six represent major components of the marine ecosystems. Other prominent issues include topics such as contaminants, harmful algal blooms, invasive species, aquaculture, and climate change and ice free Arctic. For each of the first six major themes, a brief introduction and overview of current knowledge are presented, contemporary issues and concerns are discussed, and then research needs are identified. Last, general implementation strategies are presented, with the caveat that they are a work in progress and may change as NPRB further develops its research program and releases annual requests for proposals.

Information in Chapters 2 and 3 is organized by ecosystem component and, to the extent practicable without being redundant, by the three large marine ecosystems (moving from south to north: Gulf of Alaska to Bering Sea and Aleutians to Arctic Ocean), though NPRB recognizes that there are many other suitable ways to arrange the information. Each region has a suite of features (bathymetry, regional wind fields, hydrography, sea ice, circulation and productivity) within which marine populations have adapted strategies for growth and survival. These features and their associated processes help to define unique research themes, even if the exact boundaries between regions remain porous and indistinct. While the boundaries do not conform exactly to definitions of large marine ecosystems in the literature, they do provide a convenient organizing principle that links directly to the way resources are managed and areas are viewed by managers, resource users, and the public (also see NRC 2000).

The reader should note that these sections, in striving for a concise yet robust document, are intended to provide a highly rendered overview, not an encyclopedic treatise, of what is known about major ecosystems components of the marine regions off Alaska. Original citations should be consulted for more comprehensive and detailed information, discussions, and qualifications on each subject. A list of species and common names referenced in the plan is provided in Appendix A. An acronym guide is available in Appendix B.

Chapter 3 ends by returning to the ultimate challenge posed to the NPRB: developing an integrated ecosystem research program. The Board has been cautioned by the NRC about continuing to use traditional components (e.g., fish, marine mammals, seabirds, etc.) to organize its science plan. The Board believes, however, that such an approach in this first plan is appropriate and functional at this stage of our understanding of the marine ecosystems off Alaska. It will allow the reader to obtain a succinct overview of a particular topical area efficiently, and certainly it will not slow the Board's progress toward integrated ecosystem research, which it plans to pursue vigorously in the coming years. Examples of multidisciplinary studies are provided at the end of Chapter 3 that cut across scientific disciplines and begin to address critical questions regarding ecosystem structure and function and how they might be influenced by natural variability and human use of resources. These examples will need to be developed further using synthesis teams and meetings, though as noted earlier, there may be funding constraints to having more than one IERP per region.

Chapter 4 describes other research approaches and partnerships that NPRB may pursue in its research program. The Board recognizes that the plan will be successful particularly if those who use the resources and live with them daily are involved in research planning and execution, and receive feedback explaining the research. Toward that end, the plan describes a role for local and traditional knowledge, coordination with other entities and programs, cooperative research with industry, and a program for education, outreach, and community involvement.

Chapter 5 covers several policy issues including scientific quality and integrity, data standards, confidentiality of information, specimen archives, protection of intellectual property rights, and equipment sharing. Though these policies are described in the plan as a convenient reference, their basic provisions will be incorporated outside the plan in the Board's operating procedures and will be subject to periodic revision as necessary.

Implementation Plan

This science plan is intended to be sufficiently broad so that it does not need frequent revision. The purpose is to retain flexibility to study a diverse array of issues in the coming years without having to revise the science plan. While some initial thoughts on implementation strategies are provided, a separate, more specific, implementation plan is updated annually to accompany the plan and provide the basis for the annual request for proposals. This three-tier approach will ensure that the Board's research program adheres to the broad guidance in this plan, but is responsive to contemporary needs and evolves with new scientific findings.

Science Plan Review

The science plan is intended to be an evolving, "living" document that is updated periodically. The NPRB intends to request reappraisals of its science plan and research activities by a qualified entity every five years, but the first review may come after seven years or so to allow early research programs to come to fruition before the plan is revised.

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Chapter 2
Scientific Foundations

Introduction

The conceptual foundation for the science plan is presented in this chapter. It is based on knowledge gained from the many past and ongoing science programs and research approaches described here. This chapter is intended to: (1) define the geographical regions for research; (2) review the major atmospheric/oceanographic features and research activities in each region; (3) integrate existing knowledge into a conceptual scientific foundation; (4) describe basic research approaches; and (5) discuss the use of ecosystems indicators as a means of synthesizing diverse information about an ecosystem and providing a basis for ecosystem-based management. Information presented in this foundational chapter will serve as a backdrop for a more detailed examination of individual ecosystem components, concerns, and research priorities and strategies in Chapter 3.

The term 'conceptual foundation' is used here in the context of providing the scientific base upon which to build future research programs. The NRC (2004a) noted that in the case of NPRB: The conceptual foundation must be specific enough to guide the first years of its research and monitoring program, but general enough to remain relevant over the longer term to provide the science needed to respond to new and unforeseen management issues and technology development and to accommodate increased understanding of the ecosystem and its components. The research programs of the Board must have the potential to elucidate the sources and nature of impacts (human or natural), provide information that enhances understanding of ecosystem dynamics, and educate and involve stakeholders so that management of human activities leads to ecosystems with sustainable services (food and fuels, as well as spiritual, recreational, educational and numerous other nonmaterial benefits to people). Scientists and managers must be able to distinguish between natural and human-induced variability, on the basis of sound science, so that both can be addressed to accomplish sustainable management.

The following sections are intended to provide a highly rendered overview, not a treatise, of what is known about major features and processes of the marine region off Alaska. Original citations should be consulted for more comprehensive and detailed information, discussions, and qualifications on each subject.

Conceptual Foundation

Large Marine Ecosystems: Atmospheric and Oceanographic Features

The NPRB research region is comprised of several large marine ecosystems (LMEs), each having a suite of features (bathymetry, regional wind fields, hydrography, sea ice, circulation and productivity) within which marine populations have adapted strategies for growth and survival. These features and their associated processes help to define unique research themes, even if the exact boundaries between regions remain porous and indistinct. For purposes of the science plan and defining unique research themes, the marine region is divided into three LMEs (NRC 2004a) which include the Gulf of Alaska (GOA), Bering Sea/Aleutian Islands (BSAI), and Arctic Ocean (Chukchi and Beaufort Seas) (Fig. 2-1). This agrees with NOAA's description of LMEs (see http://www.LME.noaa.gov), except for combining the Chukchi and Beaufort Seas into one Arctic Ocean LME for purposes of establishing a regional marine research program that conforms to accepted jurisdictional boundaries (NRC 2000).

Atmospheric Climate Features Paleoclimate data demonstrate that large, regional to global scale climate changes have occurred over periods from years to decades (e.g., Higgins and Vellinga 2004): climate change is a natural feature of the earth. Owing to some extent to human activities, however, the atmospheric concentrations of the greenhouse gas CO_2 are now higher than those recorded over the past several million years (Hood 2004). This change impacts both the global heat balance and the amount of CO_2 in the ocean. Global warming is likely to be enhanced at high latitudes: sub-arctic and arctic regions are particularly sensitive to climate change due to impacts on the extent of sea ice cover, timing of its advance and retreat, and ice thickness and trajectories (Serreze, et al. 2000). It is not known how global warming will impact the frequency, intensity and/or dominant modes of such features as the El Niño/Southern Oscillation or the Pacific Decadal Oscillation.

Fig. 2-1 Three large marine ecosystems off Alaska.

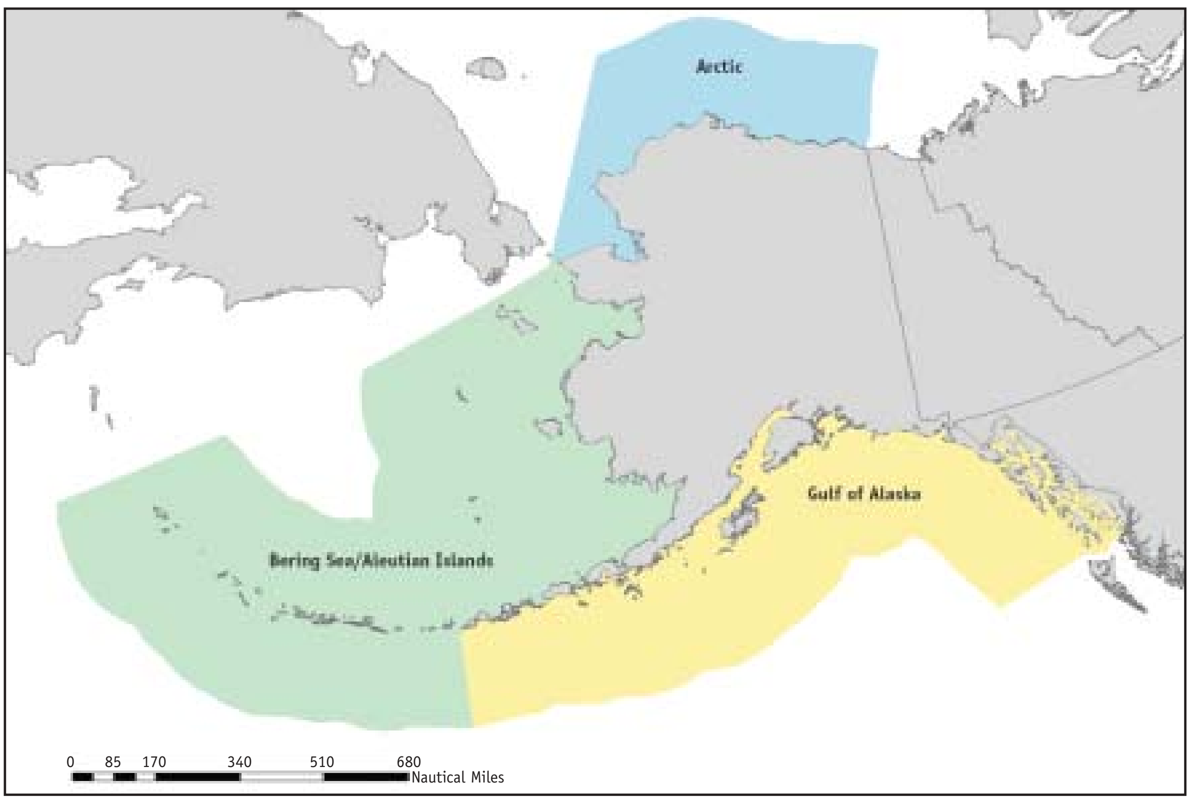


Fig. 2-2a The Pacific Decadal Oscillation (PDO) showing typical wintertime Sea Surface Temperature (colors), Sea Level Pressure (contours) and surface windstress (arrows) anomaly patterns during warm and cool phases of PDO. The color bar is the anomaly in sea surface temperature (degrees C). (From http://www.jisao.washington.edu/pdo/).

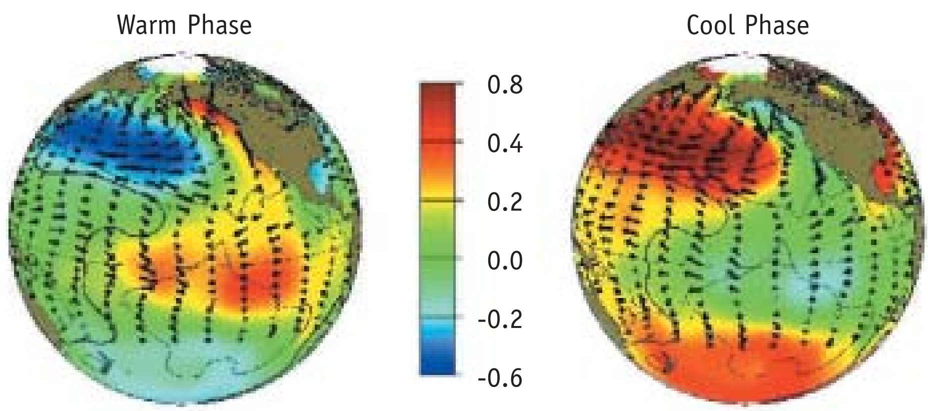


Fig. 2-2b Monthly mean values for the PDO index that show the magnitude of time behavior and changes from warm to cool phases. The transition in 1976/77 is evident. Note that more recent changes in North Pacific sea surface temperature have occurred in more of a north-south mode known as the Victoria pattern (e.g., Bond et al. 2003). (From http://www.jisao.washington.edu/pdo/).

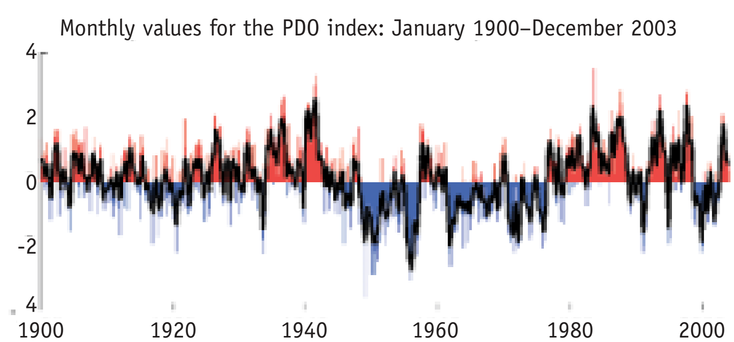


Fig. 2-2c The spatial representation of the Arctic Oscillation shown in terms of the height of the 1000 mb atmospheric pressure surface. The color-coded scale shows anomaly in meters from the mean. (From http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/loading.html).

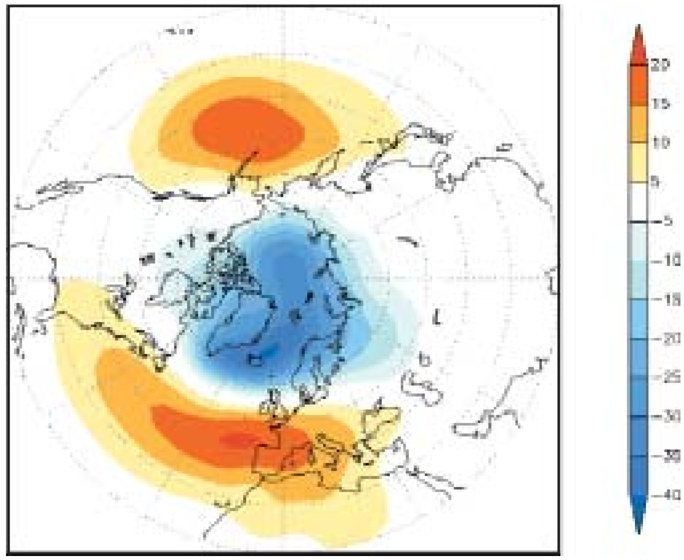
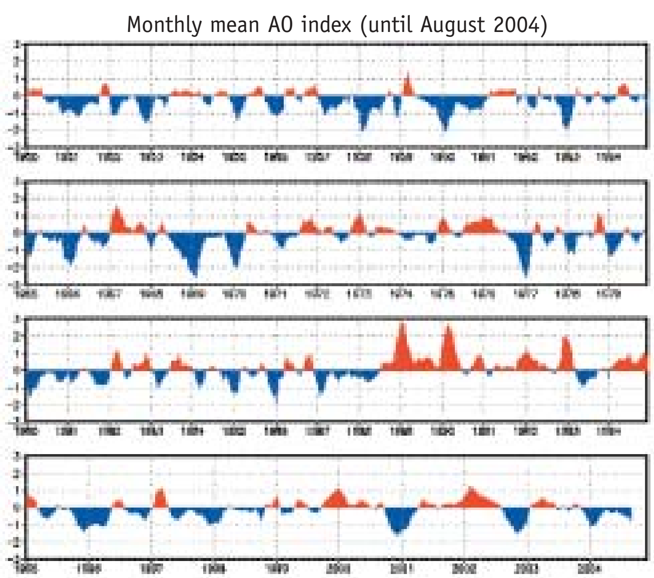


Fig. 2-2d Time history of the monthly mean Arctic Oscillation index.
(From http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/aao/month_aao_index.html).



Among the major atmospheric climate features (i.e., those on time scales of seasons and longer) influencing the NPRB region, are the El Niño/Southern Oscillation (ENSO), atmospheric-related patterns in sea surface temperature (including the Pacific Decadal Oscillation (PDO) and the Victoria Pattern), the Arctic Oscillation (AO), and the Aleutian Low Pressure System (Fig. 2-2). ENSO influences global climate variability at time scales of 2-7 years, and, at times, has a small (~7%) influence on the annual change in sea ice coverage (Niebauer 1998), and on the marine climate of the GOA and BSAI via atmospheric teleconnections (e.g., Niebauer et al. 1999; Hollowed et al. 2001; Overland et al. 2001).

The PDO is a spatial east-west pattern of sea surface temperatures that in its positive phase has warm coastal temperatures in the eastern North Pacific and cold temperatures in the central North Pacific (or the reverse in the negative phase). The PDO has a period of 20-30 years, and has generally been the strongest pattern of variability in the monthly sea surface temperatures, explaining ~21% of the total variance (the largest amount of any pattern of the last 50 years). Since 1989, however, the PDO appears not to be the dominant pattern in sea surface temperature in the North Pacific: it has been replaced by a north-south pattern called the Victoria Pattern (Bond et al. 2003; PICES 2004). Because monitoring of atmospheric parameters over broad spatial scales is relatively recent (<100 years), resolving features with periods of decades is challenging. The AO is the strongest pattern of the winter sea level pressure fields north of 20 N, accounting for ~21% of the change in sea level pressure. The accompanying time/space patterns in surface air temperature closely resemble those in sea surface temperature. The strongest signal in the AO time series is interannual, but it also contains decadal scale signals (i.e., regime shifts), having changed sign in 1976-77 and 1989 (Overland et al. 1999). Changes in the AO are influenced by the Aleutian Low (the monthly or seasonal mean location of the center of low sea level pressure resulting from storm passage, typically along the Aleutian Islands) and the Siberian High pressure systems. The magnitude and position of the Aleutian Low are primary factors determining surface winds (advection and mixing of the upper ocean and production/advection of ice), heat fluxes (mixing and ice formation), and precipitation over the BSAI (which is also influenced by the Siberian High) and GOA.

Gulf of Alaska Oceanography Research in the Gulf of Alaska has been conducted mainly in support of environmental assessment, fisheries, and ecosystem dynamics. Emphasis has been on waters west of Yakutat; southeast Alaska has received relatively less attention. Reviews of regional oceanography and/or biological resources of portions or all of GOA include Dodimead et al. (1963), Favorite et al. (1976); Hood and Zimmerman (1986); Reed and Schumacher (1986); Royer (1998); NRC (2003); and Stabeno et al. (2004). Special issue journal publications exist for Prince William Sound and Shelikof Strait/Western GOA (e.g., Fisheries Oceanography Vol. 5 (1996) and Vol. 10 (2001)). The following is a review of several past major programs and their synthesis volumes that provided information for developing the conceptual foundation, and overarching research philosophy and premises. Selected programs and their abbreviations are shown in Table 2-1.

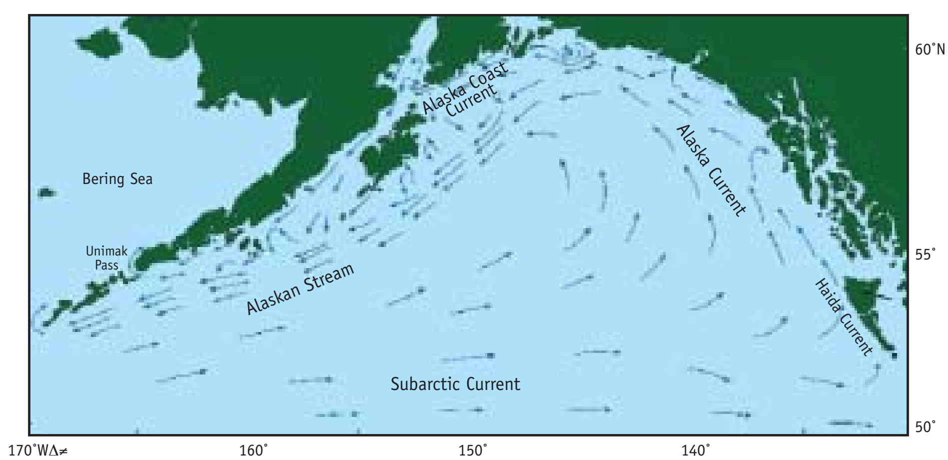
The OCSEAP program conducted studies of most of the components of the ecosystem from 1974 to the mid-1980's (Hood and Zimmerman 1986). The APPRISE program focused on environmental variation and its effects on larval recruitment in Auke Bay (e.g., Ziemann and Fulton-Bennett 1990; Bienfang and Ziemann 1995). Ongoing programs include FOCI that began in 1986 and has generated over 450 papers to date, and continues to provide input to the North Pacific Fishery Management Council's (NPFMC) annual stock assessment and fishery evaluation report (Boldt 2003); other programs and monitoring activities conducted by National Marine Fisheries Service (NMFS) Alaska Fisheries Science Center, including the Ocean Carrying Capacity program; the EVOSTC/GEM program; the Northeast Pacific GLOBEC program; National Park Service Alaska Region Inventory and Monitoring Program; Oil Spill Recovery Institute; Prince William Sound Science Center; US Fish & Wildlife Service; monitoring of deep ocean water properties by autonomous profiling floats in the north Pacific and deep basin of the Bering Sea (ARGO program; http://www.argo.ucsd.edu); the Sound Ecosystem Assessment (SEA) project funded by GEM to investigate factors affecting recovery of pink salmon and Pacific herring in Prince William Sound; and the University of Alaska Coastal Marine Institute.

Table 2-1 Selected North Pacific Science Programs 1970–2004.

APPRISE	Association of Primary Production and Recruitment in a Subarctic Ecosystem
ARGO	Global array of temperature/salinity profiling floats
AYKSSI	Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative
BASIS	Bering-Aleutian Salmon International Survey
BERPAC	Third Joint US-USSR Bering and Chukchi Seas Expedition
FOCI	Fisheries Oceanography Coordinated Investigations
GEM	Gulf Ecosystems Monitoring
GLOBEC	Global Ocean Ecosystems Dynamics
INNER FRONTS	Inner Fronts study supported by NSF
ISHTAR	Inner Shelf Transfer and Recycling in the Bering and Chukchi Seas
LSI	Land-Shelf Interactions
MIZEX	Bering Sea Marginal Ice Zone Experiment
OCSEAP	Outer Continental Shelf Environmental Assessment Program
PACTS	Pan-Arctic Cycles, Transitions and Sustainability
PROBES	Processes and Resources of the Bering Sea
RUSALCA	Russian-American Long-Term Census of the Arctic
SBI	Shelf-Basin Interactions
SEA	Sound Ecosystem Assessment
SEARCH	Study of Environmental Arctic Change
SEBSCC	Southeast Bering Sea Carrying Capacity
SNACS	Study of the Northern Alaska Coastal System

The Subarctic Current (also called the North Pacific Current or West Wind Drift), Alaska Current and Alaskan Stream constitute the sub-arctic gyre (Figure 2-3). The southern boundary of the Gulf of Alaska LME is defined by the eastward flowing Subarctic Current and Samalga Pass as the western extent of the GOA (waters north of ~52 N and east of ~169 W). It is the deeper GOA (>250 m) waters that contain the ocean's most developed oxygen minimum zone and the highest concentrations of dissolved silicate, phosphorus, and nitrate (Mantyla and Reid 1983). Through various mechanisms (being explored by GLOBEC and GEM programs), these waters are transported onto the shelf, resulting in high nutrient concentrations in coastal waters. The transport of nutrients onto the GOA shelf and, downstream, onto the Bering and Chukchi/Beaufort Sea shelves, provides the fuel for high primary and secondary production that supports diverse Alaskan ecosystems with extensive marine mammal, bird, fish and shellfish populations.

Fig. 2-3 Schematic showing the general circulation in the Gulf of Alaska. Note: There is some recirculation from the Alaskan Stream back into the Subarctic Current, and likely a buoyancy driven flow along the entire coast of southeastern Alaska. (From P.J. Stabeno, personal communication).

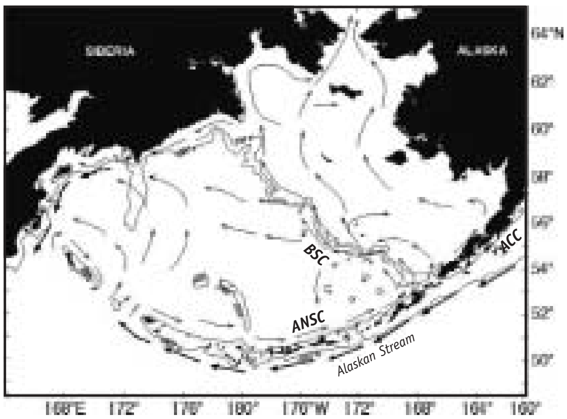


The topography of the relatively deep GOA continental shelf is extremely irregular, reflecting both tectonic and glacial influences, and a nearly continuous coastal mountain barrier along the GOA results in coastal enhanced wind and precipitation (Wilson and Overland 1986; Stabeno et al. 2004). The Alaska Coastal Current flows along the entire GOA coast, extending northward from the coast of British Columbia (Royer 1998) and continuing west to Unimak Pass (Reed and Schumacher 1986). Sea level observations show the seasonal nature of the flow (Reed and Schumacher 1981). Some portion (~15% from estimates of baroclinic transport, i.e., resulting from differences in density) of the Alaska Coastal Current flows into Prince William Sound, a feature that is large enough to be considered an inland sea (Royer 1998). Between Prince William Sound and Kodiak Island, direct current observations (e.g., Reed and Schumacher 1986) show speeds of ~10 to >100 cm s^{-1} with a transport of (~$1x10^6$ m^3 s^{-1}), which is forced by a combination of coastal wind-driven convergence and freshwater runoff from land.

In the western Gulf of Alaska, the continental shelf varies in width from ~150 km west of Kodiak Island, to only ~10 km near Samalga pass. The westward flowing Alaska Coastal Current dominates shelf circulation in the western GOA (Schumacher and Reed 1986), whereas the Alaskan Stream is the main flow over the slope. The Alaska Coastal Current flows through Shelikof Strait and bifurcates near the Semidi Islands with some transport continuing along the coast and the remainder flowing seaward with some later returning to the shelf (Kendall et al. 1996). While most of the Alaska Coastal Current transport flows through Unimak Pass (Stabeno et al. 2002), recent measurements indicate that some transport continues as far west as Samalga Pass (Ladd et al. in press). Nutrients are supplied to the Shelikof sea valley from the slope waters flowing into this bathymetric feature (Reed et al. 1987). The Shumagin gully may also be a conduit for an on-shelf flux of nutrients.

Bering Sea/Aleutian Islands Oceanography Most early oceanographic research in the Bering Sea and Aleutian Islands was conducted to address questions relating to international fisheries (Arsenev 1967; Hood and Kelley 1974; and Favorite et al. 1976). In the early 1950s, Hokkaido University began annual training cruises to the Bering Sea and established what has become one of the longest physical and biological time series available in the region (e.g., Sugimoto and Tadokoro 1998). Between the mid-1970s and late 1980s, the emphasis changed to resource assessment focusing on the eastern shelf as part of the OCSEAP Program (Hood and Calder 1981). This was followed by ecosystem research over the southeastern (PROBES; Hood 1986) and northern shelf (ISHTAR; McRoy 1999), and examination of ice-related phenomena during MIZEX (Muench 1983). During the 1990s, research focused again on fisheries and the influence of the physical factors on the ecosystem. Major contributions included those from FOCI (Schumacher and Kendall 1995: Napp et al. 2000); National Oceanic and Atmospheric Administration's Coastal Ocean Programs (e.g., Macklin 1999; Macklin and Hunt 2004); the National Science Foundation (NSF) Inner Front Program of prolonged production, trophic transfer, and processes at the Bering Sea inner front (Stabeno and Hunt 2002); a study that examined the ecosystem of the endangered Steller sea lion in the Aleutian Islands (Fisheries Oceanography Special Issue, in preparation); and an international program to conduct long-term ecological research on marine ecosystems in the Arctic and Pacific Oceans (BERPAC: Tsyban 1999). Much of the research has been synthesized in Loughlin and Ohtani (1999). The Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative is also presently funding research (NRC 2004b). The North Pacific Anadromous Fish Commission is presently conducting a Bering-Aleutian Salmon International Survey (BASIS) and the NPRB has provided funds for this effort. Alexander (1999) provides a review of many of the former interdisciplinary studies of the Bering Sea. (Also see: NRC 1996, 2003; Loughlin and Ohtoni 1999; BSERP 1998; PICES 1995; BESIS 1997; and Dagg and Royer 2002).

Fig. 2-4 Schematic of circulation in the Bering Sea Aleutian Island LME. Note that the Alaskan Coastal Current (ACC) flows through both Unimak and Samalga Passes, while the primary impact on this LME from the Alaskan Stream is flow thorough Amukta and Amchitka Passes. The Aleutian North Slope Current (ANSC) and Bering Slope Current (BSC) are shown also. The flow through Unimak Pass and around the perimeter of the coast is the Bering Sea Coastal Current. (After Stabeno et al 1999).



The Aleutian Islands form a porous boundary between the GOA/North Pacific Ocean and the Bering Sea. There is little if any continental shelf around these islands owing to plate tectonics. After leaving the GOA, much of the Alaskan Stream flows north into the Bering Sea through various passes west from Amukta Pass to Kamchatka Strait and there is some recirculation back into the Subarctic Current (Stabeno et al. 1999) (Fig. 2-4). Strong tidal currents mix the northward flowing Alaskan Stream waters, providing nutrients to the euphotic zone (Ladd et al. in press, Stabeno et al. in press (a)). Most transport flows north through Amchitka Pass (~2.0 x 10^6 m^3 s^{-1}) and straits further west (Stabeno et al. 1999). Transport through Amchitka and Amukta Pass produces the Aleutian North Slope Current (2-4 x 10^6 m^3 sec^{-1}; Reed and Stabeno 1999). The Aleutian North Slope Current flows eastward along the northern side of the Aleutian Islands and is the main source of the Bering Slope Current. The Bering Slope Current exists either as an ill-defined, variable flow interspersed with eddies or meanders, or as a more regular northwestward flowing current (Stabeno et al. 1999). Shelf/slope exchange, which is important for planktonic and nutrient transport, likely differs depending upon which flow pattern is dominant. The Bering Slope Current continues northwestward along the slope with the majority turning westward across the basin at about 59 N. Samalga Pass is the western extent of the Alaska Coastal Current flow into the Bering Sea and is a biogeographical boundary between eastern and western eco-regions (Ladd et al. In press).

The continental shelf of the eastern Bering Sea is broad (~500 km) and relatively shallow (<180 m) with canyons incising the shelf break. Mean currents over the shelf proper are generally sluggish, however, there is a moderate northwesterly flow over the outer shelf (Schumacher and Reed 1992) and a weaker feature (Bering Sea Coastal Current) around the perimeter of the eastern shelf in the general vicinity of the 50 m isobath (Schumacher and Stabeno 1998; Kachel et al. 2002). Nutrients are exchanged from the slope to the outer shelf by transport of eddies onto the shelf and flow up canyon features. Some flow along the outer shelf continues into the Gulf of Anadyr and then northward through the western passage of Bering Strait. This flow provides nutrients to sustain high productivity in the so-called "Green Belt" (outer shelf/slope) and Chirikov Basin. The Bering Sea Coastal Current includes water from the GOA via Alaska Coastal Current inflow through Unimak and Samalga Pass, continues counterclockwise around the coast and exits through the eastern side of Bering Strait. Tidal currents dominate current energy, resulting in a generally mixed coastal domain and low frequency currents in canyons and around the Pribilof Islands (Stabeno et al. 1999). Within the eastern Bering Sea are definable sub-regions, the southeastern and northern shelves. In both regions, cross-shelf differences exist in water column structure, currents, and biota (Coachman et al. 1975; Cooper et al. 2002).

The eastern Bering Sea has an oceanic and a shelf region whose physical features have recently been described (Schumacher and Stabeno 1998, Stabeno et al. 1999; Stabeno et al. in press). Over the southeastern shelf (south of a line from the Pribilof Islands to Nunivak Island), three distinct hydrographic domains exist which are characterized by water column structure, currents and biota (Cooney and Coyle 1982; Coachman 1986; Schumacher and Stabeno 1998; Stabeno et al. in press (a)). These are the coastal (<50 m deep often mixed throughout the water column with weak stratification), the middle shelf (~50-100 m deep and characterized during summer by a wind mixed surface layer and a tidally mixed bottom layer), and the outer shelf (>100-200 m deep with mixed upper and lower layers separated by slowly increasing density). Separating these domains is a system of transitional zones or fronts (Iverson et al. 1979; Coachman 1986; Schumacher and Stabeno 1998; Stabeno et al. in press (b)). A shelf-break front separates the outer shelf from slope waters; the broad middle shelf transition zone lies between outer and middle shelf waters; and an inner (or structure) front separates the coastal waters from the two-layered middle shelf domain. The balance of wind and tidal energy plays a major role in shaping the vertical structure characteristics of both the coastal and middle shelf domains (Schumacher and Stabeno 1998; Coachman 1986). During winter, strong winds result in well-mixed water to a depth of ~90 m or more.

Recent results (e.g., Kachel et al. 2002) from the Southeast Bering Sea Carrying Capacity (SEBSCC, a NOAA Coastal Ocean Program) and the NSF Inner Front Program have refined understanding of the physical characteristics, processes and role that the inner front plays in regional ecosystem dynamics. The inner front is wider than previously thought and its location varies by tens of kilometers rather than being relatively fixed to the 50 m isobath as earlier hypothesized. Nutrients are pumped into the euphotic zone, which can prolong primary and associated higher trophic level production. All of the domains provide unique habitats for biota. For example, the meso-zooplankton community in the two shallower domains is comprised primarily of the small to medium-sized copepods, whereas in the outer shelf domain and oceanic region, large copepods dominate (Cooney and Coyle 1982; Vidal and Smith 1986).

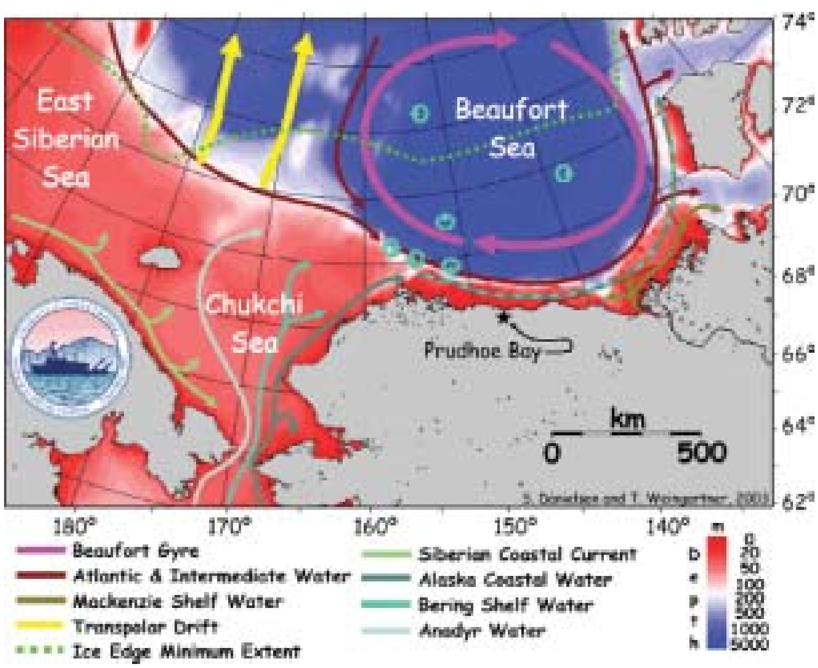
The primary production regime differs significantly between the northern and southeast Bering Sea shelves. The products of the primary production over the southeastern shelf tend to sink to the benthic system, especially in cases where early season blooms at the ice edge rapidly produce large amounts of chlorophyll in the absence of an active grazing community of zooplankton (Niebauer et al. 1995; Hunt and Stabeno 2002; Hunt et al. 2002). Under these conditions, the zooplankton is dominated by euphausiids. During warm periods in the southeast region, the bloom occurs later, following the establishment of thermal stratification, and under these conditions the zooplankton population is present and able to utilize the material effectively; a larger portion remains in the pelagic system. The dominant pathway in the northern shelf is benthic (McRoy 1993), and here the primary production is based on high nutrient levels transported by the cross shelf and northward Anadyr Current flow. Resulting benthic "hot spots" have provided the habitat for summer grazing by marine mammals (Grebmeier et al. 1988; 1989).

Changes in sea ice coverage are mainly driven by atmospheric phenomena. Recent information (Niebauer et al. 1999; Stabeno et al. 2001; Stabeno et al. in press) provides the salient features of seasonal cover. Sea ice begins to form on the leeward side of coastlines in late fall with frigid northerly winds blowing the ice southward. There is large interannual variation in the timing of ice advance/retreat and percent coverage: when the Aleutian Low is farthest east and high pressure is strong over Siberia, the greatest ice coverage occurs. While there is an indication of longer period signals, the most striking signal is interannual variations in sea ice cover. Potentially important is the strong difference (~2 months) in the time of ice melt. On average, melting has been 1-2 weeks earlier in the period 1990-1998 than in 1978-1989 (after the 1976/1977 regime shift), and is associated with changes in atmospheric temperature and circulation (Stabeno and Overland 2001).

Arctic Ocean (Chukchi/Beaufort Seas) Oceanography Lacking major commercial fisheries, research in the Chukchi/Beaufort Seas has been conducted mainly in support of environmental assessment, impact of water exchange with the Arctic Ocean, and pan-Arctic response to climate change. Barnes et al. (1984) present a synthesis of the Alaska Beaufort Sea ecosystem. OCSEAP funded research in the 1970-1980s and Minerals Management Service (MMS) programs continue to generate numerous reports (e.g., Proshutinsky et al. 2003; Wang 2003). The NOAA Arctic Program Office is presently funding the RUSALCA-2004, focusing on the northern Bering and Chukchi Seas. The Office of Naval Research and NSF also have been involved in research with a major program called Shelf-Basin Interactions (SBI) which is presently underway (e.g., Grebmeier et al. 2001; Grebmeier 2003) and directed at elucidating physical and biological shelf/slope processes that influence the structure and functioning of the Arctic Ocean. NSF is also sponsoring the Pan-Arctic Cycles, Transitions and Sustainability (PACTS: A Science Plan 2003) and Study of the Northern Alaska Coastal System (SNACS: a contribution to SEARCH). This program draws on the community planning embodied in the LSI study (Cooper 2003) and PACTS (Strum et al. 2003) science plans. The Study of Environmental Arctic Change (SEARCH) is a broad pan-Arctic (includes the Bering Sea), interdisciplinary study of changes in the AO and how they may impact climate and Arctic ecosystems. The Arctic Research Consortium of the U.S. (ARCUS) has produced several documents that outline research needs and strategies for the Arctic (e.g., Aagaard et al. 1999; Schlosser et al. 2003.

The Chukchi Sea is a shallow (typically <50 m) sea bounded by the Bering Strait to the south, and the Arctic Ocean to the north, with the Alaskan mainland as the eastern boundary and Siberia and Wrangle Island to the west (Fig. 2-5). Two canyons, Wrangle and Barrow, provide conduits for saline water to flow into the Arctic Ocean. Tides and tidal currents are small with a tidal range on the eastern coast of <30 cm. Wind-driven changes in sea level (>3 m) far exceed the tides (Johnson 1988). Transport (~0.8 x 10^6 m^3 s^{-1}) northward through Bering Strait is driven on average by a sea level difference between the Arctic and Pacific Oceans (Stigebrant 1984) that responds to wind driven perturbations that can reverse transport for periods of 2-10 days (Aagaard et al. 1985; Roach et al. 1995). Northward transport is comprised of three water masses, Anadyr, Bering Shelf and Alaska Coastal Water (i.e., the Bering Sea Coastal Current) that change character through lateral mixing within a short distance north of the strait (Coachman et al. 1975; Johnson 1988).

Fig. 2-5 Arctic Ocean currents.



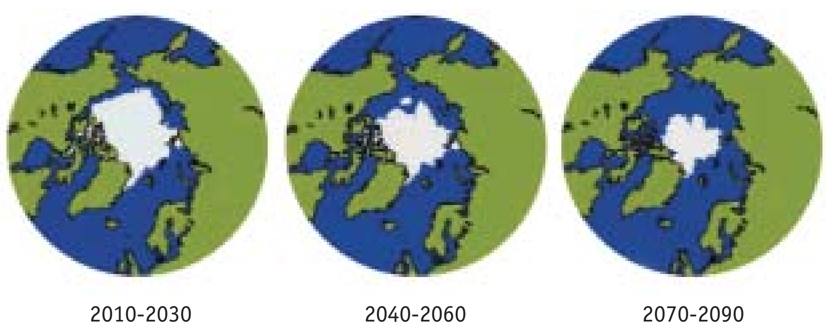
The Anadyr water contains high nutrient concentrations that came onto the Bering Sea shelf from the Bering Slope Current. This water extends the high ecosystem productivity from the GOA, through the Aleutian Islands, into the eastern Chukchi/Bering Seas and finally the Arctic Ocean. The Siberian Coastal Current has its origin as far west as the Laptev Sea, and is forced by winds, with river discharge and ice melt as it flows along the Siberian coast (Weingartner et al. 1998). In the Chukchi Sea, this incoherent flow (due to baroclinic instabilities) converges with northward flow from Bering Strait and is deflected and mixes with that flow. In essence, there are three currents over the Chukchi shelf: the Siberian Coastal Current, the northward flowing Anadyr water and a flow along the Alaskan coast. This latter feature is recognizable to Point Barrow (Johnson 1988) and likely continues to some extent along the Beaufort Sea coast.

Most of the year, the Chukchi is covered by seasonal and polar pack ice. Typically ice begins to form in early October and by late October or early November, pack-ice is found in Bering Strait. Melt-back begins near mid-June in the southern Chukchi. The coastal regions are covered with shorefast ice for about eight months. The formation of first year ice and the extension of polar pack-ice into the region modify water masses. During ice formation, brine is extruded and highly saline water is formed, while nearly fresh water is added to the surface during melt (Aagaard 1984). The pathway for dense salty water off the shelf is likely through the two major canyons.

The Beaufort Sea may be delineated as waters between Point Barrow to the Mackenzie River (~700 km), and from the coastline to the slope (~100 km). The clockwise flowing Beaufort Gyre dominates surface currents and large-scale movement of sea ice over the slope and basin. Below this feature is the counterclockwise flowing Beaufort Undercurrent (Aagaard 1984) that provides an offshore source of nutrients (Macdonald et al. 1987). Eddies have been identified as an important source of transport and exchange between the shelf and slope waters (Aagaard and Carmack 1994). Over the shelf proper (<100 m), currents (including tidal currents) tend to be weak and variable.

The volume of sea ice in the Arctic is maintained by dynamic and thermodynamic forcing. Over the past two decades, sea ice extent has diminished. The ice severity index (distance from Point Barrow to the 50% ice concentration from National Ice Center charts for mid-September) shows that in 1998 the ice limit was 46% (569 km) farther away than in the previous record. In addition, complete freeze-over did not occur until the second week in November (Proshutinsky et al. 2003). The ice thickness also has been decreasing. Since 2000 water temperatures in the southeastern Bering Sea have been warm, and the area has been particularly sea ice free (Overland and Stabeno 2004). The heat content of the water column, i.e. degrees C above the freezing point, may now be sufficient to preclude the return to ice concentrations observed in the 1970's and 1980's, unless there are several back-to-back years of very cold temperatures. In the recent Arctic Climate Impact Assessment report (ACIA 2004), results from five global climate models using lower emissions scenarios indicate that by 2090, average annual air temperatures are projected to rise across the entire Arctic region by roughly 3-5 C over land areas and up to 7 C over the oceans. Some models predict a decline of roughly 10-50% in annual average sea ice extent by 2100, and the complete disappearance of summer sea ice by 2040 (Figure 2-6).

Fig. 2-6 Projected sea ice extent from five IPCC models for September. (Corell and Weller 2004).

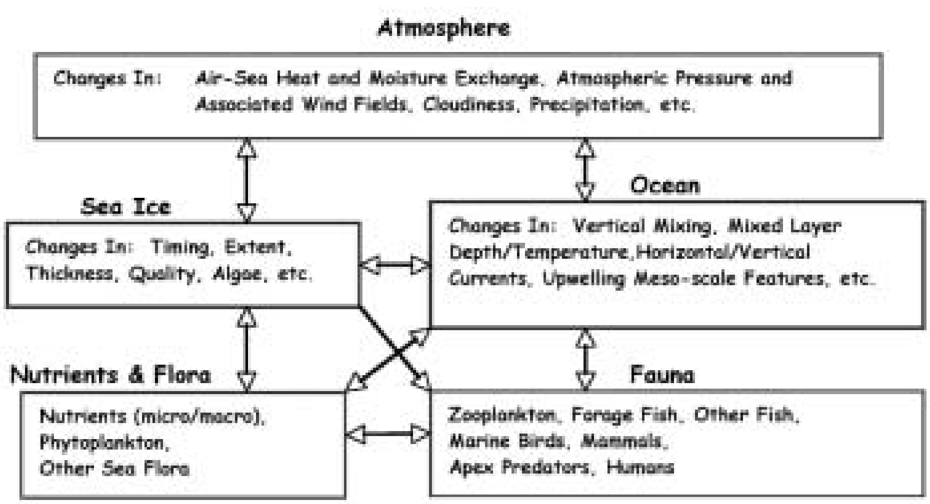


Changes in sea ice extent, thickness and timing likely will have significant impacts on the ecosystem: sea ice provides an important substrate for pinnipeds and polar bears, is linked to primary-secondary production which supplies prey for fish and marine mammals (Tynan and DeMaster 1997), and may have a profound social and economic impact on coastal communities. These impacts may include reduced access to subsistence foods because of unstable ice and increased coastal erosion resulting from a longer period of open water combined with a greater distance for wind to generate waves. Carmack and Macdonald (2002) discuss the importance of oceanographic features to marine life. Landfast ice is an important feature of the Beaufort Sea; it has a maximum thickness of ~2 m and extends seaward to the ~20 m isobath. A stamukhi or rubble ice field, formed by convergence of ice, defines the outer boundary of landfast ice and forms an inverted dam behind which a brackish water pool or lake is formed. Off the Mackenzie River, this lake is extensive (Macdonald et al. 1995) and is a vital component of the nearshore ecosystem.

Ecosystem Dynamics

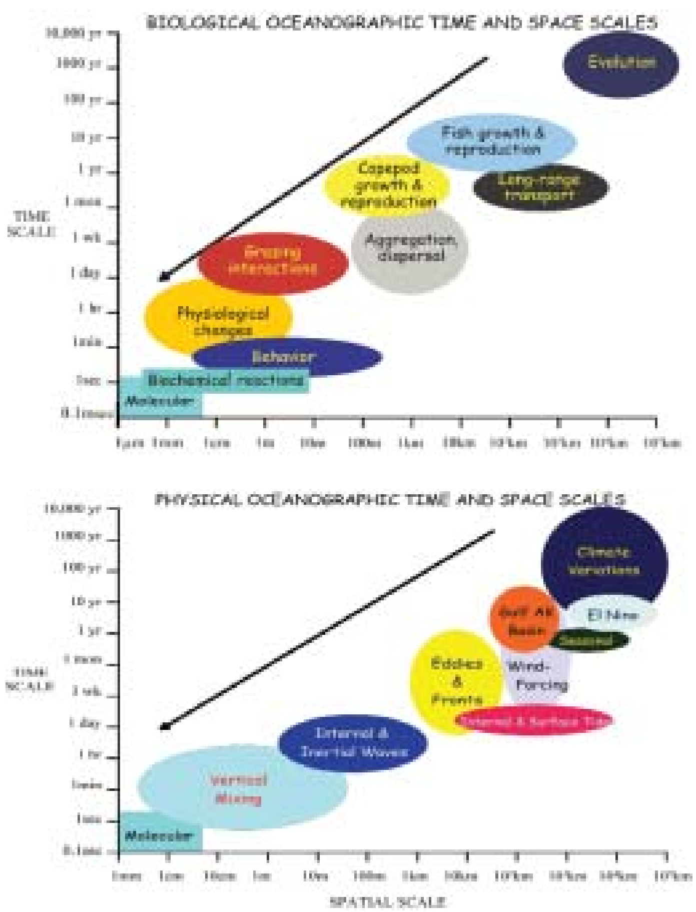
Concepts of Energy Flow and Time-Space Scales Alaska's three LMEs, as described above, while interconnected to some degree, are characterized by bathymetric and oceanographic features, with major differences in current structures and sea-ice cover. The physical-chemical attributes of each region, as influenced on a broader scale by atmospheric and climate conditions, provide the foundation for similarly distinct, rich and varied food webs. Processes that influence energy flow through the ecosystem must be identified to better understand the dynamics of the three marine ecosystems. Francis et al. (1998) developed a conceptual model for the northeast Pacific that identifies key elements of ecosystem dynamics. Schumacher et al. (2003) modified this model for the Bering Sea by including sea ice. The conceptual model presented here (Figure 2-7) is a further modification, to include other factors, principally human activities. The conceptual model is not specific to any particular LME. Depending upon LME, however, the elements in the model may become more specific. For example, sea ice is regionally critical in the Arctic Ocean and Bering Sea, but only of local importance in the Gulf of Alaska; major fish populations, such as pollock, may be the key species in the Bering Sea, relatively less important in the Gulf of Alaska, and of no importance in the Arctic ecosystem.

Fig. 2-7 Conceptual model showing pathways of energy flow through the marine ecosystem. Within each box are features and processes that affect exchange within and among boxes. The Sea Ice box is seasonal; when there is no ice, energy flows directly to the next box. (After Schumacher et al. 2003).



The primary driving force for the coupled atmosphere-ocean system is differential heating of the earth that generates a pole-ward atmospheric and oceanic heat flux that is acted upon by the earth's rotation and heat and moisture fluxes from the sea and land. Changes in the coupled atmosphere-ocean system impact biota. Also, there is feedback from changes in biota to the atmosphere-ocean system. Feedback exists between all elements as indicated by two-way arrows and this feedback can impact intermediate trophic levels either from phytoplankton up or apex predators down. For example, water temperature can affect rates in the nutrient-phytoplankton-zooplankton sequence, and/or can change zoogeographical boundaries for predators. Even the atmosphere element can be affected by biota: for example, Gildor et al. (2003) proposed that variations within the phytoplankton community could induce fluctuations within seasons in sea surface temperature through regulation of solar radiation penetration due to absorption by chlorophyll and other optically active organic components. Variations in sea surface temperature, in turn, affect the flux of heat and moisture into the atmosphere, thereby changing atmospheric features. For simplicity, only a limited set of trophic levels is shown in the fauna box. A central challenge to further understanding of ecosystem dynamics is to identify and determine the functional form (e.g., linear or non-linear) of the various processes that direct energy flow leading to ecosystem change.

Fig. 2-8 Biological (from: Strom, Western Washington University) and physical oceanographic time-space scales. (From Weingartner, Institute of Marine Science/UAF).



In establishing a scientific program, the challenge of integrating time-space scales of the biological and physical ecosystem components (Figure 2-8) must be considered. Carmack and McLaughlin (2001) provide a perspective on time-space scales as they apply specifically to Arctic biota and climate change. The NRC (2004a) acknowledges the complexity of time-space scales. The science plan for the Bering Sea Ecosystem Study (BEST 2003) raised questions related to integration across time-space scales: *Understanding consequences of different life-history patterns of organisms is important for integration across time and space scales. Concepts of scale are particularly important for developing model frameworks, because they define the context for local, regional and large-scale interactions, integration of single species processes into multiple species models, and up-scaling and downscaling of climate effects. Small organisms, such as viruses, bacteria, and small phytoplankton, can pass through many generations in the time that it takes for a storm to pass through a region. In contrast, cetaceans, and some seabird species do not breed until they are ten years of age or older and live for several decades. For them, a storm occupies but a tiny fraction of the length of a generation. Population-level responses of these organisms to climate change will differ depending on the timescale of the climate forcing.*

The BEST science plan goes on to note that the timing of sea ice presence and melt influences the primary/secondary production sequence that is the basis of the food chain. Shifts in timing could lead to a potential mismatch between predators and prey availability. An early melt before sufficient sunlight in spring leads to a later phytoplankton bloom when water temperatures are warmer: this might favor larval growth and increased survival for some fish species depending on their reproductive timing. Also, some individual species may be affected by shorter time scales early in life and longer scales as adults.

NPRB intends to enhance the understanding of the North Pacific, Bering Sea and Arctic Ocean ecosystems to support sustainable management of the region's resources. To attain this, there must be a better understanding of how (1) natural climate change and (2) human impacts affect the ecosystem (including humans), and then application of this knowledge to management strategies. Natural events, such as a regime shift, can have profound effects on an LME. Human activities, such as fishing or oil and gas development, also may have major impacts on the habitat, fish and invertebrate, marine mammal, and seabird components of the marine ecosystem. In addition, economic considerations can cause significant impacts even to fisheries on abundant stocks (Adkison and Finney 2004). It will be critical for scientists and managers, on the basis of sound science, to be able to distinguish between natural and human-induced variability, so that both can be addressed to accomplish sustainable management.

Natural Forcing Natural control in LME's occurs through effects of predator abundance or distribution (top-down) and/or effects of changes in lower trophic levels (bottom-up). The relative importance of either mechanism can vary, perhaps due to changing climate (e.g., in the Arctic (Carmack and McLaughlin 2001)), and dominance of one or the other may oscillate (as hypothesized in the southeastern Bering Sea: Hunt et al. 2002). Distribution and abundance of upper trophic level species, such as fish, seabirds and marine mammals, are influenced by climate variability either directly or indirectly. Direct effects include alteration of physical habitat (e.g., temperature, mixed layer depth, bottom disturbance, stream flow) with impacts on growth, mortality, and reproductive success. Indirect effects may be through trophic impacts at lower trophic levels or on predator abundance or distribution. Understanding the impacts of climate change is of utmost importance to resource managers striving for balanced regulations that provide for sustainable harvest of some living marine resources while protecting other components of the ecosystem, including threatened and endangered species.

Biological components are dynamic over a broad range of time scales. Populations in all three LME's have shown wide ranges in production. In recent decades in the GOA, marked declines have occurred in pollock, forage fish, shrimp, king crab, harbor seals, and Steller sea lions, while arrowtooth flounder, sockeye and pink salmon, some groundfish, and human populations have increased (NRC 2003, 2004a; Hollowed et al. 2001). Among the populations in the BSAI are: Steller sea lions, Pribilof northern fur seal pups, herring, crab and spectacled eiders (decreases); and pollock, arrowtooth flounder and humans (increases). Declines in many mammal and bird populations are thought to be related to prey abundance and availability, but some could be mediated by abundance of their predators or declines of alternate prey of their predators (NRC 1996, 2003; Hunt et al. 2002). Over the northern Bering Sea shelf, a sharp decrease in zooplankton abundance occurred between 1983 and 2003 (Moore et al. 2003). Recent documents summarize many changes in the biological components of this region (ACIA 2004; Boldt 2003).

In the Arctic LME, composition of sea ice-related algal species changed due to changes in salinity (Melnikov et al. 1998), and during years with early ice breakup, many ringed seal pups were abandoned. In addition, underweight walruses were observed and their population may be declining (SEARCH SSC 2001). Changes also have occurred in the distribution of salmon, with sightings of Pacific salmon species entering rivers in the eastern Arctic and more salmon being caught off Barrow (Carmack and McLaughlin 2001). Large shifts in species composition of many fishes and invertebrates may be triggered by effects of changes in productivity on early life history survival and growth rates of individual species, through runs of strong year classes that sustain fisheries or runs of poor year classes that result in stock declines. Phytoplankton also experience large shifts in abundance and composition that are thought to be a response to direct climate effects on upwelling, nutrient supply and length of growing season (influenced by changes in sea ice in the BSAI and Arctic). Though the root causes of these and other fluctuations are seldom known, they may reflect either natural, climate-related changes or responses to human-induced forcing or some combination of both.

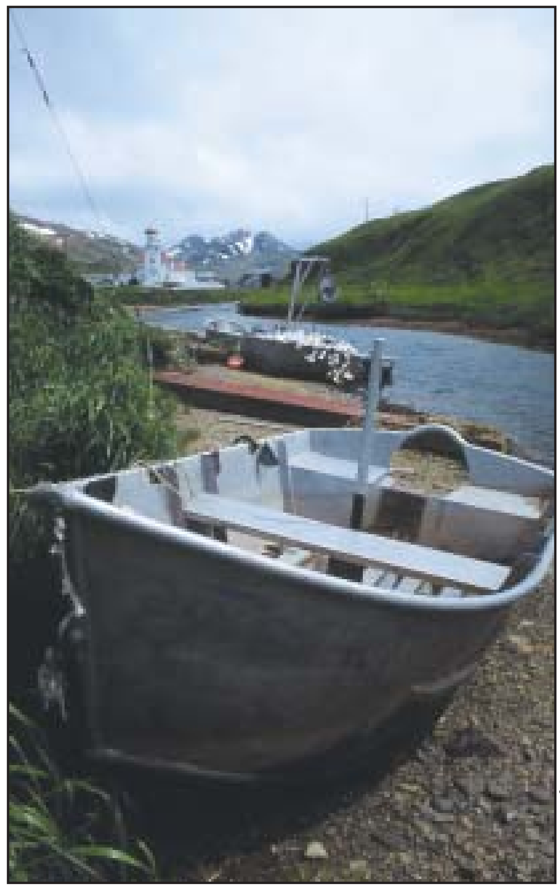
The physical environment also has undergone marked changes, particularly since the 1960's and increasing in the 1990's (BESIS 1997; Schumacher and Alexander 1999; SEARCH SSC 2001). The dramatic change in the winter climate (regime shift) during 1976/1977 illustrates the magnitude and nature of some of these changes. There was a step-like increase of nearly 2 C in air temperature over Alaska (Bowling 1995). Sea-ice extent decreased by ~5% in the eastern Bering Sea (Niebauer 1998) and ~7% in the Arctic (Johannessen et al. 1999), and sea-ice thickness also has decreased in both LME's (Wadhams 1995; Rothrock et al. 1999). Many local residents around the Bering Sea also noted changes in ice thickness and strength (Huntington 2000). Over longer time scales, the extent of glaciers has decreased markedly, which has increased the freshwater discharge rate into the Gulf of Alaska by nearly 15% (Arendt et al. 2002; Royer 2005). Permafrost temperatures measured in boreholes in northern Alaska are 2-4 C warmer than they were 50-100 years ago (Lachenbruch and Marshall 1986). Discontinuous permafrost has warmed considerably and is thawing in some locations (Osterkamp 1994). There also are marked changes in atmospheric pressure patterns, circulation, cloudiness, precipitation and evaporation. Some North American regions are experiencing an increase in runoff (due to increased rain) of major rivers as well as changes in the time of river ice breakup and the onset of the summer peak in river flow. Recent documents summarize changes in physical components of the BSAI (Boldt 2003; NRC 2004b).

Regime Shifts A regime may be defined as a persistent state in climate (atmosphere and ocean) and biological systems (Beamish et al. 2004), which means a meta stable ecosystem state (i.e., one that persists but is subject to change). Throughout the world, a great deal of interest is being focused on regime shifts (e.g., Progress in Oceanography Volume 60, Nos. 2-4, Special Issue: Regime shifts in the ocean: reconciling observations and theory, 402 pp.). While there is some controversy about interpretation and analysis techniques and even how to best define a “regime shift” (e.g., deYoung et al. 2004), clearly marked changes have occurred in the North Pacific ecosystem, as characterized by indices of atmospheric and oceanic features together with indices of biota (e.g., Hare and Mantua 2000; Hollowed et al. 2001).

Two major regime shifts occurred in the past thirty years: winter 1976-1977, in which the winter PDO and the AO both shifted; and after the winter of 1988-1989, when only the AO shifted (Beamish et al. 1999; Hare and Mantua 2000) (Fig. 2-2). There is some evidence that a third shift occurred after the winter of 1998-1999 (Peterson and Schwing 2003). Recent analysis suggests that this third shift (the Victoria Pattern) bears little resemblance to the prior two: it was primarily expressed along the U.S. west coast whereas conditions in the GOA and BS remained similar to those prevailing since the early 1990s (Bond et al. 2003). Often these regime shifts are clearer in biological than physical time series. Shifts in fish production, however, are often unrecognized until young fish approach age of maturity when they are more easily caught in research surveys and commercial fisheries. As noted by Rice (2001), for several reasons it is wise to be particularly cautious in exploiting systems during periods of rapid environmental change. All three LME's in the NPRB research region are influenced by interrelated atmospheric and oceanic phenomena, and complex responses have occurred in biota. Because of this, the impact of ongoing and future climate change on the ecosystem is unlikely to be systematic and/or repetitive; the response might vary from one regime shift to another (Hunt et al. 2002).

Human Impacts The impacts of humans on climate and the marine environment are marked. Some impacts, like global warming, are manifested over many years. Most scientists agree that this increasing trend in global temperature is due to greater concentrations of human-generated greenhouse gases (e.g., AGU 1999; Levitus et al. 2001; IPCC 2001), and that the warming is amplified in polar regions (Moritz et al. 2002). A recent American Geophysical Union Council (AGU 2003) position statement on human impacts on climate states: human activities are increasingly altering Earth's climate, and natural influences alone do not explain the increase in global near-surface temperature in the latter half of the 20th century. The exact cause of global warming may be in dispute, but, as the NRC (2004a) points out: The important issue is that climate change, whatever its causes, affects ecosystems, and these, in turn, affect the people of the region.

Other human-induced impacts work on shorter time scales, but still may have major consequences for marine ecosystems. These include, among others, fishing, hunting, coastal and shelf development (typically associated with gas and oil development), shipping, contaminants, invasive species, and tourism. Sometimes, the impacts can be catastrophic, such as the Exxon Valdez oil spill in 1989 that impacted marine ecosystems of Prince William Sound and the adjoining northern Gulf of Alaska. Such human impacts on the air, land and sea can interact with natural cycles, likely changing amplitudes and phases of those cycles and making them less predictable.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Commercial fishing, in the aggregate, is likely to be the most important direct human impact on a marine ecosystem. Commercial fishing (and to a lesser degree recreational fishing in the nearshore environment) and its associated activities provide a major forcing in the GOA and BSAI LMEs. Effects of fishing may be direct (e.g., removal of targeted and other species) or indirect (e.g., a trophic cascade). One hypothesis for the present wealth of pollock in the eastern Bering Sea is the cascade hypothesis: the removal of large amounts of biomass of both fish and mammals (mostly whales) between 1950s and early 1970s likely resulted in an increase in the amount of zooplankton and forage fish. Coupled with a regime shift in 1976/1977, this change in the ecosystem fueled a rapid increase in the pollock biomass in the late 1970s (NRC 1996). Merrick (1995) proposed a similar hypothesis as a potential factor resulting in the decline in the western Alaska Steller sea lion population, where the increase in pollock potentially limited abundances of favored prey items (e.g., capelin, sculpins) for Steller sea lions in the western Gulf of Alaska and Bering Sea.

The U.S. Commission on Ocean Policy (USCOP 2004) observed that the NPFMC appears to be working well in most facets of its management responsibility, and that of the 82 stocks under its jurisdiction with sufficient information to assess, none was classified as overfished in 2001 and only two stocks are at levels of abundance that indicate past overfishing. The commission recommended that fishery managers across the nation should begin to move toward a more ecosystem-based management approach, and that such an approach will require managers to look beyond fisheries to consider interactions with other resources and activities. Resource managers must not only consider the impacts of commercial fishing on the target species and related bycatch species, but must also be aware of impacts of fishing on other marine ecosystem components, for example, the disruption of prey fields for marine mammals (NRC 2003) and seabirds, or direct effects such as entanglement.

Fishing also impacts habitat and the bottom communities of plants and animals that provide structures within that habitat. Reductions in habitat heterogeneity may have important ecological consequences for juvenile flatfishes: complex habitats with sponges, bryozoans, shells and other physical structures can reduce mortality rates on juvenile flatfishes compared with habitats not containing physical structure (Stoner 2003). A region presently receiving much attention is the deep-sea coral and sponge distribution and habitat in the Aleutian Archipelago. These deep-sea cold water corals may live centuries (Heifetz et al. in press) and are vulnerable to disturbance by bottom contact fishing gear. Research recently funded by NPRB, in collaboration with other projects, will provide estimates of the relative abundance of corals and sponges, their importance to commercially valuable fish and invertebrates, and the degree to which these living substrates have been disturbed, including disturbance by fishing gear.

Intersection of Impacts Natural changes in the coupled atmosphere-ocean-biota system intersect with changes created by human activities. As changes occur in distributions, abundances, and species composition due to impacts generated by this combination of forces, the ecosystem will change, and pressing fisheries management needs will surface. Unraveling the causes of the resulting changes is the ultimate challenge. The solution to this challenge of complex changes is three-fold: (1) develop well-designed, long-term, integrated ecosystem research projects, (2) have flexibility to address short term pressing issues and/or to develop technologies and analytic methods, and (3) fund some projects that address education, outreach, community involvement and other human dimensions for a greater understanding and appreciation of the role of humans as an integral part of the ecosystem. In the conceptual model (Fig. 2-7), humans are identified as a component of the ecosystem and the feedback arrows show that they can influence and be impacted by all aspects of an ecosystem. Solution item (3) infers that by involving and training community people and educating all stakeholders, NPRB is helping to seed the next generation of potentially more knowledgeable scientists, resource managers and leaders.

Human Dimensions

The human dimension is concerned with how impacts of ecosystem change will affect the livelihoods and quality of life for all who depend on the region's marine resources. Climate change affects biological populations. For example, on decadal time scales, the abundance of salmon populations and other commercially important species appears to covary out of phase between the GOA and Pacific Coast, perhaps related to what fraction of the sub-arctic gyre flows south or north (Hare et al. 1999; Strub et al. 2001). Salmon support not only major commercial fisheries, but also are of utmost importance to subsistence and sport fisheries.

For subsistence, marine mammals provide food and clothing, and seabirds and their eggs are a food source, and all these resources vary with climate/ecosystem change. Although the importance of the sea and its resources to subsistence users is well established (e.g., NRC 1996; SEARCH SSC 2001; BEST 2003), there is still a need to know how changes in the LMEs will affect the availability of fish and other marine resources for use by people. The question of what poses a pressing fisheries issue has a variety of answers that encompass many scales. To a subsistence user in western Alaska, the inability to harvest a few dozen or so salmon each year is a pressing issue. To fishermen in the Shelikof Strait/Western GOA region, loss of thousands of metric tons of harvest owing to potential closures of the entire pollock fishery due to perceived interactions with endangered species is a critical pressing issue. To subsistence users, commercial and sport fishers, and a sizable portion of Alaska's economic community, uncertainties resulting from lack of knowledge regarding fluctuations in salmon abundance (and the value on the world market) constitute a pressing need. In addition to salmon, halibut, groundfish and crabs support some of the largest and most lucrative fisheries in U.S. waters. Changes in species composition, abundance, quality, or distribution of these fish and shellfish can have major economic and social impacts, particularly in coastal communities.

It is important to note that the compensatory changes in the ecosystem (e.g., increases in jellyfish, groundfish and salmon versus declines in sea lions, crabs, and shrimps) are neither "bad" nor "good", they simply are. Climate change may favor increases in some species and decreases in others owing to differences in their strategies for survival. At present, warming of the eastern Bering Sea appears to be causing a shift in the ecosystem at least through its influence on the location of cold bottom waters and hence distributions of fishes (Overland and Stabeno 2004). The region of highest pollock catch per unit effort has moved approximately 200 km toward the northwest between 1999 and 2003. This means an increase in sailing time to the target region and hence greater cost per unit effort. Further, should this trend continue, the center of fishing action might transfer from the exclusive economic zone of the U.S. to waters under Russian jurisdiction.

It is essential to direct research funded by the NPRB in a manner to provide managers and planners with tools and informational products to generate narratives of how climate and/or ecosystem change will impact important ecosystem services, including commercial and subsistence species. Climate change may be most important in terms of long-term impacts on changing the ecosystem. The success of this approach relies on (1) attaining a far greater understanding of ecosystem dynamics than presently exists, and (2) determining how management can adapt to the inevitable changes using this knowledge. Further, economic and social data should be gathered systematically to help evaluate the changes new management strategies produce and to determine the long-term viability of the subsistence economy and the social changes that are spurred by decreasing resources and increasing population (NRC 2004a). Such an acquired store of knowledge also makes it possible for humans to choose appropriate adjustments in their behavior and for investments to be in harmony with the changes.

Research Approaches

The conceptual foundation just presented has been developed over many decades of research in the North Pacific and Arctic. In general, ecosystem understanding has advanced based on a relatively modest number of key research approaches as described in the Bering Sea Ecosystem Research Plan (BSERP 1998). Those generic approaches will be the primary ones applied to the major research themes identified in the next chapter:

- Monitoring and development of indices to detect and track changes in ecosystem elements provide data for modeling and context for process studies.
- Process studies to identify and understand potentially important rates and processes.
- Retrospective studies to maximize use of existing long-term observational records.
- Modeling to synthesize, extrapolate in time/space, test ideas and forecast future scenarios.

Monitoring

The greatest payoffs from NPRB research may come from well-designed, high quality monitoring projects which focus on collection of physical, biological, and/or socio-economic aspects of the ecosystem and develop indices of ecosystem status from the ensuing time series. The NRC (2004a) identified monitoring in three of its findings/recommendations to the NPRB. The lack of sustained funding for monitoring is presently a limitation. Indeed, Fluharty et al. (1999) noted that without a coherent monitoring program, an ecosystem-based approach cannot be effective. Monitoring always ensures some success, because observations will be of great value in answering current and future questions about the ecosystem and its dynamics. Such observations also provide background for process-oriented studies and input to modeling simulation efforts. Monitoring aspects of the physical environment is at a more advanced state than that of biological components of the ecosystem. Examples of essential ongoing monitoring efforts are biophysical observations at moorings M2 and M4 on the southeastern Bering Sea shelf (presently funded by NPRB) and physical observations at the Gulf of Alaska site (GAK-1) off Seward funded by GEM and NPRB. At the center of most ecosystem modeling efforts in the eastern Bering Sea are results from annual bottom trawl surveys conducted by AFSC/NMFS. Trawl, marine mammal, seabird and other surveys of biological components are essential both for understanding ecosystem dynamics and for management of human impacts considering ecosystem consequences.

The biota, including humans themselves, can provide clues to ecosystem change. A network of local inhabitants, commercial, recreational, and subsistence fishermen could be established to report observations of changes in local ecosystem (e.g., marine bird die-offs, changes in species, habitats, sea ice, etc.; also see LTK section in Chapter 4). Biological sentinels also may serve as indicators of ecosystem productivity. Complex changes in ecosystem structure, function, and productivity can often be foretold from changes in individual components, either individual species or assemblages, e.g., mussels for contaminants, phyto-plankton, zooplankton, and ichthyo-plankton assemblages for regime shifts (McGowan et al. 1998; Baier and Napp 2003, Peterson and Schwing 2003), and apex predators for ecosystem change. Decadal changes in Bering Sea chlorophyll (Sugimoto and Tadokoro 1997) and zooplankton abundance (Napp et al. 2002) have been observed and can serve as indices for climate-induced change. Seabird reproductive success can provide inexpensive and immediate indices of the availability of their prey (e.g., Hunt et al. 1996; Sydeman et al. 2001; Gill et al. 2002). Marine mammals can also provide early evidence of shifts in prey availability that may indicate ecosystem change. For example, gray whales appear to no longer forage extensively in the northern Bering Sea concomitant with a decline in benthic community biomass and change in infauna there (Moore et al. 2003; Grebmeier and Dutton 2000). They must now migrate much farther north to find feeding grounds with ample food. Foraging patterns and diet of some foragers, for example, of Northern fur seals on the Pribilof Islands (Ciannelli et al. 2004), can provide information on the productivity of their foraging grounds. Careful monitoring of linkages at key nodes in the food web can serve as sentinels for larger system-wide changes due to climate and permits the development of indices that may synthesize and interpret the observations in terms of potential changes in ecosystem structure and function. Examples of ecosystem indicators and their potential interpretation can be found in Boldt (2003) or Livingston et al. (2003).

The lack of long-term time series information is detrimental to other types of research, and data gaps can severely limit the value of retrospective studies. In such studies, tantalizing suggestions can be made, but time series of vital parameters often simply do not exist. The Alaska Ocean Observing System will help to fill monitoring requirements when it is fully funded. NPRB also may help to fill monitoring gaps and thereby establish a legacy for the future. NPRB may also support development of new technologies and analytical methods to improve monitoring studies. Technology is rapidly advancing to meet the challenge of monitoring biological parameters, e.g., acoustic techniques are presently being used to count whales as they migrate off Kodiak Island.

Process Studies

Process studies also must be undertaken to elucidate processes, rates and mechanisms crucial to LME dynamics. For example, there are specific mechanisms that contribute to variability of survival of early life stages of fish and invertebrate populations. Process-oriented field studies are needed to identify these mechanisms and how they function and elucidate direct links between oceanography, marine habitat, food availability and survival, and/or whether predator dynamics interact with the ocean processes (Logerwell et al. 2003). Process-oriented studies are also needed to determine the functional form of biophysical processes. Megrey and Hinckley (2001) used a modeling approach to determine the functional form of how turbulence impacts feeding of pollock larvae. Such information is essential to modeling of ecosystem dynamics.

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Retrospective Studies

Retrospective studies can lead to new understanding of ecosystem components and new or refined hypotheses. For example, how are climate patterns (e.g., AO, PDO) manifested on time/space scales important to a particular LME? The potential value of retrospective studies of atmospheric parameters and sea ice behavior is evident in the development of the Oscillating Control Hypothesis for energy flow over the shelf of the southeastern Bering Sea (Hunt et al. 2002). A more recent analysis of sea ice observations from the eastern Bering Sea for 1972-2003 found that there have been five distinct patterns of ice retreat during May (McNutt et al. 2004). Retrospective studies also can be used to develop indicators of ecosystem status and relate those to patterns in recruitment (e.g., pollock by Megrey et al. 1995).

Modeling

An important measure of success of NPRB's science program will be improved ability to forecast ecosystem change and the incorporation of those improved predictions in decision-making by ecosystem resource managers. These are essential for maintaining the status and vigor of Alaska's ecosystem, on which so many species and people depend for their livelihood and sustenance. Such objectives require the development of ecosystem models that capture essential abiotic and biotic phenomena, account for crucial mechanisms that influence energy flow through the ecosystem, and have an adequate monitoring system to supply information for future forecasts. Numerical modeling provides one approach for integrating across space and time scales and for examining system stability and resilience. Numerical models also provide a means of interpolating among scattered and scarce data sources, and across disparate time and space scales. They will be critical to developing reasonable predictions of ecosystem change.

Ecosystem Indicators

The research approaches described above will help to improve our understanding of the complexity and variations of the marine ecosystems off Alaska. Complex changes in ecosystem structure, function, and productivity can often be foretold from changes in individual components, such as physical or chemical elements detected by remote or in situ instruments, or individual species or assemblages that serve as biological sentinels of ecosystem or climate-induced change. Careful monitoring of linkages at key nodes in the food web can serve as sentinels for larger system-wide changes due to climate and permits the development of indices that may synthesize and interpret the observations in terms of potential changes in ecosystem structure and function. These are elements of an ecosystem that may be viewed as indicators of its status (Goodman et al. 2002; Boldt 2003).

Ecosystem indicators include biological elements such as: habitat, zooplankton, chlorophyll and nutrients, forage fish, groundfish biomass and recruitment trends, historical abundance trends from bottom trawl data, benthic communities, non-target fish species, marine mammals, seabirds and other ecosystem or community properties (diversity, trophic level). Among the physical element indicators are patterns in atmospheric features (AO, ENSO), sea ice characteristics, water properties (sea surface and bottom temperatures, mixed layer depth) and changes in currents and eddy fields. Given the typical lack of long-term observations (more than a few decadal cycles), the interpretation of the observed changes needs to be done separately and in the context of how the indicator relates to a particular ecosystem component. For example, particular oceanographic conditions such as bottom temperature increases might be favorable for some species but not for others.

Indicators also exist for human-induced impacts on the ecosystem. They can provide early signals of direct human effects on ecosystem components. Among these indicators are ones that summarize information about the characteristics of the human influences (particularly those related to fishing, such as catch composition, amount, and location) on a particular ecosystem component. On a wider ecosystem scale, two indicators that have been found to be relatively explanatory of fishing-induced changes at a more system-wide level are community size spectrum and k-dominance curves (Bartkiw et al. 2003). As more is learned about the role that climate, humans, or both may have on the system, this will enable ecosystem indicators to be developed that reflect that new understanding. Issues related to the development of indicators of ecosystem status include identifying the features of the marine ecosystem that are indicators of status and how these indicators function; and determine which observations are needed to provide the information necessary to develop useful indicators. This understanding of ecosystem indicators will help managers be in a better position to embrace ecosystem-based management.

The North Pacific Fishery Management Council has moved in this direction by establishing an Ecosystem Committee in 1996, and compiling Stock Assessment and Fishery Evaluation (SAFE) Reports (e.g., Boldt 2003) that contain a vast resource of ecosystem information, including a summary of indicators and their present status, and, importantly, the interpretation of what those observations might mean to the ecosystem. The Ecosystem Advisory Panel (Fluharty et al. 1999) recognized that ecosystems are likely to have thresholds which, when exceeded, may cause the system to shift to a new, potentially irreversible state. However, defining those levels for ecosystems is more difficult than for single species due to the complex interactions and greater uncertainties associated with larger numbers of parameters (e.g., the Ecosystem Advisory Panel noted that the ability to predict ecosystem behavior is limited). This suggests that traditional disciplinary science and expert predictions, the basis for much of the advice given to managers, have limited applicability (Kay et al. 1999).

The challenge of developing new approaches to support ecosystem-based management includes the following (after Fluharty et al. 1999): delineating geographical extent of the region of interest; developing indicators of ecosystem status as targets for management; developing conceptual food web models; describing habitat needs of different life history stages and documenting how this information can be used in conservation and management measures; and assessing ecological (including human) and institutional elements of the ecosystem that most significantly affect fisheries. The role of NPRB would be to support research that would provide the sound science necessary to move in the direction of ecosystem-based management, including the development of robust ecosystems indicators.

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Chapter 3
Research Themes

3

Research Themes

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Introduction

Major Research Themes

Lower Trophic Level Productivity

Fish Habitat

Fish and Invertebrates

Marine Mammals

Seabirds

Humans

Other Prominent Issues

Integrated Ecosystem Research Programs

Overview

The purpose of this chapter is to develop major research themes based on the overarching research premises and conceptual model presented in the last two chapters. The NPRB has identified eight general thematic categories: lower trophic level productivity, fish habitat, fish and invertebrates, marine mammals, seabirds, humans, other prominent issues, and integrated ecosystem research programs. The first six represent major components of the marine ecosystem. Other prominent issues include topics such as contaminants, harmful algal blooms, invasive species, aquaculture, and climate change and ice free Arctic. The last and perhaps most important thematic category, integrated ecosystem research programs, was introduced in Chapter 1. Here we provide examples of multidisciplinary studies that would cut across and build upon issues raised in the other themes. As noted earlier, the Board will strive to develop integrated ecosystem research programs based on interdisciplinary cooperation, in addition to addressing pressing fisheries management needs as required by its enabling legislation.

For each of the first six major themes, a brief introduction and overview of current knowledge are presented. Information is organized as much as possible by regions, the Gulf of Alaska, Bering Sea and Aleutians, and Arctic Ocean (Chukchi/Beaufort seas), representing the three large marine ecosystems as described in Chapter 2. The regions are interconnected and share some common features. Contemporary issues and concerns then are presented, generic where possible and differentiated by region where appropriate. This is followed by suggested research needs, arrayed against the Board's two legislated priorities: pressing fishery management issues and marine ecosystem information needs. And finally, general implementation strategies over the next 2-4 years are identified where appropriate, with the caveat that they are a work in progress and may change as the Board further develops its research program and releases annual requests for proposals.


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As emphasized in Chapter 2, the following sections of this chapter are intended to provide a highly rendered overview, not a treatise, of what is known about major ecosystems components of the marine regions off Alaska. Original citations should be consulted for more comprehensive and detailed information, discussions, and qualifications on each subject. A list of species and common names referenced in the chapter is provided in Appendix A. An acronym guide is available in Appendix B.

Sectional Guide to the Chapter

The enabling legislation for NPRB places priority on research that addresses pressing fishery management or marine ecosystem information needs; i.e., the Board is not simply a curiosity-based organization, but must be cognizant of applied components of its research program. In that light, the research needs identified in the following sections generally are responsive to and characterized in terms of those two statutory priorities. Table 3-1 provides an overview of the broad categories of research needs for each major ecosystems component compared with the two legislated priorities. More detailed needs are identified for the associated categories in the respective sections.

Lower Trophic Level Productivity

Here the research needs are associated with the bottom of the food web, and all are responsive mainly to marine ecosystem information needs. Nutrient flux onto the continental shelves and processes that drive primary and secondary production are the keys to the highly productive marine ecosystems that exist off Alaska. Sea ice is a very significant modifier of this component of the food web, and must be accounted for in modeling the nutrient-phytoplankton-zooplankton sequence and comparing and contrasting the three LMEs.

Fish Habitat

Habitat, of course, is everywhere in the three LMEs, and broadly defined, includes the ocean bottom as well as the water column and sea ice where present, and all their components. The habitat section, however, focuses on benthic habitat and its relation to fish, in keeping with the mandates of NPRB. It does recognize that habitat serves much broader ecosystems functions than just supporting commercially-fished species. For example, deep water corals are unique highly diverse assemblages that need to be studied. It will be shown that habitat research needs span the range from purely ecosystem information needs to pressing fishery management issues such as effects of fishing on various types of habitat, as well as gear research that will mitigate those impacts.

Fish and Invertebrates

Here the plan moves up the food web to fish and invertebrates, many of which are the basis for important commercial, recreational, and subsistence fisheries. The section also examines some species such as forage species, sharks and skates that are for the most part lightly used by humans, but play significant roles in the ecosystem. Issues and concerns identified for fish and invertebrates range from a few overfished or depleted stocks to the impacts of major commercial fisheries. Research needs are responsive to marine ecosystem information needs because they examine the causes of perturbations of major species and the implications of ecosystem change. At the other end of the spectrum are those needs that could help to address pressing fishery management issues such as bycatch mitigation, socio-economic impacts, alternative harvesting strategies, and development of new methodologies for stock assessments.

Marine Mammals

This ecosystem component is viewed generally to be at the upper levels of the food web. Many people consider marine mammal populations to be harbingers of how the marine ecosystem is functioning, with abundant populations signifying a "healthy" ecosystem. Certainly resource managers must pay particular attention to marine mammal species and the impacts of human activities on those species. Research needs range from basic population dynamics and impacts of climate change under marine ecosystem information needs, to pressing issues such as the overlap of migrations with major fishing areas, concomitant impacts on foraging success, and mitigation of fisheries-marine mammal interactions.

Seabirds

There are millions of seabirds in the marine ecosystems off Alaska and they seem to be everywhere. Some populations are on a list entitled *Birds of Conservation Concern* and require close consideration to shed light on potential impacts of human activities. Seabird populations in general are considered among the indicators of status of the ecosystem and information on their dynamics needs to be developed so they can be protected properly by resource managers. Their research needs in general fall into the same categories as marine mammals, ranging from climate change, population dynamics, and foraging success, to migration patterns, fisheries interactions and other human-related impacts.

Humans

Research often is concerned with examining the impacts of humans on marine ecosystems. This section turns that around and considers the impacts of ecosystems and change on human populations. As noted by the NRC study committee (NRC 2004a): *One could argue that marine ecosystems and their fluctuations are of interest because of their effect on human societies.* Natural variability and human-induced variability in marine ecosystems both will shape the goods and services provided by the ecosystem to man. Human health also is a very significant issue. The research needs will be shown to span the range from considering climate variability and change, to improving management decisions and institutions, human health issues, and conducting the appropriate baseline assessments to detect potential impacts on humans.

Other Prominent Issues

This section is comprised of brief treatments of issues that are not necessarily core research components of NPRB's program, but nonetheless may merit attention and support on a case-by-case basis. For now, there are five issue areas identified: contaminants, harmful algal blooms, invasive species, aquaculture, and climate change, though it is recognized that climate change was addressed to varying extents in each of the ecosystem components discussed above. It is unclear at this time how the Board will address these issues. It is likely that as they are brought to the attention of the Board, they will be addressed in annual or periodic requests for proposals.

Integrated Ecosystem Research Programs

The purpose of this last section in the chapter is to provide opportunities for and examples of programs that cut across scientific disciplines and begin to address critical questions regarding ecosystem structure and function and how they might be influenced by natural variability and human use of resources. Examples are provided for a selection of marine regions within the three large marine ecosystems off Alaska. These examples will need to be developed further using synthesis teams and meetings.

Table 3-1 Summary of research themes for major ecosystems components.

	Lower Trophic Level Productivity	Fish Habitat	Fish & Invertebrates	Marine Mammals	Seabirds	Humans
Pressing Fishery Management Issues ↕ **Marine Ecosystem Information Needs**	Nutrient Dynamics Phytoplankton Ecology Phytoplankton – Sea Ice Dynamics Zooplankton Ecology	Other Human-Related Impacts Fishing Effects Habitat Mapping Ecosystem Functions of Habitat	Stock Assessment Research & Development Alternative Harvest Strategies Socio-economic Considerations Reducing Catch of Unwanted Species Causes of Perturbations of Major Species Ecosystem Change Implications on Fisheries Management	Other Human-Related Impacts Fisheries Interactions Marine Habitat Use Foraging Success Population Dynamics Long-term Climate Change	Other Human-Related Impacts Fisheries Interactions Marine Habitat Use Foraging Success Population Dynamics Long-term Climate Change	Fishery Management & Policy Baseline Assessment Issues Human Health and Marine Resources Human Values and Resource Protection Climate Variability and Change

3

Research Themes

Lower Trophic Level Productivity

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Lower Trophic Level Productivity

Lower Trophic Level Productivity Section Guide

Introduction

The NRC recommended that the NPRB support fundamental science to study the structure and function of ecosystems to understand the populations they support (NRC 2004a). Further, NRC observed that some ecosystem processes such as spring phytoplankton blooms in high-latitude regions are recurrent, predictable events, while other events, such as aperiodic coccolithophorid blooms, are not well understood, modeled, or predicted. Changes in species composition of the phytoplankton assemblage could significantly affect the efficiency of transfer of primary production through the food web (NRC 2004a).

The coupled nutrient-phytoplankton-zooplankton (NPZ) sequence fuels the upper ocean ecosystem. This aspect of the ecosystem was a focus of the APPRISE project in southeastern Alaska and remains so in the ongoing Northeast Pacific GLOBEC and GEM programs in the northern GOA. In Shelikof Strait and westward, the FOCI program also had some emphasis on the NPZ sequence. The recently completed ecosystem study in the Aleutian Islands had an NPZ element, as had all the programs in the eastern Bering Sea shelf. The processes that result in nutrient flux over the Chukchi Sea shelf are inherent in the ongoing Shelf-Basin Interactions project, while little research is now being conducted in the Alaskan Beaufort Sea. The NPRB will consider supporting research that examines the physical (air-sea interactions, transport, upwelling, processes at fronts, etc.), chemical (micronutrient limitations, re-mineralization by benthic processes, etc.) and biological (plankton dynamics, species composition, etc.) processes that drive primary and secondary production at the base of the food web. Knowledge of such processes will be needed to improve understanding of ecosystem dynamics and the ability to forecast how climate change might impact the transfer of energy through the lower trophic levels.

Overview

The southeast Gulf of Alaska shelf is typically narrow (<50 km) and cut by several deep (>200 m) passages. The region is rich with islands and passes. Regional atmospheric pressure fields and winds undergo significant modification by the rugged topography and this alters their impact on local physical oceanographic features (upwelling, coastal change of sea level, etc). Offshore, the Alaska Current is the dominant circulation feature, and as is typical with eastern boundary currents, it is highly variable and eddies are a common feature. Topographic features can result in and 'trap' eddies, as is the case off Sitka. Along the coast, the Alaska Coastal Current, a buoyancy-driven coastal current indicated in circulation schematics (e.g., Carmack and McLaughlin 2001), is a potential source of the nutrients that contribute to the high biological productivity of the southeastern shelf and inner passages. Strong tidal currents exist in this region and provide a mechanism for nutrient transport. The vast amounts of freshwater runoff may provide for generation of estuarine-like flow that may provide nutrients.

In the northern Gulf of Alaska, atmospheric features (winds, precipitation, heat and moisture fluxes) provide the primary forcing for the physical oceanography. Strong cyclonic counter-clockwise winds dominate from fall through spring, and substantial runoff occurs from late spring through fall. This combination results in an increase in transport and current speeds in the Alaska Coastal Current, which serves as both an important habitat and a migratory corridor for marine life. Waters in the northern Gulf are also considerably modified by cross-shelf transports (of freshwater, nutrients, heat, plankton, fish eggs and larvae) induced by winds, shelf break eddies, and changes in shelf bathymetry and coastline (Hermann et al. 2002; Stabeno et al. 2004). These modifications provide a changing environment for organisms moving through the region, and affect ecosystem dynamics of Prince William Sound (Niebauer et al. 1994). The Sound's unique ecosystem is a critical component of the northern Gulf ecosystem in supporting a variety of species of commercial and/or subsistence value (Cooney et al. 2001a, 2001b). The structure and function of the northern Gulf ecosystem depend critically upon abiotic and biotic exchanges between the Sound and the adjacent shelf and slope.

In the western Gulf of Alaska, shifts in atmospheric and oceanic forcing can impact transport and the presence of eddies in the Alaskan Stream, thus affecting the flux of nutrients and plankton onto or off the shelf. Fluctuations in strength and eddy behavior of the Alaska Coastal Current, together with its role as a source of nutrients, also may impact ecosystem dynamics, including recruitment of fish species (Kendall et al. 1996).

Compared to other regions, only limited research has been conducted on the processes that drive and affect lower trophic level productivity in the Aleutian Islands. The flow of the Alaskan Stream and Alaska Coastal Current through the passes and the existence of strong tidal currents are likely candidates for the source of nutrients. Frontal structures within the passes may concentrate nutrients and planktonic material, resulting in local regions of enhanced production.

The southeast Bering Sea is probably the best understood in terms of ecosystem dynamics, of all the marine regions within purview of the NPRB. A great deal of progress has been made toward developing an understanding of physical forcing mechanisms and the responses of biota over the broad and relatively featureless shelf of the eastern Bering Sea. Research programs such as PROBES, ISHTAR, Bering Sea FOCI, SEBSCC, Inner Fronts Study, and ongoing programs, provide a wealth of observations and interpretations with respect to all elements of the conceptual model. Lower trophic level productivity relies on nutrients from the Alaskan Stream, which are transported to the shelf edge via the Aleutian North Slope and Bering Slope Currents. To a much lesser degree the Alaska Coastal Current may provide some nutrients via flow through Unimak Pass. The flow of nutrients onto the shelf, together with re-mineralization, provides the basis for the observed high production. Over the southeast shelf, however, nutrients can be depleted (e.g., Kachel et al. 2002), whereas supply typically exceeds demand over the northern shelf.

In the Arctic Ocean, there has been recent progress toward developing an understanding of lower trophic level productivity, as documented in several sources, including: Aagaard et al. (1999), SEARCH SSC (2001), MBC Applied Environmental Science (2003), NRC (2004a), and Carmack et al. (2004). Algal communities flourish within sea ice (more so in pack ice than land-fast ice) and play a critical role in polar marine ecology, providing the sole source of fixed carbon for higher trophic levels in ice-cover waters and during winter when other sources do not exist (NRC 2004a). Carmack et al. (2004) note that on the Canadian shelf of the Beaufort Sea, the availability of nutrients (a function of physical processes) limits primary production. This is in stark contrast to the Chukchi Sea shelf where there appears to be an excess of macronutrients throughout summer, if iron limits production.

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In completing this overview of the lower trophic level, it should be noted that oceanic biology is an important component of the global climate system, yet many feedbacks between marine biogeochemistry and climate remain poorly understood. Photosynthetic microbes, which include *Prochlorococcus* and *Synechococcus* (Chisholm et al. 1988), the most abundant plants on earth, synthesize most of the organic matter in the sea. Heterotrophic microbes degrade it, and microbial activity regulates transformation of organic and inorganic matter, nutrient cycling, and trace gases relevant to global climate (e.g. CO_2, DMS, and N_2O; Doney et al. 2004). Thus the ecology of the sea may be viewed as governed at a basic level by the activity of microbes.

Preliminary ecosystem model simulations predict large changes in regional productivity and marine community structure as a result of climate change (Boyd and Doney 2002). Regional and seasonal distribution of phytoplankton is determined primarily by the supply of subsurface nutrients (e.g. nitrate, phosphate, silicate) and the depth of turbulent vertical mixing. Supported by upwelling and deep seasonal convection, phytoplankton blooms occur in the temperate and sub-polar latitudes in the eastern boundary coastal upwelling zones. These ecosystems are dominated by larger eukaryotic autotrophic cells such as diatoms, meso-zooplankton grazers (e.g. copepods) and high organic matter export, a process that governs the large-scale biochemistry of the ocean and the net sequestration on CO_2 (Doney et al. 2004). The eastern sub-polar North Pacific, however, is an anomaly. It has less biomass and productivity than expected and high levels of unused surface inorganic nitrogen and phosphates due to iron limitation. Given that the subsurface supply of macronutrients and iron, inputs of atmospheric iron, regeneration and partitioning of iron, and carbon flux in the ocean, are largely governed by microbes (Doney et al. 2004), their importance in the regulation of ocean productivity cannot be overstated. A critical challenge to understanding the full complexity of the marine ecosystem will be the determination of how microbe communities and ocean biogeochemistry may change as a result of climate change, and how the changes will affect higher trophic levels.

Issues and Concerns

For lower trophic level productivity, the primary issues and concerns center on identifying the processes that supply nutrients to the euphotic zone, drive primary and secondary production, and thus determine the fate and role of such production to higher trophic levels of the ecosystem. Many gaps exist in both long-term observations and results from process-oriented and model studies that could provide the keys to understanding such processes for this crucial trophic level of the ecosystem. These gaps include the identification and understanding of: the mechanisms and magnitude of climate change impacts on nutrient and plankton fluxes onto the shelf, time-space variations in phytoplankton community structure and composition, the cause and impact of aperiodic blooms (e.g., coccolithophorids, salps and harmful algal blooms), the relative importance of micro- and nano-zooplankton in the transfer of energy to higher trophic levels, and more comprehensive understanding of time-space variations in zooplankton, their community structure and potential response to climate change. In addition, various rates associated with both phytoplankton and zooplankton remain unknown, and how those rates may be differentially affected by climate-induced changes in temperature and wind mixing. Rates of transfer of energy between trophic levels also are far from complete. A comprehensive knowledge does not exist of how plankton predators such as chaetognaths, ctenophores, and larger jellyfish affect the flow of energy and how this change is influenced by temperature. In many cases, even a thorough knowledge of taxonomy and biology of plankton species, particularly phytoplankton, is unavailable. This also is true for blooms that occur under sea ice.

Once some of the crucial processes in the NPZ sequence are identified and understood, then there still remain issues regarding how lower trophic level dynamics will respond to climate change. For example, how will warmer ocean conditions, reduced ice cover and changes in atmospheric features, such as frequency, duration and strength of storms, affect these processes and associated rates? What information is necessary to make informed predictions regarding how present conditions will change?

The above issues (characterizing and elucidating the basic dynamics of the NPZ sequence and forecasting the impact of climate change) are generic; they apply to lower trophic level productivity in all three LMEs. There are, however, some issues that are specific to a given region. The following discussion is not intended to be all inclusive. Rather it provides examples of regional issues and research needs for lower trophic level productivity.

Gulf of Alaska

The shelf and inside passages of Southeast Alaska have unique features that impact the nature of NPZ dynamics, for example:

- Is there a reduction in flow (and nutrient transport) along the coast when the California Current experiences an increase in flow from the north?
- How does the vast amount of freshwater inflow affect circulation, nutrient concentrations and plankton communities?
- Is tidal mixing the primary process that supplies nutrients to the euphotic zone within the inside passages, and/or is buoyancy driven flow a factor?

In comparison with Southeast Alaska, the northern and western Gulf is better studied, with sufficient information from prior research to pose the following, somewhat more refined, regional questions.

- What are the relative contributions of 'upstream' production and local production (including that which occurs in Prince William Sound) to the regional ecosystem?
- What are the dominant mechanisms (e.g., exchange via bathymetric features, eddies, Ekman layer transport from the gyre) for the cross-shelf transport of nutrients and what is the likely affect of climate change on these?
- Does the nutrient flux into the Shelikof sea valley also supply nutrients to the shelf west of Shelikof Strait, and if not, how is this region supplied by nutrients?
- Do the numerous eddies enhance the likelihood of larval survival by providing greater prey abundance (e.g., zooplankton), or do they simply cause convergence?

Aleutian Islands

The Aleutian Islands ecosystem is influenced by transport of heat, salt and nutrients from the Alaskan Stream (and Alaska Coastal Current through Unimak and Samalga Passes) into the Bering Sea. It is this transport that provides the habitat and nutrients for lower trophic level production. This flow, however, is not unidirectional. Where the passes are sufficiently wide, water can flow southward on the west side of the pass, i.e., Bering Sea water influences the lower trophic level community within the Aleutian Islands. Here are examples of the types of research questions that should be addressed:

- What processes cause transport in the subarctic gyre to vary and what are the implications of such changes to nutrient, heat and salt fluxes through the passes?
- How will changes in these parameters impact lower trophic level productivity?
- What are the relative influences of source waters (Alaskan Stream or Alaska Coastal Current), and mixing and the adjacent Bering Sea water on the distribution of nutrients and on the distribution and composition of the plankton community?
- What are the magnitude and timing of the seasonal cycle of production and how do they compare to interannual variations in this signal?

Bering Sea

While the southeastern Bering Sea ecosystem has been studied most of all the regions, there are still many unanswered questions that demand attention if good stewardship is to be developed to sustain ecosystem services. These include, for example:

- What mechanisms are responsible for the flux of nutrients and plankton onto the shelf, and what is the relative contribution of these to nutrients that have been re-mineralized by benthic processes?
- Does significantly more phytoplankton sink to the bottom in cold years than in warm years; and how has primary production changed (increased or decreased) over the past two decades?
- How do the observed patterns of ice melt-back (McNutt 2004) affect the timing and type of phytoplankton bloom and the ensuing zooplankton dynamics and do these mechanisms work in similar ways in the southern and northern Bering Sea?
- Are ice-related blooms shorter and more intense than open-water blooms and when both are present, which is likely to fix more carbon?
- For the cold-adapted zooplankton species, are growth and production more sensitive to temperature than phytoplankton productivity?

Arctic Ocean (Chukchi/Beaufort Seas)

Examples of the specific issues in the Arctic Ocean LME include the following:

- What are the main processes and signature of water properties, chemical constituents, and primary-secondary production from the Chirikov Basin, through Bering Strait and northward throughout the Chukchi Sea, and how do these compare with processes and characteristics due to shelf-basin exchange?

- Is iron limiting production in the entire region?

- What controls this region's circulation and water properties at the boundaries: the Chukchi Sea to the west, Arctic Ocean to the north and the Canadian Beaufort (Mackenzie River) to the east; what dynamics provide the primary sources of nutrients?

- What are the major species of plankton, how does community composition change with time, and what causes the changes?

- How do the pathways of energy from ice algae, land-fast algae and phytoplankton differ; what are the rates of production and who are the primary consumers?

As basic knowledge of the plankton communities and the associated dynamics is being developed, an overarching issue will remain for all three LMEs: how global climate change will impact the dynamics of lower trophic level productivity and flow of energy from nutrients to zooplankton.

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Research Needs

Four main thematic research topics emerge from the above discussion of lower trophic productivity, all of which generally fall under marine ecosystem information needs: Nutrient level dynamics, phytoplankton ecology, phytoplankton-sea ice dynamics, and zooplankton ecology. These are summarized in Table 3-2 with specific issues associated with each topic. These will serve as the basis for development of the implementation plan and periodic NPRB requests for proposals related to lower trophic level productivity.

Research Needs

Table 3-2 General research needs for lower trophic level productivity.

Marine Ecosystems Information Needs

Nutrient Dynamics

- Sources, fluxes, and fates of nutrients key to primary production
- Effects of physical processes on nutrient supply to shelf ecosystems
- Nutrient limitation as a controlling factor in phytoplankton production
- Role of iron in limiting primary production
- Role of freshwater runoff in contributing nutrients to coastal production

Phytoplankton Ecology

- Contribution of advection and mixing to local primary production
- Species composition and abundance under variable oceanographic conditions
- Temporal and spatial changes in community composition
- Factors leading to extraordinary blooms, such as of coccolithophores, and role of such blooms in energy flow through the ecosystem
- Affects of cold versus warm water years on phytoplankton production

Phytoplankton - Sea Ice Dynamics

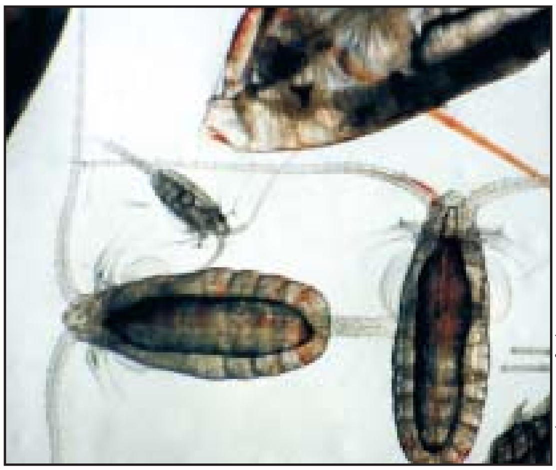
- Impacts of sea ice cover on phytoplankton production
- Energy pathways in ice-related communities
- Eventual changes in phytoplankton communities with recession of sea ice

Zooplankton Ecology

- Relative importance of advection and local zooplankton production
- Timing of zooplankton growth and production in relation to ice edge
- Role of eddies in zooplankton productivity
- Species composition and contribution of each to upper food chain
- How zooplankton predators impact energy flow through the ecosystem
- Cold-adaptation of zooplankton

Implementation Strategies

In general, research implementation strategies on lower trophic level productivity will require all of the research approaches identified in Chapter 2, including monitoring, retrospective analysis, process studies, and modeling. In developing its implementation strategies for the near term for lower trophic level productivity, the Board will have the advantage of having funded the projects shown in the table below over the past three and a half years (detailed project information by project number is available at http://www.nprb.org).



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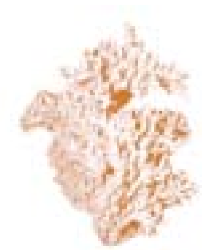
Models of the nutrient-phytoplankton-zooplankton sequence can be used to provide a holistic picture of causes and variations in lower trophic level productivity and to examine how this production relates to the surrounding environment. The Board may provide funding support for a conference on ecosystem modeling and support future ecosystem model development and maintenance in the next four years. The models and understanding of lower trophic level productivity will require basic biological oceanographic research in all three LMEs. It is essential that observations be made year-around if possible, and costs of such research will increase significantly in northern areas covered by sea ice. Owing to the pack and sea ice in many locations, as well as the land-fast ice, development of remote sensing technologies and methods will be essential in order to make year-round observations. The Board may convene a conference on latest remote sensing technologies and also will need to evaluate plankton monitoring methods. The development of a strategy for determining new sites for biophysical moorings, development and utilization of new techniques, and for establishing the types of information that may provide the greatest value to NPRB's goals could be determined by a combination of information from various working groups (e.g., Alaska Ocean Observing System, PICES, etc.) and through additional synthesis meetings sponsored by the NPRB. The Board may support long-term ocean monitoring that will improve understanding of processes that impact lower trophic level productivity.

Current Projects

Project	Project Number
Monitoring of biophysical moorings in the Bering Sea	203, 211, 315, 410, 517
Evaluation of circulation models for Bering Sea and Aleutians	402
Bering Sea ecosystem study of effects that lead to ecosystem reorganization	207
Continuous plankton recording across North Pacific	302
Synthesis of marine biology and oceanography of southeast Alaska	406
Utility of ecosystems indicators for the Bering Sea	502
Long term observations along the Seward Line in the Gulf of Alaska	520
Profiling echosounder for North Pacific monitoring for micronekton	521

Fish Habitat



Fish Habitat Section Guide

Introduction

The National Research Council (2004a) found that the lack of basic information on distribution and habitat use of most early life stages of fish and the ecosystems that support them could pose a major constraint to managing fisheries. It also found that research is needed to evaluate marine protected areas as another tool for fisheries management. In addition to fishing impacts, the committee identified other human-induced impacts that could degrade habitat: coastal development, oil exploration, aquaculture, mining, logging, contaminants and waste discharge.

Similar concerns were echoed in the report of the U.S. Commission on Ocean Policy (USCOP 2004). Noting that maintaining healthy, functioning habitats is an essential element of an ecosystem-based management approach, the commission found there is scant legislative guidance and little scientific information available on habitat requirements for fish, which leads to broad designations of fish habitat requirements. The commission recommended changing to a multispecies approach for defining habitat, and basing those designations on well-documented science-based analytical methods that also consider ecologically valuable species that are not necessarily commercially important. The commission identified marine protected areas as important tools for ecosystem-based management, with the caveat that such areas alone may not deliver long-term sustainable use of the oceans, and that other pressing problems will continue to require attention, including resource use outside protected areas, point and non-point source pollution, and intensive coastal development. The commission concluded that if marine protected areas are determined to be the best approach to address ecosystem goals in a particular area, they must be designed using the best available scientific information to ensure that their establishment is likely to meet the intended objectives.

In the NPRB region, fishery managers already have adopted many aspects of the general recommendations from the NRC and USCOP for ecosystem-based management and use of marine protected areas as a management tool for fisheries. Using criteria from Sustaining Marine Fisheries (NRC 1999a), the North Pacific Fishery Management Council evaluated progress being made in federal waters and found substantial progress (Witherell et al. 2000b) toward implementing measures toward ecosystem-based fishery management. Additional measures taken to implement new fishery mandates under the Sustainable Fisheries Act of 1996, for example, for essential fish habitat, are focusing on spatially explicit measures as further building blocks toward ecosystem-based fishery management. The USCOP (2004) found the Alaska region to be a model for the other regions in the United States with respect to ecosystem-based fishery management.

Using the criteria developed by the National Marine Protected Area Center (2004) to assess the progress toward use of marine protected areas, Witherell (2004a) found that the Alaska region had already established by the end of 2004, over 104,000 sq nm for fishery management measured toward the primary conservation goal of "sustainable production." While the direct goal of the measures is to sustain fisheries production, there are substantial direct and indirect effects on benthic ecosystems and biodiversity. Based on Witherell and Coon (2000) and additional habitat mapping studies, the North Pacific Fishery Management Council moved forward in February 2005 to protect additional habitat. In the Aleutians, the NPFMC prohibited all bottom trawling, except in small discrete open areas. Over 95% of the Aleutian Islands management area will be closed to bottom trawling (277,100 nm^2). Additionally, six areas with especially high density coral and sponge habitat will be closed to all bottom contact fishing gear. These coral garden areas, which total 110 nm^2, are thus considered marine reserves. In the Gulf of Alaska, the NPFMC prohibited bottom trawling in ten designated areas along the continental shelf which are thought to contain high relief bottom and coral communities. (see NPFMC newsletter at http://www.fakr.noaa.gov/npfmc/current_issues/efh/efh.htm).

In making funding decisions, the Board will consider the issues raised by the NRC and the USCOP, in the context of existing legal mandates. Decisions by resource managers to protect certain types of habitat should be based on sound science and the Board intends for its research to be responsive to those needs. While the Board potentially could choose to fund research on any of a number of human-induced impacts on habitat, the following discussion focuses mainly on habitat research as it relates to fish and fishing, which is more in keeping with its legislative mandate to give priority to pressing fisheries management issues and marine ecosystems information needs. Further, the emphasis of the Board's habitat research program will be on benthic habitat, though the Board recognizes that habitat, used in the broadest sense, encompasses the total environment in which organisms live, from bottom substrate up through the water column to the sea surface, and sea ice cover if present. Habitat research needs of marine mammals and seabirds are addressed in in their respective section.

This section begins with an overview that generally describes types of fish habitat and how fish relate to them. It goes on to discuss some unique areas such as coral gardens that may not have much relationship to major commercially-fished species, but still will need to be studied to determine their role in the ecosystem and their need for protection. Following this overview, issues and concerns are identified, for example, how fishing affects habitat. And finally, research needs and strategies are identified for four major thematic areas: other human-related impacts, fishing effects, habitat mapping, and ecosystem functions of habitat (Table 3-3).

Except as noted, the following discussion is summarized from the larger body of work reviewed in the final programmatic supplemental environmental impact statement for Alaska groundfish (NMFS 2004b) and the draft environmental impact statement for essential fish habitat (NMFS 2004c).

Overview

The continental shelf off Alaska accounts for about 70% of the total continental shelf of the U.S. Most bottom fishing takes place on this shelf and the upper slope in waters less than 500 m in depth. The affected seafloor covers a wide range of habitats, from relatively featureless sand and mud, to more complex rocky areas. Hard substrates and rocky areas may be more vulnerable because they provide the most habitat complexity for the benthic community.

General Habitat Types

The Gulf of Alaska has relatively weak currents and tidal action near the seafloor. Therefore, a variety of seabed types such as gravely-sand, silty-mud, and muddy to sandy gravel, as well as areas of hardrock is present. Most of the western Gulf has slopes that are steep and dissected by canyons. It has many banks and reefs with numerous coarse, clastic, or rocky bottoms, and patchy bottom sediments. Around Kodiak Island, there are flat, relatively shallow banks cut by transverse troughs. The northeast Gulf of Alaska shelf is relatively wide, and the dominant shelf sediment is clay silt that comes primarily from either the Copper River or from the Bering and Malaspina glaciers. Sediments from those glaciers generally are transported to the west. Sand predominates near shore.

The Aleutian Islands shelf is narrow, ranging in width from about 4 km or less to 42-46 km on the north and south sides of the approximately 150 islands. Browers Ridge is a submerged structure about 550 km long and 75-110 km wide that extends northward and is approximately 150-200 m deep in the southern portion, deepening northward to about 800-1,000 m at its northern edge. The Aleutian Island region has a complicated mixture of substrates, including a significant proportion of hard substrates (pebbles, cobbles, boulders, and rock), but data are not available to describe the spatial distribution of these substrates. The substrate in the area from Near Strait eastward to the vicinity of Buldir Island, Amchitka, and Amukta Pass is mainly bedrock outcrops and coarsely fragmented sediment interspersed with sand bottoms.

The Bering Sea shelf has four general habitat types. The first is composed of sand substrates with small amounts of gravel situated around the shallow eastern and southern perimeter of the shelf and near the Pribilof Islands. The second is a mixture of sand and mud laying across the central shelf out to the 500 m contour. It is subject to a high level of effort from a variety of fisheries: pollock being the largest, but also for flatfish and Pacific cod. A third habitat type is mud (silt) substrates with some sand mixed in, primarily west of a line between St. Matthew and St. Lawrence Islands. The fourth habitat type is north and east of St. Lawrence Island, including Norton Sound, consisting of a complex mixture of substrates that are not easily separated or defined, and not subjected to much fishing effort.

Nearshore areas in the Bering Sea, Aleutians, and Gulf of Alaska, also are important: they provide food and rearing habitat for juvenile fish and spawning areas for species such as Atka mackerel and yellowfin sole. Habitat types include intertidal and submerged vegetation, rock, and other substrates, all of which have a high potential to be affected by shore-based activities. As will be described further below, shallow nearshore areas provide important structural habitat for red king crab. Juveniles of some species of rockfish use eelgrass (*Zostera spp.*) beds and herring spawn near the shoreline, depositing their eggs on vegetation, primarily rockweed (*Fucus spp.*) and eelgrass, found along much of the Alaska coastline.

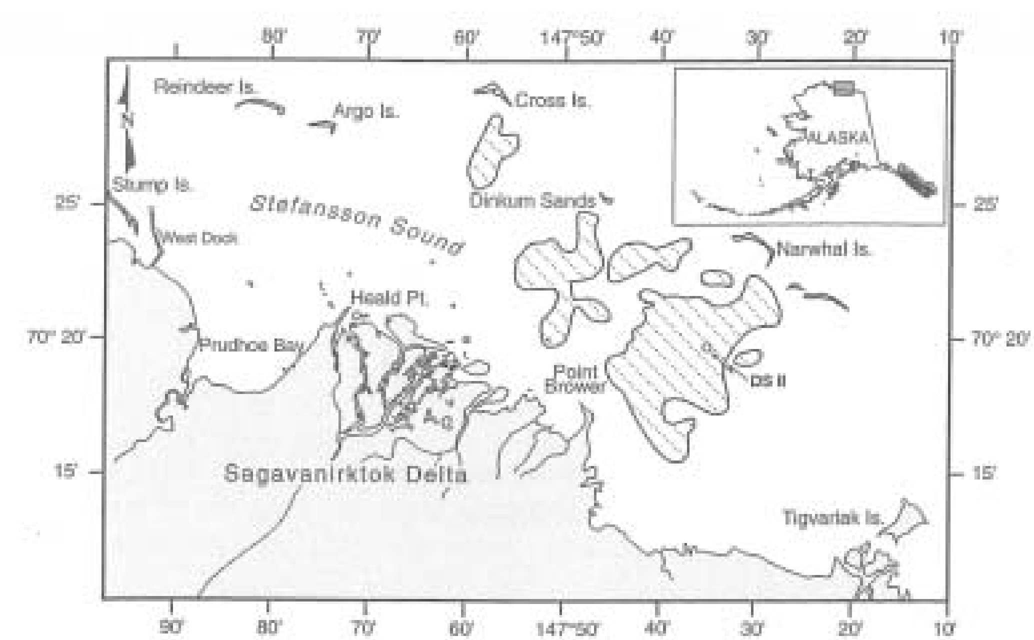
Living benthic habitat includes epifaunal and infaunal communities. Epifaunal communities, in particular, have received considerable attention in reference to fish habitat. They mainly include coral, sponges, anemones, and bryozoans, which add structural complexity to the seabed and provide cover and prey for groundfish and other organisms. Even when not associated with particular commercial fish species, they still contribute a rich biodiversity to the marine ecosystem. Corals are a prime example of highly diverse, vertical structure that fish use for protection and cover, particularly rockfish (Krieger and Wing 2002). Five major taxonomic groups and at least 34 species of coral occur off Alaska: *Alcyonacea* (soft corals), *Gorgonacea* (sea fans, bamboo corals, and tree corals), *Scleractinia* (cup corals or stony corals), *Stylasterina* (hydrocorals), and *Antipatharia* (black corals).

Soft corals are most frequently found in the Bering Sea, while gorgonian corals are most common in the Aleutians (Heifetz 2002). The Aleutians also have the highest diversity and abundance of corals. In the Gulf of Alaska, gorgonian corals and cup corals are dominant. Gorgonian corals, because of their size and longevity, may be especially vulnerable to fishing impacts.

Sponges are another common member of epifaunal communities, and their body size and shape can vary highly and are strongly influenced by currents and other environmental parameters (Bell and Barnes 2000; Bell et al. 2002). They normally reach a maximum height of 25-30 cm, and together with bryozoans and hydroids, provide prime habitat for young red king crab. They also are commonly associated with rockfish and Atka mackerel (Malecha et al., 2002 unpublished). Bryozoans are small colonial animals common on hard substrates in the southeast Bering Sea, and of about 90 species that have been identified, roughly two-thirds are low-profile encrusting forms. Rock, live and dead bivalve and gastropod shells, and crab shells are common substrates for attachment, and bryozoans commonly are associated with juvenile red king crab. Other sessile epifauna include hydroids, sea raspberries, sea pens, anemones, sea onions, and sea peaches, many of which may provide habitat for juvenile crab.

The coastal areas of the Chukchi and Beaufort seas were extensively sampled in the 1970s and 1980s, revealing faunal assemblages of polychaetes, tiny crustaceans, and mollusks living in soft sediments, but few algae or epilithic (living on rocks or stony substrates) invertebrates (Dunton and Schonberg 2000). Boulders and cobbles covered with algae, including large kelp, and fauna appear to be rare features on the Alaska Beaufort Sea shelf, which is blanketed mainly with silty sands and mud from the many rivers that empty into the Beaufort Sea from the MacKenzie Delta west to the Kuparuk and Colville rivers. An exception is the Boulder Patch, an area of cobbles and boulders that supports many species of algae and invertebrates in Stefansson Sound off Prudhoe Bay (Figure 3-1). The area is protected from deep-draft sea ice by a chain of offshore barrier islands and shoals that include Dinkum Sands. Dunton and Schonberg (2000) found about 140 taxa of benthic infauna from 11 invertebrate phyla between and under rocks, and epilithic communities rich with fishes, sponges, mollusks, and other fauna representing about 158 taxa. They concluded that the rich community of the Boulder Patch is important in arctic nearshore food webs, and its rock habitat needs to be protected because it provides refuge for such organisms.

Fig. 3-1 Location of the Boulder Patch (diagonal lines) in Stefansson Sound, Alaska. (Dunton and Schonberg 2000, with permission of the author).



Relating Fish to Habitat

There is a variety of relationships between major fished species and benthic habitat. Some species are almost entirely independent of benthic habitat, while others closely depend on particular bottom structure. The following examples for pollock, Pacific cod, rockfish, Atka mackerel, halibut, herring, salmon and crab, help to characterize the diverse relationships of fish to habitat in Alaska waters.

Two of the largest groundfish fisheries off Alaska are based on pollock and Pacific cod. Pollock are found throughout the water column in the Gulf of Alaska and Bering Sea and Aleutians, from the surface down to 500 m, with seasonal migrations from over-wintering areas along the outer shelf to shallow waters for spawning. Adults, eggs, larvae, and juveniles are only loosely associated with particular benthic habitat structure. In contrast, Pacific cod occur as adults from the shoreline to 500 m, and converge in large spawning masses over relatively small areas, preferring a substrate of soft sediment, from mud to clay-sand. Spawning occurs near the bottom and eggs sink to the bottom and are somewhat adhesive (Hirschberger and Smith 1983). The larvae are primarily in the upper 45 m shortly after hatching, but move deeper as they grow.

Rockfish species may be pelagic or demersal. Pelagic shelf rockfish inhabit waters of the continental shelf and typically exhibit mid-water schooling behavior. Pacific ocean perch larvae are pelagic and drift with the current, with post-larval and early young-of-the-year occurring offshore. Later-stage juveniles are believed to migrate to an inshore, demersal habitat, where they seem to inhabit rockier, higher relief areas than adults (Carlson and Straty 1981; Straty 1987; Pearcy et al. 1989; Krieger 1993). As they mature, juveniles move to progressively deeper waters of the continental shelf. Whereas adult Pacific ocean perch are associated with pebble substrate on flat or low-relief bottom, juveniles prefer rugged areas containing cobble-boulder and epifaunal invertebrate cover (Krieger 1993).

Atka mackerel are abundant in the Aleutian Islands. They are semi-pelagic as adults and spend most of the year over the continental shelf in depths generally less than 200 m. Adults migrate annually to shallow coastal waters during spawning, forming dense aggregations near the bottom (Morris 1981). Females deposit adhesive eggs in nests or rocky crevices. The nests are guarded by males until hatching occurs (Zolotov 1993). Planktonic larvae are found up to 800 km from shore, usually in the upper water column.

Pacific halibut spawn in winter, mostly off the edge of the continental shelf at depths of 400 to 600 m. Fertilized eggs float free for about 15 days before hatching; the larvae drift free for up to another 6 months and can be carried great distances to shallower waters by prevailing currents. Young halibut begin life in shallower waters as bottom dwellers and spend 5-7 years there. Younger halibut (up to 10 years of age) are highly migratory, generally migrating in a clockwise fashion throughout the Gulf of Alaska. Older halibut tend to be much less migratory and sometimes leave the ocean bottom to feed on pelagic fish such as herring and Pacific sand lance.

Pacific herring spawn in mid-March in southeast Alaska and as late as June in the eastern Bering Sea. Spawning occurs in shallow, vegetated intertidal and subtidal areas. The eggs are adhesive, and survival is greater for those eggs that stick to vegetation than for those that fall to the bottom. Milt drifts among the eggs, fertilizing them. The eggs hatch in about two weeks, depending on water temperature. The young larvae drift and swim with the ocean currents. After developing to their juvenile form, they rear in sheltered bays and inlets and appear to remain segregated from adult populations until they mature. After spawning, most adults leave inshore waters and move offshore to feed, primarily on zooplankton, spending daylight hours near the bottom and moving upward during the evening to feed (Hart 1973).

Pacific salmon spawn in fresh water, and their eggs hatch and go through several developmental stages in fresh water until they out-migrate to the ocean as fry or smolts. The young salmon feed and grow to maturity, ranging widely over the North Pacific Ocean, Bering Sea, and Chukchi Sea. They return to fresh water, often migrating tremendous distances to reach their natal streams, where they spawn and then die.

Commercially-fished invertebrate species are for the most part bottom dwellers in their juvenile and adult stages. King and Tanner crabs share a similar life cycle, although particular life cycle traits are distinct for each species. After males and females mate, the female carries the eggs for approximately one year, at which time the eggs hatch into free-swimming larvae. After drifting with currents and tides and undergoing several development changes, larvae settle to the ocean bottom and molt into non-swimmers, looking very much like miniature adult crabs. The juvenile crabs settle on preferred habitat, where they continue to molt and grow for several years until they become sexually mature. Each life stage for crab stocks is concentrated at some combination of depth, habitat, geographic area, and time of year. Juvenile king crabs need high-relief habitat or coarse substrate, such as boulders, cobble, shell hash, and living substrates, such as bryozoans and stalked ascidians (Stevens and Kittaka 1998). Adult crabs also use highly structured shallow water habitat during the mating period and will use macroalgae as cover during this period (Stone et al. 1993). Small (<20 mm carapace width) juvenile Tanner crabs have been found on silt, fine sand, and mud substrates in depths >50 m.

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Issues and Concerns

Information Required for Management

Marine resource managers are under increasing pressure to assess and mitigate habitat disturbance by fishing operations. As noted earlier, both the NRC (2004a) and the USCOP (2004) found that comprehensive habitat information was very scarce. And yet the Magnuson-Stevens Act (MSA) requires NMFS and the NPFMC (as well as the other seven councils) to describe and protect essential fish habitat (EFH), broadly defined as those waters and substrate necessary for fish to spawn, feed or grow to maturity, and to mitigate, to the extent practicable, any adverse impacts potentially caused by fishing activities. A council also may designate certain types of habitat for extra protection, identifying them as "habitat areas of particular concern" (HAPC) on the basis of the importance of their ecological function, sensitivity to human-induced environmental degradation, extent to which they are stressed by development activities, and their rarity as a habitat type.

Comprehensive habitat information is needed to respond to these management needs. Pertinent information includes geographic range and habitat requirements by life stage, distribution and characteristics of those habitats, and current and historic stock size as it affects occurrence in available habitats. Temporal and spatial distribution of each life history stage is necessary to understand the relationship of each species to, or dependence on, various habitats. Information is needed summarizing environmental and habitat variables that control or limit distribution, abundance, reproduction, growth, survival, and productivity of the managed species. Four levels of data are used to describe and identify EFH, and federal managers need to strive for level 4:

Level 1: Distribution data for some or all portions of the geographic range of the species.

Level 2: Habitat-related densities of species. Density data should reflect habitat utilization, and the degree that a habitat is utilized is assumed to characterize habitat value. When assessing habitat value on the basis of fish densities in this manner, temporal changes in habitat availability and utilization should be considered.

Level 3: Growth, reproduction, or survival rates within habitats are available. At this level, data are available on habitat-related growth, reproduction, and/or survival by life stage. The habitats contributing the most to productivity should be those that support the highest growth, reproduction, and survival of the species (or life stage).

Level 4: Production rates by habitat are available. At this level, data are available that directly relate the production rates of a species or life stage to habitat type, quantity, quality, and location. Essential habitats are those necessary to maintain fish production consistent with a sustainable fishery and the managed species' contribution to a healthy ecosystem.

Resource managers with the State of Alaska also have responsibilities to protect habitat, and thus have research needs. Alaska Statutes 41.14.840 (Fishway Act) and 41.14.870 (Anadromous Fish Act) require individuals or governmental agencies to notify and obtain authorization from the Alaska Department of Natural Resources for activities that impact fish habitat, particularly anadromous fish habitat and for ADFG to specify the various streams that are important for spawning, rearing, or migration of anadromous fishes. The description and location of specified anadromous waterbodies are contained in the Catalog of Waters Important for the Spawning, Rearing, or Migration of Anadromous Fishes and Atlas to the Catalog of Waters Important for the Spawning, Rearing, or Migration of Anadromous Fishes. The Atlas shows locations of these waters and the species and life stages that use them. The State of Alaska also manages fisheries for groundfish (Pacific cod, pollock, sablefish, lingcod, and rockfish), herring and invertebrates, and one of the *Guiding Principles for Groundfish Fishery Regulations* (5 AAC 028.89) is to protect habitat and other associated fish and shellfish.

Fishing Effects on Habitat

Many fishing gears are used in Alaska fisheries, ranging from salmon troll gear, gillnets, set nets, and purse seines, to scallop dredges, crab pots, and a variety of groundfish gear including trawls, longlines, pots, and hook-and-line. All may impact the surrounding environment, but the large trawl fisheries for groundfish are the most controversial in terms of potential impacts on benthic habitat. While the emphasis below is on trawl gear, the NPRB may sponsor research on other gear impacts as they are identified and funds made available.

Virtually all of the Bering Sea has experienced some degree of trawling, with the three most fished places being along the shelf edge, along the Alaska Peninsula near Unimak Island, and in Togiak Bay. The primary targets are pollock, Pacific cod, and various flatfishes such as yellowfin sole and rock sole (Fritz et al. 1998). Large areas have been closed to trawling, primarily to reduce bycatch in sensitive nursery areas for crabs and halibut, and to protect Steller sea lions. In the Aleutians, bottom trawling targets Atka mackerel and Pacific ocean perch. In the Gulf of Alaska, trawling has been greatest near Kodiak Island for Pacific cod, Pacific ocean perch, and flatfish. While trawl fisheries account for the majority of groundfish catch off Alaska, the region experiences lower overall fishing intensity per unit area than other regions of the U.S (NRC 2002b). Overall, trawling intensities greater than one event per year in a 5 by 5 km area are less than 2 percent for the eastern Bering Sea, 3 percent for the Aleutians, and 2 percent for the Gulf. In comparison, it is 56 percent for northeastern United States fisheries.

The impacts of fishing gear on habitat normally are characterized in terms of intensity and frequency of fishing, types and specific characteristics of the gear, environmental and habitat characteristics, and the level of naturally occurring disturbance. Trawls have four main components that can contact the seabed: doors, sweeps, footrope, and netting. The doors spread the net horizontally and force it downward, contacting the seafloor during bottom trawling, but flying above the seafloor in pelagic trawls. Sweeps are steel, fiber or combination steel and fiber cables that connect the doors to the trawl nets. When used on bottom trawls, the cables commonly contact the seafloor. The footrope is a cable or chain connected along the bottom edge of the trawl net and is designed to contact the seafloor on bottom trawls. The footrope usually has rubber cones, spheres or disks, collectively known as bobbins, strung along its entire length, which limit damage to the netting and reduce bycatch of crabs and other invertebrates. Tire gear may be used in place of bobbins to fish over rough substrates where fishing would not otherwise be possible. Pelagic trawl gear is modified to fish above the bottom. By regulation, these trawls must not use bobbins or other protective devices, so the foot ropes are small in diameter, and typically consist of bare chain. Since pelagic trawls are fished with the doors above the seafloor, the doors have no effects on substrate. The footrope is unprotected and therefore, pelagic trawls are not used on rough or hard substrates and are less likely to contact some of the most vulnerable habitats.

Recovery times of habitat from trawling will depend on the type and extent of the habitat alteration, frequency of the disturbance compared with natural changes, habitat characteristics, and species and life history characteristics (NRC 2002b). A meta-analysis by Collie et al. (2000) showed that recovery rate appears to be slowest in the more stable muddy habitats and structurally complex, biogenic habitats. In comparison, mobile sandy sediment communities would be able to withstand 2-3 trawl passes per year without changing markedly (NRC 2002b). As a rule of thumb, recovery times often are one to five times the generation time of the organism disturbed (Emeis et al. 2001), and therefore could range from a few months or less, to several decades (Hutchings 2000). Because many of the larger biogenic structure-forming organisms, such as corals and sponges, are slow growing and long lived, they may take decades to centuries to recover (NRC 2002b).

The Draft Essential Fish Habitat Environmental Impact Statement of January 2004 (NMFS 2004c) draws the following conclusions relating trawl research to the fisheries of Alaska:

1. Bottom trawls commonly, but not always, cause detectable short-term changes in infauna, epifauna, megafauna, and substrates in different habitat types.
2. In comparable environments, studies using larger diameter footropes with noncontinuous contact along their length, such as those used in Alaska, indicated less damage to upright, attached epifauna than those with smaller diameters and continuous contact (Moran and Stepheson 2000; VanDolah et al. 1987).
3. At higher trawling intensities, bottom trawling can produce persistent changes in megafauna communities (McConnaughey et al. 2000) on naturally disturbed sandy substrates.
4. Even at relatively high intensities (12 tows per year), effects on infaunal communities may be ephemeral (Kenchington et al. 2001) on fine- to medium-grained sandy bottoms.
5. Large bodied, attached, and emergent epifauna are particularly vulnerable to trawl damage, even by a single pass at unimpacted sites (Collie et al. 2000; Van Dolah et al. 1987; Freese et al. 1999; Moran and Stepheson 2000). Effects can last at least a year in Alaska waters (Freese 2002). These fauna constitute the living substrate categories of HAPC.
6. Specific effects on habitat will depend on the fine-scale distribution and intensity of fishing effort relative to habitat distribution, levels of natural variability relative to fishing effects, and the nature of habitat dependencies of managed fish stocks. These are poorly known for Alaska EFH. Given discrete but overlapping spatial distributions of species reflecting different habitat preferences and requirements (e.g., McConnaughey and Smith 2000), differential responses to fishing gear effects are likely. In general, the ecological implications of reported changes due to bottom trawling are poorly known, particularly as they relate to sustainable fishery production and healthy ecosystem function.

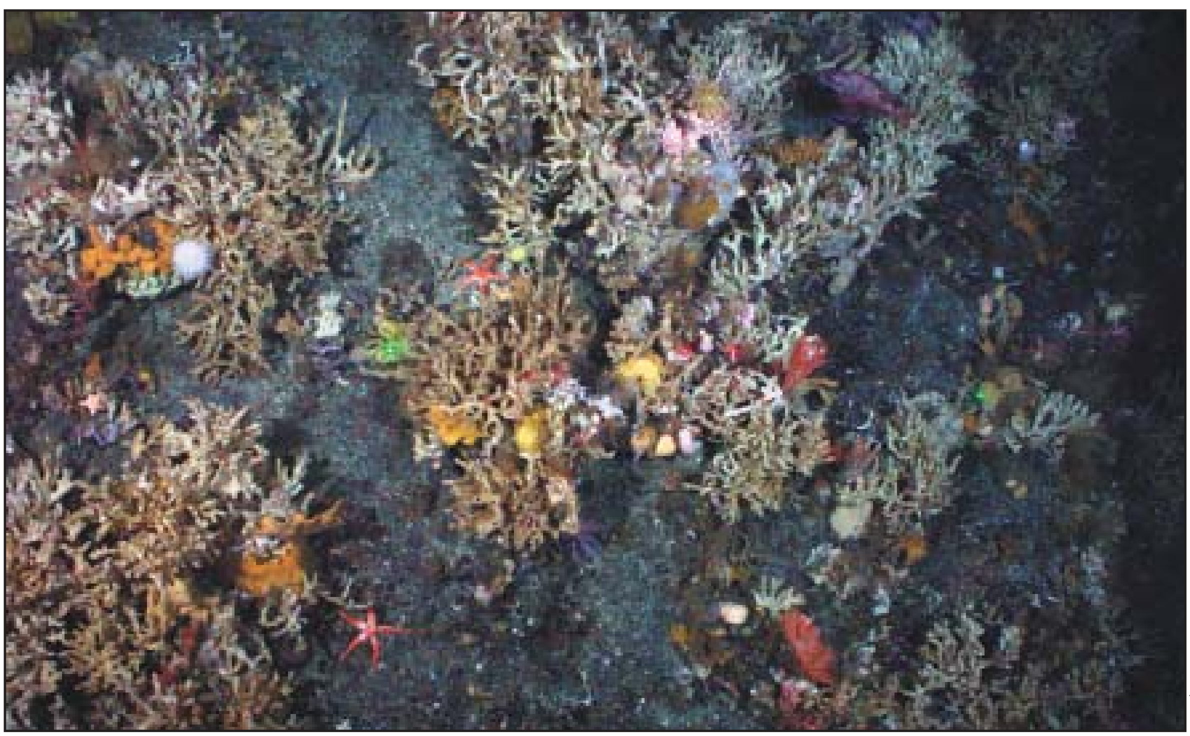
In summary, fishing gear has several potential effects on benthic habitat. It may alter physical structure and cause sediment suspension. It may cause direct mortality to benthic organisms and result in changes to benthic communities and the surrounding ecosystem. It should not be overlooked that recreational fisheries also may impact habitat. Heavy recreational traffic may cause erosion and pollution in streams and rivers, and high-speed boats, wave-runners, etc., may exacerbate erosion and be a source of significant underwater noise.

Other Sources of Habitat Degradation

As the NRC (2004a) noted, there is a variety of other human-induced impacts on habitat. To assess cumulative impacts, fishery plans and analyses must assess the impacts of non-fishing activities that may adversely affect EFH, including: logging, dredging, filling, excavation, port development, oil and gas exploration and development, mining, impoundment, discharge, water diversions, thermal additions, actions that contribute to non-point source pollution and sedimentation, introduction of potentially hazardous materials, introduction of exotic species, and conversion of aquatic habitat that may eliminate, diminish, or disrupt the functions of EFH. Coastal development is more likely near urban centers in Alaska, such as Anchorage, Juneau, Sitka, Ketchikan, Kodiak, and Dillingham. But any area near logging or mining activities, for example, in southeast and southcentral Alaska, could be impacted by those industries. Another major oil spill such as the Exxon Valdez spill in 1989 also could have catastrophic impacts on habitat. Natural events such as storm surges, wind generated waves, climate effects, volcanic eruptions, and earthquakes and underwater landslides, also must be assessed.

Ecosystem Functions of Habitat

The NRC (2004a) noted that no research has been done to assess the benefits of marine protected areas as an approach to provide long-term value for effective fisheries management and stewardship in the NPRB region. There is a need to view habitat for habitat sake, not just in terms of whether it supports important commercially-fished species. As mentioned earlier, deepwater coral gardens represent rich, highly biodiverse, epifaunal communities. They clearly provide vertical structure for a variety of fish species which use it for protection and cover. Even if they are found to not contribute to major commercially-fished species, their ecological functions should be assessed. Because many deep water areas are characterized as stable environments dominated by long-lived species, the fishing and other impacts can be substantial and long-term.



Research Needs

As is clear from the above discussion, basic research is needed to characterize habitat and its relationship to fish, to assess the direct and indirect effects of fishing gears and other human-induced impacts on habitat, and to determine the overall ecosystem function of specific types of habitat. For commercially-fished species, research should strive to improve understanding of the relationship of fish to habitat, with the goal of using levels 3 and 4 information for designating essential fish habitat, rather than levels 1 and 2 presence-absence type data.

The Final Programmatic SEIS for Groundfish (NMFS 2004b) identified the following habitat research needs surrounding the groundfish fisheries off Alaska:

1] <u>Determine Effects of Fishing on Benthic Habitat</u>
   - a) Compare conditions in heavily fished and lightly fished/unfished areas that are close in proximity and otherwise similar.
   - b) Compare conditions before and after fishing to identify effects on the benthos.
   - c) Determine rates of disturbance with repetitive fishing of specific grounds.

2] <u>Specific Studies</u>
   - a) Effects of specific gear on specific habitat.
     - i. Effects of bottom trawling on soft bottom habitat of Gulf of Alaska.
     - ii. Effects of bottom trawling on soft-bottom habitat of the Bering Sea shelf.
     - iii. Effects of scallop dredging on benthic communities
     - iv. Effects of longline and pot gear on sensitive habitats
     - v. Effects of fishing on hard-bottom habitat of the Aleutian Islands.
     - vi. Impacts of fishing on crab resources and habitat
     - vii. Effects of bottom trawling on shelf break and upper continental slope habitats.
   - b) Linkages of fishing-induced disturbance to population dynamics.
     - i. Laboratory and field studies.
     - ii. Modeling.
   - c) Mitigation-related Studies.
     - i. Evaluation of mitigation measures and impacts with research closures.
     - ii. Reducing fishing gear effects through gear modifications.

3] <u>Spatial Extent of Fishing-Induced Disturbance</u>
   - a) Habitat evaluation in current fishery management plan fisheries.
   - b) Mapping of habitat features of major fishing grounds.
   - c) Retrospective analysis of seafloor geologic and biologic character.
   - d) Quantify abundance of habitat types over large geographic areas.
   - e) Characterization of benthic habitat in habitat areas of particular concern.

While the above list was developed specifically for the groundfish complex, many of the same issues would apply as well to other fish complexes. Further, the need for habitat research extends beyond the relationship of fish and fishing activities to habitat. If, as suggested by the NRC and the USCOP, managers decide to take a close look at establishing marine protected areas as part of an ecosystem-based approach to resource management, such designations of sensitive areas will need to be based on sound science. Habitat research can help answer questions such as whether a particular habitat or area needs protection and the long-term consequences (i.e. biological, social and economic) of such protection. Habitat research on non-fishing impacts will be necessary also, especially near population centers where coastal development may occur.

Based on the above review of issues and concerns, and on topical areas identified in recent habitat proposals received by the Board, research needs generally fall into four major thematic areas: other human-related impacts on habitat, fishing effects, habitat mapping, and ecosystem functions of habitat. These are summarized in Table 3-3, with specific suggested research activities identified for each thematic area.

Research Needs

Table 3-3 General research needs for fish habitat.

Pressing Fishery Management Issues ↕ Marine Ecosystems Information Needs

Other Human-Related Impacts

- Contaminants impacts
- Coastal development and disturbance of habitat (e.g., on salmon spawning areas)

Fishing Effects

- Assess fishing gear impacts on EFH and its ability to support fish populations
- Assess vulnerability and resilience of habitat to fishing disturbances
- Compare natural versus fishing induced disturbance of habitat
- Assess recovery rates for various benthic substrates and related communities
- Disturbance/depletion of prey fields and competition for food resources
- Evaluate current closed areas with respect to their efficacy
- Assess management, biological and socioeconomic consequences of closed areas
- Determine disturbance rates and magnitude by repetitive fishing
- Gear research to lessen impacts on seafloor
- Recreational fishing effects on habitat (e.g., erosion, pollution, noise, etc.)

Habitat Mapping

- Develop mapping and classification technologies and software
- Document habitat complexity and sensitivity
- Identification of epifaunal communities
- Application of GIS mapping tools

Ecosystem Functions of Habitat

- Determination of ecological value of habitat types to fish and shellfish
- Assess role of benthic invertebrates such as deep corals and sponges
- Identification of potential refugia
- Assess vulnerability of habitat to natural disturbances
- Identify important nursery areas
- Link habitat to species population dynamics

Implementation Strategies

The above review of research needs will serve as the basis for development of the implementation plan and periodic NPRB requests for proposals related to habitat research. In developing its nearer term implementation plan for habitat, the Board will have the advantage of having approved the projects in 2002-2005 as shown in the table below (detailed project information by project number is available at http://www.nprb.org).

The Board likely will consider a mix of habitat-related research and activities over the next 2-4 years. Though undecided now, the primary focus may be on the Bering Sea, Aleutian Islands, and western Gulf of Alaska where major fisheries occur. A target amount may be set aside each year for two to three studies of fish-habitat relationships that promise to enhance understanding of how fish relate to habitat. The Board may fund comparisons of fished and unfished habitat to determine impacts and recovery and may support gear mitigation research. The Board may also support advances in technology that would enable efficient mapping and characterization of the seafloor, possibly hosting a synthesis meeting on new technologies as a starting point.

Current Projects

Project	Project Number
◆ Nearshore mapping in Togiak Bay	201
◆ Mapping deep sea coral distributions in Aleutians	304
◆ Evaluation of essential fish habitat for juvenile flatfish around Kodiak	301
◆ Essential fish habitat for Pribilof blue king crab	316, 507
◆ Investigations of a skate nursery in the southeast Bering Sea	415
◆ Ecological value of juvenile rockfish habitat	416
◆ Reproductive ecology of Atka mackerel and characterization of nesting habitat	417, 522
◆ Valuation of habitat closures	529

Fish & Invertebrates

Fish & Invertebrates Section Guide

Introduction

The vision of NPRB is to build a clear understanding of the North Pacific, Bering Sea, and Arctic Ocean ecosystems that enables effective management and sustainable use of marine resources. A major goal of the Board is to improve our ability to manage and protect the healthy, sustainable fish and wildlife populations that comprise the ecologically diverse marine ecosystems of the North Pacific, and provide long-term, sustainable benefits to local communities and the nation. This is a very large task, considering that the marine regions off Alaska support rich assemblages of fish and invertebrates, on which are based the largest fisheries in the U.S. These assemblages are extremely important not only economically, but also ecologically and socially. If fishing is the human activity that has the greatest impact on both targeted and non-targeted populations in the North Pacific, as the NRC (2004a) contends, resource managers must have available to them, not only knowledge about how the ecosystem functions, but a fundamental understanding of the distribution and population dynamics of the fish stocks themselves and how they are influenced by fishing and variability in their surrounding environment.

This section begins with an overview of the commercial fisheries and the major fish and invertebrate stocks of the three LMEs off Alaska as characterized in this plan. Next, current issues and concerns are identified, including overfished stocks and disaster declarations, and natural and human factors affecting fish populations. Research needs then are presented for six thematic areas: stock assessment and development; alternative harvesting strategies; socio-economic considerations; bycatch mitigation; causes of perturbations of major species; and implications of ecosystem change on fishery management. This is followed by discussion of general implementation strategies.

Good trend data for marine fish and invertebrates come from stock assessments and harvest statistics. Information summarized below, except as noted, is based on summaries provided by Kruse et al. (2001), NPFMC (2003a,b,c,d), Witherell et al. (2000a), and Witherell (2004). Forage fish data come largely from bycatch in surveys of commercial species and from a few directed studies. Forage fish trends were summarized by Boldt (2003). The Arctic is treated lightly here, because this region supports only minor commercial marine fisheries.

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Overview

Commercial Fisheries

As noted earlier, Alaskan commercial fisheries are an extremely important component of the U.S. fishing industry. In 2002, the domestic groundfish fishery alone off Alaska accounted for 49% of the weight and 18% of the exvessel value of total U.S. domestic landings. This domestic groundfish fishery off Alaska resulted in a catch of 2.1 million metric tons, an exvessel value of $566 million, and an economic value after primary processing of approximately $1.5 billion. In recent years, statewide fishery landings have been dominated by groundfish (81%), followed by salmon (15%), shellfish (2%) and herring (2%), (Figure 3-2a). On the other hand, owing to relatively lower prices paid for groundfish relative to some other seafood products, groundfish account for 50% of the total exvessel value (price paid to fishermen for landed catch), followed by salmon (28%), shellfish (21%), and herring (1%), (Figure 3-2b).

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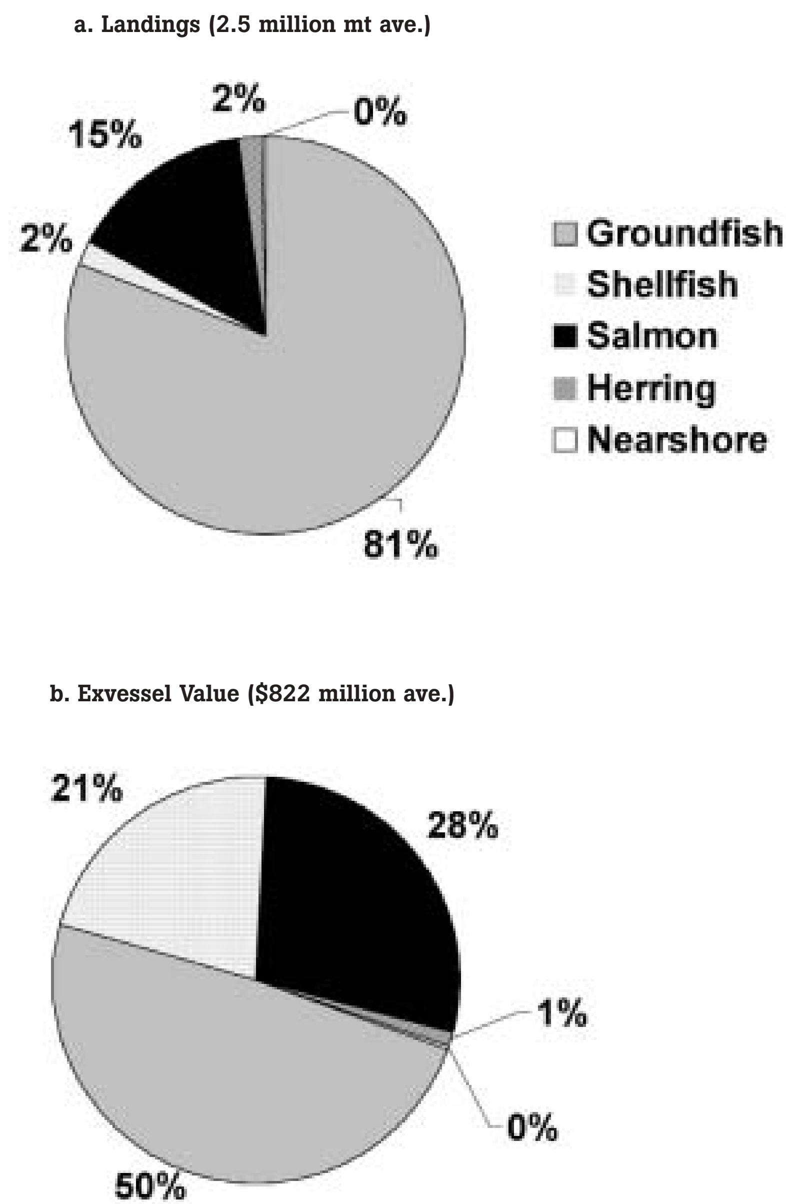
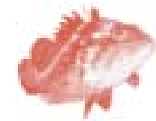
The relative importance of these groups to domestic fisheries off Alaska changed over time (Figure 3-3). Foreign fisheries (especially by Russia and Japan) accounted for roughly 1.5-2.0 million metric tons in annual landings during the mid-1970s to mid-1980s. Joint-venture fisheries, involving domestic harvesting and foreign processing, developed in the 1980s and served as a transition to domestic-only groundfish fisheries off Alaska in the 1990s. Major trends in domestic fisheries since 1975 include a large increase in landings due to increased biomass and conversion from foreign to domestic fisheries, declines in the landings and value of shellfish, and a decline in the value of salmon owing to depressed prices largely due to a worldwide glut of farm-reared salmon. Historical catches are not necessarily representative of total fish biomass. For instance, Bering Sea groundfish catches are constrained by a 2 million metric ton cap, even when high biomass would otherwise support even larger catches. Harvests of some individual species (e.g., flatfishes) are constrained by market demand or bycatch constraints rather than supply of resources.

Figure 3-2 Proportion of landings and exvessel value by major species group taken by commercial fisheries of Alaska in recent years. (From D. Witherell, North Pacific Fishery Management Council).





Gulf of Alaska

A high level of diversity exists among groundfish species in the Gulf of Alaska; this diversity peaks at depths of 200-300 m (Mueter 1999). Higher groundfish abundance and lower species diversity occur in the western GOA compared to the eastern GOA. Also, there are differences in species composition and fisheries among the eastern and western GOA. For instance, crab and shrimp stocks in Southeast Alaska tend to be more stable than those in the western GOA.

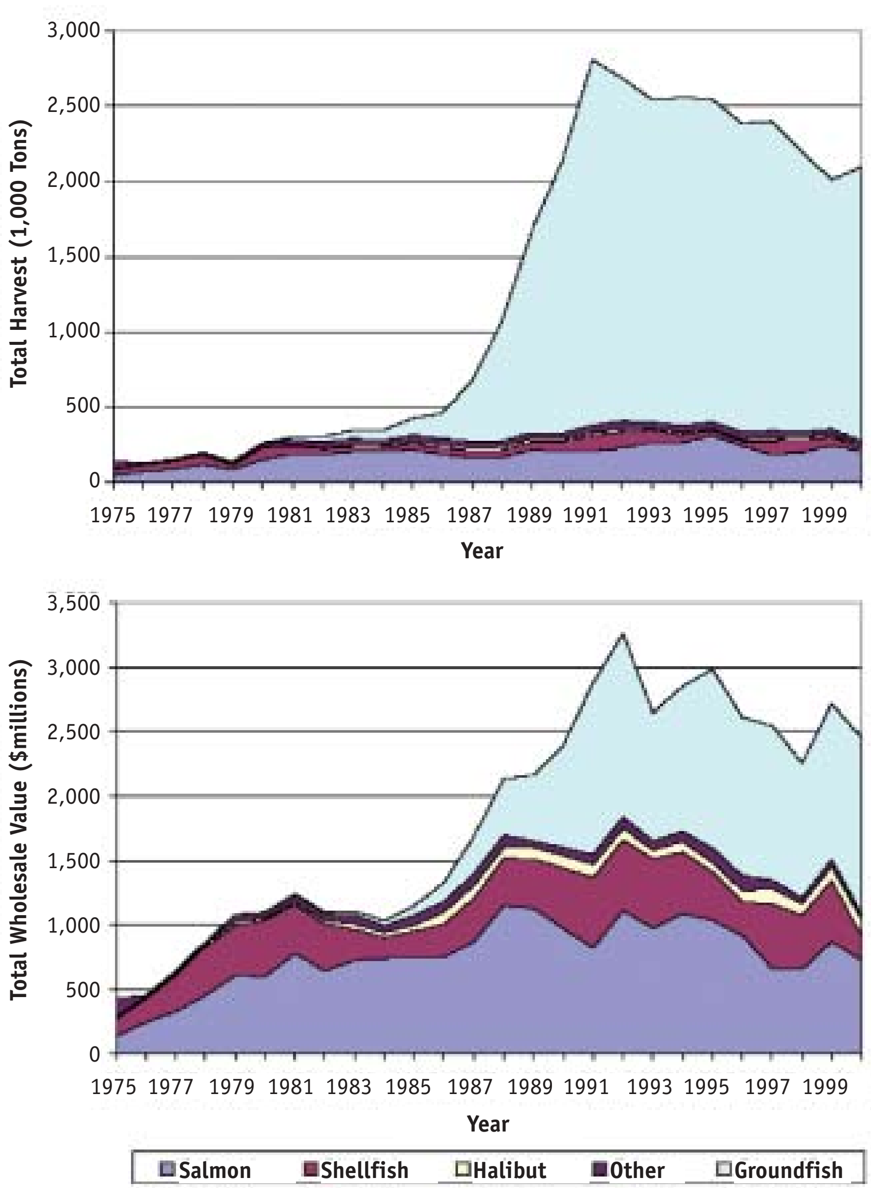
Commercially important groundfish species include walleye pollock, Pacific cod, sablefish, and a number of flatfish species, including Pacific halibut, arrowtooth flounder, flathead sole, rock sole, rex sole and Dover sole. The most diverse group is the rockfishes, which include about 30 species in two genera, *Sebastes* and *Sebastolobus*. Commercially important rockfishes include Pacific ocean perch, rougheye rockfish, shortraker rockfish, and black rockfish among others. Along the slope of the continental shelf, rattails and thornyhead rockfishes are important components of the groundfish community.

Biomasses of major species have fluctuated over the past four decades (Figure 3-4). Two of the most notable changes were a huge increase in flatfish, primarily attributable to arrowtooth flounder, and a large increase in pollock with a peak in the mid 1980s followed by a steady decline thereafter. Cod displayed a biomass trend somewhat similar to pollock, whereas sablefish have tended to oscillate. Pacific ocean perch have been slowly rebuilding from overfishing by foreign fleets in the 1960s and 1970s. Other ecologically important groundfish species include many species of sculpins.

Five Pacific salmon species are important in the GOA: pink (humpy), sockeye (red), chum (dog), coho (silver), and Chinook (king) salmon. Salmon spend part of their time in freshwater (spawning and rearing of fry) and saltwater (smolts, juveniles, and maturing adults). Other fish species common in the GOA include large predators, such as three shark species, and multiple forage species, such as herring, sand lance, and capelin. Fish distribution varies with location and seasonally. Many forage fishes and early life stages of salmon prevail over the continental shelf, whereas other species, including later stages of salmon, dominate in the open ocean waters of the GOA. Many forage species migrate nearshore for spawning in spring, whereas salmon return to natal rivers and streams in summer. Some predators, such as spiny dogfish, migrate nearshore in spring and summer to prey on salmon and other forage fishes available in high densities at this time of year.

There is a large number of important invertebrate species. Nearshore invertebrates include sea urchins and sea cucumbers. Nearshore areas contain high densities of mussels and clams, but fisheries for these mollusks are severely constrained by the potential of shellfish poisoning, paralytic of domoic acid caused by naturally occurring phytoplankton. Other commercially important species have distributions that may include both embayments and open ocean areas extending from the coast across the continental shelf. These include red king crabs, Tanner crabs, Dungeness crabs, northern shrimp and other shrimp species, and scallops. Corals, sponges, and many other invertebrates are found throughout the continental shelf and slope. A few commercially exploited invertebrates that live along the continental slope include golden king crabs, scarlet red king crab, and triangle and grooved Tanner crabs. Squid are likely to be abundant and important prey for salmon and other predators in the GOA over the continental shelf and offshore waters. However, little is known about their abundance and distribution.

Figure 3-3 Estimated total retained harvest (upper panel, 1,000s of metric tons) and wholesale value (millions of dollars) of domestic fisheries off Alaska waters during 1975–2000 (Northern Economics and EDAW, Inc. 2002). Foreign and joint-venture fisheries (not shown) dominated groundfish landings prior to 1988. For instance, foreign fisheries landed approximately 1.5 million mt in 1977.



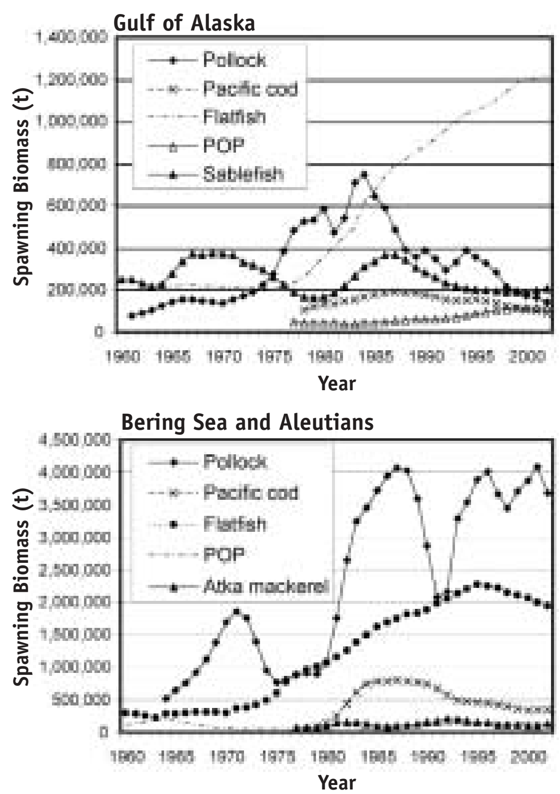
Bering Sea/Aleutian Islands

Despite containing about 300 species of fish and 150 species of crustaceans and mollusks, (Livingston and Tjelmeland 2000), the eastern Bering Sea has a lower diversity of commercially important fish species than the GOA. On the other hand, because the eastern Bering Sea has a broad, shallow continental shelf and the GOA has a narrow, deep shelf, the eastern Bering Sea supports much larger commercial fisheries, some of the largest in the world. Abundance of many commercially important species diminishes from south to north in the Bering Sea. The Bering Sea has some similarities to the GOA concerning commercially important groundfish, but also some notable differences. Perhaps the most striking difference is the predominance of pollock biomass in the Bering Sea (Figure 3-4). Also, unlike the GOA where arrowtooth flounder dominate the flatfish assemblage, flatfish biomass is more evenly distributed among yellowfin sole (25%), arrowtooth flounder (25%), rock sole (18%), Alaska plaice (13%), and flathead sole (13%) based on stock assessments for 2002. Flatfish have generally increased in the eastern Bering Sea since 1970, but not quite to the same magnitude as the increase in the GOA (Figure 3-4). Greenland halibut, one of the few flatfish that have a declining trend in abundance, tend to be more prevalent in the BSAI than GOA regions. The Bering Sea is important for halibut, but more as a juvenile rearing area as older halibut tend to re-enter the GOA and migrate against the Alaska Coastal Current as they return toward their parental spawning areas. Compared to the GOA, some BSAI species are somewhat less important, such as sablefish and some rockfishes (e.g., Pacific ocean perch and black rockfish). Atka mackerel are more abundant along the Aleutian Islands than in either the GOA or eastern Bering Sea, and there are some other apparent changes in fish fauna in the eastern versus western Aleutian Islands.

As in the GOA, salmon, forage fishes, sharks, sculpins, and other fishes are found along the shelf, but some notable differences exist among the GOA and BSAI areas. For instance, pink salmon are much more important in the GOA (particularly Prince William Sound and Southeast Alaska), whereas the Bristol Bay region supports the largest sockeye salmon runs in the State. Abundant herring spawn along the Bering Sea coast from Togiak (Bristol Bay) to Norton Sound, but herring are not so abundant in the Aleutian Islands.

There are some similarities and differences in the invertebrates among the BSAI and GOA. The eastern Bering Sea supported the largest crab fisheries in the state for red king crab and Tanner crab. Snow crab had supported the largest crab fishery in Alaska, and this species only occurs in the Bering Sea. Korean hair crab is another species confined to the Bering Sea. On the other hand, unlike the GOA, Dungeness crab specimens are rarely seen in the BSAI region. Many deepwater crab species extend throughout the GOA and BSAI regions. Surf clams are extremely abundant in the eastern Bering Sea, where they are a primary food source for walruses. Many species of erect epifauna occur in the BSAI region, and corals and sponges are found in high abundance throughout the Aleutian Islands.

Figure 3-4 Estimated female spawning biomass (metric tons) for major groundfish species in the Gulf of Alaska (GOA, upper panel) and eastern Bering Sea/Aleutian Islands (BS/AI, lower panel) during 1960 – 2002. Pacific ocean perch is denoted by POP. For the GOA, flatfish estimates are dominated by arrowtooth flounder, but also include flathead sole, whereas six species comprise the BS/AI flatfish estimates. Statewide biomass estimates for sablefish are plotted in the Gulf of Alaska, because most of the sablefish biomass resides in that region. For the GOA, Atka mackerel biomass is low but has not been assessed. Pollock and cod biomass from the Aleutian Islands are not included in the BS/AI estimates. Data were obtained from the 2002 SAFE reports and are available from http://www.afsc.noaa.gov/databases.htm.



Arctic Ocean (Chukchi/Beaufort Seas)

Information about the fish and invertebrates of the Arctic Ocean is very limited owing to few marine resource assessments and minimal commercial fisheries in the region. In fact, a standing issue for this LME is the need for comprehensive surveys to establish biological baselines against which to monitor future changes in response to climate change and development of human activities.

Most species of fishes (e.g., salmon, herring, Pacific cod, sablefish, halibut) and invertebrates (e.g., crabs, shrimps) that are economically important in the other two Alaska LMEs, occur in low abundance in the Arctic Ocean. Small amounts of groundfish were taken in commercial fisheries by the former Soviet Union from the Chukchi Sea during the 1960s to early 1980s and from the Beaufort Sea during the late 1960s. Annual landings averaged <20 mt and never exceeded 110 mt in the Chukchi Sea (including both U.S. and former U.S.S.R. waters, and catches from the Beaufort Sea (including U.S. and Canadian waters) peaked at 254 mt in 1968. Catches from the Chukchi Sea were comprised mainly of walleye pollock and Greenland turbot, whereas catches from the Beaufort Sea were Greenland turbot only. (see catch information for specific LMEs at at: http://saup.fisheries.ubc.ca/lme/lme.aspx).

There are about 17 marine species of fish in the nearshore coastal waters, of which three species, arctic cod, fourhorn sculpin, and arctic flounder, comprise 86 percent of all marine fish collected in studies during open water seasons since 1981 (BP Exploration, 2001). In addition, there are other species that spend most of their lives in freshwater, but also venture into nearshore coastal waters to feed. These include arctic, Bering and least ciscos, broad and humpback whitefish, Dolly Varden char, rainbow smelt, and two species of sticklebacks (Moulton and George 2000). The short arctic summer is a period of intense biological activity in coastal waters and the nearshore zone is invaded by marine invertebrates that thrive in the warm detritus-laden shallow. These invertebrates include mysids and amphipods that serve as principal prey for many of these fishes that disperse out from their overwintering rivers (Gallaway and Fechhelm 2000).

Some species are the basis for important subsistence and commercial fisheries. For example, arctic cisco, abundant in coastal waters of the Beaufort Sea, is the principal species harvested in the fall subsistence and commercial fisheries in the Colville River delta west of the Prudhoe Bay oilfields. Because of its importance, it has been designated as one of four key indicator species for monitoring impacts of oilfield activities on coastal fish populations (BP Exploration 2001). Another indicator species is least cisco which spends nine months of the year overwintering beneath the ice in North Slope rivers and then disperses into coastal waters during summer to feed. It also is a principal species harvested in fall subsistence and commercial fisheries (BP Exploration 2001).

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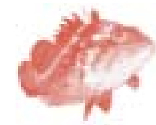


Issues and Concerns

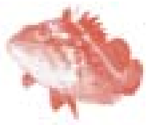
Overfished Stocks and Disaster Declarations

Some of the most pressing issues concerning fish and invertebrates involve stocks and fisheries suffering recent declines and resulting in special state and federal designations. NMFS prepares annual reports to Congress in which they report on the status of fisheries within regional council authority (i.e., under a federal fishery management plan) and identify those which are overfished or approaching the overfished condition. The overfished condition corresponds to a stock size that is estimated to be below a prescribed biomass threshold. A fishery is determined to be approaching an overfished condition if it is estimated to become overfished within two years based on trends in harvesting effort, fishery resource size, and other appropriate factors. It is important to note that these designations do not ascribe cause; that is, they do not distinguish stocks that declined due to natural factors from those that resulted from human causes.

During the most recent year (2003), only two commercially fished stocks were listed as overfished in the Alaska region: eastern Bering Sea snow crabs and Pribilof Islands blue king crabs (NMFS 2004a). These are new determinations. In the assessment for 2002, Pribilof Islands blue king crabs were determined to be approaching an overfished condition, and snow crabs were determined to be rebuilding. In 2002, NMFS determined that Saint Matthew Island blue king crabs and Bering Sea Tanner crabs were overfished, but both of these stocks were determined to be rebuilding in 2003. So, in the past two years, four major Bering Sea crab stocks were listed as overfished. Many king and Tanner crab stocks in the GOA have undergone similar or even more severe declines since the 1980s. However, because there is no federal fishery management plan for GOA crabs, NMFS does not consider the condition of these stocks in their annual report to Congress.

Although most salmon runs in Alaska are abundant, notable exceptions include Western Alaska Chinook and chum salmon runs that have declined markedly over the past two decades. In the late 1990s and early 2000s, extremely poor returns of salmon to the Yukon River, Kuskokwim River, and rivers draining into Norton Sound, led to severe restrictions on commercial and subsistence fisheries. Although NMFS has not designated these salmon runs as overfished, severe declines led to several disaster declarations by state and federal governments in recent years, which can be made for economic as well as biological reasons. For example, on July 30, 1998, under the authority of Alaska Statute 26.23.020, the governor of Alaska declared that a disaster existed in certain communities and regions of Western Alaska due to catastrophically low salmon returns. A second disaster declaration was made in September 1998, for the communities of Stebbins, St. Michael, Minto, Manley Hot Springs, False Pass, Nelson Lagoon, and Tyonek, due to low salmon returns. In addition, declines in Kvichak River sockeye salmon led the Alaska Board of Fisheries to designate this salmon run as a stock of yield concern in 2001 and stock of management concern in 2003. Such poor salmon runs, combined with poor prices, create many hardships for the people and communities, not only due to economic losses, but also due to hardships on their subsistence ways of life.

Some other species have undergone similar severe declines, but “overfished” determinations have not been rendered by NMFS, because these species are not managed under the auspices of federal fishery management plans. These stocks include king and Tanner crabs and shrimps (in most areas in GOA), herring (Prince William Sound, lower Cook Inlet, and Kodiak), abalone (Southeast Alaska), and Dungeness crabs (Yakutat, Prince William Sound, lower Cook Inlet). Issues surrounding these declines include development of rebuilding plans and future sustainable harvest strategies, severe economic impacts by affected users, problems of overcapitalization, and loss of subsistence lifestyles and associated effects on non-market economies and social issues in resource-dependent coastal communities.



Role of Forage Fish

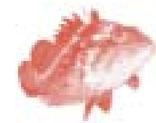
Many species of fish and larger invertebrates have planktonic early life stages (eggs and larvae), which depend on phytoplankton and zooplankton for their early life survival and which also serve as important prey for planktivorous species of fish, invertebrates, birds and mammals. Juveniles (e.g., pollock, Tanner crabs) and adults (e.g., herring, squid) of some species also serve as important forage for higher trophic levels. Unfortunately, little knowledge exists about the biology, life history, and distribution of most of the important pelagic (e.g., eulachon, squid, lanternfish) and benthic forage species (e.g., polychaetes worms, clams, amphipods) that support the bulk of Alaskan marine ecosystems. Fluctuations in their abundance are not routinely monitored, thus preventing an ability to understand the impacts of changes in their abundance and distribution on the upper trophic levels.

Natural Factors Affecting Fish Populations

Many issues and concerns for fish and invertebrates involve the difficulty of distinguishing changes in stock status owing to natural causes from those caused by humans. If species declines are attributable to human factors, such as overfishing or habitat destruction, corrective action should be taken. Although fishery managers have no control over environmental conditions, an understanding of natural causes of variability in fish stocks would assist managers developing better fishery management plans that account for these fluctuations. Other issues concern increases of species such as sharks, rays, and flatfishes, including arrowtooth flounders, all of which are important predators. These species have been subject to either relatively low or no harvest, so the primary issue here concerns the effects of increased predator abundance on other parts of the marine ecosystem and their future consequences to fishery sustainability and management.

For most marine fish and invertebrates, year-class success is thought to be determined in early life by environmental factors. Many studies have suggested general associations between climate and fish production in the North Pacific Ocean. Regime shifts between periods of weak and intense Aleutian Lows in winter have been linked to periods of low and high salmon catches (e.g., Beamish and Bouillon 1993; Mantua et al. 1997) and increased frequency of strong recruitment in groundfish stocks (Hollowed and Wooster 1992, 1995) and other species (Beamish and Bouillon 1995). Northern shrimp appeared to decline in response to warmer temperatures and in response to increased abundance of groundfish predators in association with the regime shift of the late 1970s (Anderson and Piatt 1999). Likewise, productivity of some crab stocks appears to be inversely related to changes in groundfish and salmon, yet others demonstrate divergent trends (Zheng and Kruse 2000).

Despite the existence of general patterns in fish production and climate, there are many stock-specific differences, and reliable predictions of recruitment strength remain elusive for most species. Yet, prediction remains one of the goals of annual stock assessments. Failure to understand and predict recruitment variations has adverse consequences on the annual harvest specification process that considers current stock status and the near term recruitment outlook in the setting of annual harvest specifications. Hypothesized causes for variability in year-class success usually involve changes in food availability, predation, and advection during early life stages. In the case of pollock, FOCI studies in the Gulf of Alaska indicate that coastal runoff from precipitation fosters instabilities (e.g., eddies) in the boundary between coastal waters and the Alaska Coastal Current. These instabilities enhance larval retention and feeding success, thus enhancing survival and leading to the formation of strong year classes. Recruitment mechanisms for pollock in the eastern Bering Sea appear to involve advection of young away from cannibalistic adults (Wespestad et al. 2000), but, even for pollock, development of reliable predictions remain elusive (NPFMC 2003a). Likewise, advection appears to be important to winter spawning flatfish in the eastern Bering Sea; periods of cross-shelf advection during early life are associated with higher then average recruitment (Wilderbuer et al. 2002). Progress on understanding recruitment of invertebrates (e.g., crabs and shrimps) and other groundfish remains largely speculative. Statistical relationships between environment and recruitment have been developed for only one crab stock (Rosenkranz et al. 2001).



Human Factors Affecting Fish Populations

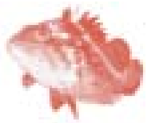
Exploitation of fish resources usually leads to a number of common effects. Even unfished populations fluctuate owing to natural changes in recruitment, growth and mortality. The addition of fishing to natural systems leads to increases in mortality, thereby reducing standing stock biomass and shifting the age and size composition to younger ages and smaller sizes. Contemporary fishery management practices strive to set harvest rates at levels that do not compromise stock productivity, and it is generally agreed that fishery management practices in Alaska are conservative. Nonetheless, the potential adverse effects of loss of old ages from fish populations and the potential additional effects of fishing on genetic diversity, reproductive behavior and fish habitat are topics of ongoing research.

Despite the current conservative fishery management approaches that prevail in Alaska, there were historical periods when overfishing occurred. Generally recognized instances of overfishing included: (1) salmon in the 1920s-1950s when fish traps were used to catch salmon, (2) herring in the early to mid 1900s, when a large domestic reduction fishery sequentially depleted herring from Southeast Alaska to the central and western Gulf of Alaska, (3) yellowfin sole, which were overfished by foreign trawl fisheries in the 1960s in the eastern Bering Sea, and (4) Pacific ocean perch that were depleted by foreign trawl fisheries in the 1960s and 1970s.

Regarding salmon, debate exists about the effects of hatchery programs on wild stocks, (e.g., Hilborn 1992; Smoker and Linley 1997). Much of the debate focuses on pink salmon. Concerns include genetic effects associated with co-mingling of hatchery and wild salmon in spawning streams, harvest rates that might disproportionately affect weaker wild stocks, and overall stress on the carrying capacity of the marine ecosystem Other concerns have been expressed about the potential effects of escaped Atlantic salmon from salmon farms in British Columbia (Gaudet 2002). These concerns include disease, colonization, interbreeding, competition, and predation.

Finally, an emerging issue concerns the growing public interest in ecosystem-based fishery management. Some of the concerns here involve potential fishing effects on seafloor habitats (e.g., EFH and HAPC) and associated benthic species composition and productivity. These concerns are greatest in the GOA and BSAI regions, particularly in areas of attached epifauna that provide structural habitat. Other ecosystem concerns involve the perceived need to move toward approaches that set harvest guidelines based on considerations of the interactions among the targeted species, the fishery, and other components of the marine ecosystem. Concerns for other ecosystem components goes beyond bycatch, because bycatch is already rather well estimated in Alaska, at least for groundfish, scallop and crab fisheries with onboard observer programs operated by federal and state agencies. Rather, the concern for other species involves the potential direct or indirect effects of fishery removals of one species on its prey, predators, and competitors in the marine ecosystem.

At least three obstacles have prevented development of full-blown ecosystem-based management plans. First, such approaches require a high level of understanding about complex ecosystem interactions; such an understanding does not currently exist. Second, complex ecosystem models must be developed to accurately estimate and predict effects of alternative management scenarios so that alternatives can be selected that best meet management objectives. Existing mass-balance models make use of available information, but they rely very heavily on assumptions and therefore they are not yet reliable to provide explicit management advice. Third, ecosystem-based management requires prescription of a new set of management objectives and harvest control rules that have yet to be articulated, much less fully specified for management. Despite these obstacles to developing fully integrated ecosystem-based management plans, Alaska has been leading the way in applying ecosystem considerations to fisheries management (Witherell et al. 2000b). Such considerations resulted in management measures, such as bycatch caps and gear modifications to reduce bycatch, area closures to minimize habitat disturbance and reduce potential for competition between fisheries and marine mammals, prohibition of fisheries for forage fishes, and a number of other management measures that address other ecosystem concerns.



Research Needs

There are many research needs for fish and invertebrates, spanning the full range of the Board's legislative mandate from pressing fishery management issues to marine ecosystem needs. Because fisheries extract living marine resources, understanding the effects of humans on the ecosystem is particularly important. Therefore, research needs for fish and invertebrates tend to be weighted more toward pressing fishery management issues. However, just as natural forces cause fluctuations of fishery resources, it is also important to consider the consequences of natural changes on how fisheries should be managed.

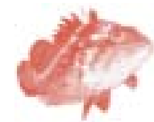
Identification of research needs on fish and invertebrates was motivated by several recent planning documents. First, the GOA and BSAI groundfish plan teams of the NPFMC developed a list of research needs that were prioritized by the NPFMC's Scientific and Statistical Committee in their April 2003 meeting minutes (see: http://www.fakr.noaa.gov/npfmc/minutes/ssc903.pdf). Second, research themes and approaches were identified in the Draft Bering Sea Ecosystem Research Plan (BSERP 1998). Third, information gaps and research needs were identified in the recent Alaska Groundfish Fisheries Final Programmatic Environmental Impact Statement (NMFS 2004b). Fourth, research approaches were outlined in the development of the Environmental Impact Statement for considerations of essential fish habitat (NMFS 2004c). Finally, several pressing research needs became apparent in the 2000 Biological Opinion in which NMFS considered the potential for groundfish fisheries to jeopardize the existence of Steller sea lions and to adversely modify their critical habitats (NMFS 2000). After considering these reviews, the North Pacific Research Board developed its own set of research needs for fish and invertebrates, discussed below, and summarized in Table 3-4. The list is not intended to be exhaustive, but instead attempts to identify some of the highest priority areas of research.

Stock Assessment Research and Development

Research and development of new stock assessment techniques and methods are needed. Whereas routine stock assessment surveys of exploited fish and invertebrates fall within the purview of state and federal management agencies, technical obstacles prohibit routine assessments for some species complexes. For instance, new methods or techniques are needed to assess the abundance and distribution of forage fish, rockfishes in untrawlable rocky habitats, and Greenland turbot in deep waters beyond the continental shelf. Also, it should be noted that even for well known species, many assumptions, sometimes very tenuous, are made in determining population status and trends. For example, routine stock assessments are questioned for some species owing to significant uncertainties about gear selectivity and catchability. These include selectivity curves for Pacific cod that imply a larger biomass of old/large fish than observed, catchability of snow and Tanner crabs in deep waters that may indicate larger abundances than currently estimated, and potential for herding of rockfish into survey trawl nets or capture of rockfish during gear deployment and/or retrieval, perhaps inflating abundance estimates. In effect, more information is needed on all species, not just little known ones.

Alternative Harvest Strategies

Future research may be needed on alternative harvest strategies. Many groundfish fisheries in Alaska are managed with spawning stock biomass per recruit (SSB/R) strategies, typically one based on F40%, the fishing mortality rate that reduces SSB/R to 40% of the unfished level. Further consideration needs to be given to whether F40% is appropriate for all species, including rockfishes, which have extreme longevity and other life history features that render them very vulnerable to overfishing (Goodman et al. 2002). Additionally, there are alternative strategies, used either instead of or in combination with SSB/R strategies, that account for other stock features, such as implications of truncated age and size distributions, potential for genetic selection and loss of genetic variability, effects of fishing on spawning schools and reproductive success, and effects of spatially and temporally disproportionate distributions of harvest, such as impacts of nearshore depletion on specific species (e.g., halibut) due to high recreational and/or commercial fishing effort.



Socio-economic Considerations

Fuller attention should be given to social and economic studies related to fisheries management. To perform meaningful analyses of the effects of fishery management measures on communities and on the individual and collective economics of fishing fleets, some way has to be found to develop time-series and cross-sectional databases on the fixed and variable costs of fishing. Notably, as a part of the crab rationalization program now being implemented, the industry agreed to make cost data available for purposes of assessing the "fairness" of the negotiated grounds price for crab. Other critical information would include the impact of rising cost of fuel or effect of a rationalized fishery on demand for supplies and services. Recent analyses of alternatives for essential fish habitat and habitats of particular concern have highlighted the difficulty of placing a meaningful value on fish habitats that can be compared to usual economic indices, such as exvessel and wholesale values and personal income. Therefore, estimation of aesthetic and non-market valuations of ecosystems is an area of needed research. Finally, whereas various federal laws require significant assessment of impacts of changes in management measures, there is seldom a conscious effort to develop baselines for conditions prior to implementation. Also, follow-up studies are needed to estimate the impacts of major regulatory decisions once they are implemented. For example, studies on the implementation of sablefish and halibut individual fishing quota (IFQ) programs would be highly valuable in consideration of potential future IFQ programs.

Reducing Catch of Unwanted Species

There are continuing needs to improve mitigation measures designed to reduce catch of unwanted species, or perhaps certain age groups of targeted species. Incidental catch of endangered (e.g., short-tailed albatross) or bycatch of prohibited species (e.g., red king crab, Pacific herring, Chinook and chum salmon) can lead to curtailment of fisheries and elevate concerns for the effects of fishing on other living resources. At a minimum, incidental catch of undesirable species can lead to increased costs of fishing operations. Priorities for research should include mitigation of seabird and marine mammal interactions with fisheries, new technologies and methods to reduce bycatch, and studies of survival rates of discarded fish to allow accurate estimation of total fishing mortality.

Causes of Perturbations of Major Species

There are many ecosystem research needs, but investigations into the causes of perturbations of some major species are among the highest priorities. Understanding the role of natural and human causes on species declines (e.g., crab, shrimp, western Alaskan salmon, Greenland turbot, and halibut in IPHC Area 4C) and increases (e.g., arrowtooth flounder, other flatfish, sharks, skates) is important to developing management strategies that reflect their causes. Some species are particularly important owing to their high economic value (e.g., crab and shrimp), others for their cultural significance and local value (e.g., western Alaska salmon), and others for their perceived roles in restructuring the ecosystem (e.g., arrowtooth flounder, sharks). Much work has been done on recruitment and growth as affected by climate variability for groundfish and salmon, but relatively little attention has been paid in this regard to crab stocks. Yet the high value of crab makes it a worthy candidate for studies to better understand fishery management and environmental processes and their effects on crab stock abundance. Salmon are another species of special interest, particularly concerning their ocean migrations and intermingling of stocks on the high seas, effects of fisheries and environmental conditions on ocean survival, and the issue of overall ocean rearing capacity which is being stressed by increasing releases of young salmon from hatcheries around the Pacific Rim. High-seas capture of salmon bound for Alaskan watersheds also remains an area of continuing concern.

Implications of Ecosystem Change on Fishery Management

As with all other LME components, there are many research needs to investigate implications of ecosystem change on fishery management. Effects of fishing on fish habitats and fish productivity are poorly known for Alaska. There is a long history of research on these topics in other regions, such as the North Atlantic, and some studies have been conducted in Alaska in recent years, primarily by NMFS. Research needs for fish habitat were covered more thoroughly in the previous section on habitat.

Although harvest rates are set at levels estimated to be sustainable, removals are not evenly distributed within fish populations and the potential exists for competition between fisheries and other species for resources. To answer questions about competition, it is insufficient to know that a seabird or marine mammal eats the same species that is captured by a fishery. Rather, competition requires the use of the same resources that are in limited supply; resource limitation is rarely studied, so the existence of competition is almost always speculative.

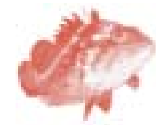
Likewise, although harvest rates may be sustainable for single species, it is unclear what effects there may be on the ecosystem by harvesting some species and not others. One emerging challenge to fisheries management involves concerns that fishing has significant impacts on biodiversity at the complex, species, stock, and genetic levels. Another challenge at the complex level is the issue of "fishing down" food webs (Pauley et al. 1998). In the North Pacific, it appears that trophic levels in the food web are being maintained largely because of the dominance of pollock in the ecosystem (Boldt 2003).

In moving toward ecosystem-based fishery management, there is much discussion about identifying ecosystem indicators to assist in monitoring trends in the ecosystem. Shrimp have been proposed as one such indicator (Anderson and Piatt 1999), however, the entire topic of ecosystem indicators deserves considerable attention and was discussed in more detail in Chapter 2.

Most assessments of the potential role of climate on regime shifts consider statistical relationships between various climate indices (e.g., PDO, Aleutian Low Pressure Index) and time series of fish catches and recruitment. Although speculations about cause and effect have been offered, explicit mechanistic linkages between climate conditions and fish survival and growth remain largely uncertain. Most published correlations between fish and climate ultimately fail, because the true mechanisms have not been uncovered. Research into these processes would deepen our understanding of ecosystem function.

Regardless of causation, the implications of regime shifts require additional research, as well. For instance, forage fish abundance and distribution may have shifted in the late 1970s and perhaps more recently. Forage fish are an important component of the North Pacific ecosystem yet relatively little is known about forage fish species such as capelin, eulachon, and sand lance. Some progress has been made to understand the effects of changes in local availability of forage fish to some seabird colonies (e.g., Litzow et al. 2002), but ecosystem-wide implications of forage fish changes on other ecosystem components remain speculative. Likewise, the effects of large fluctuations of other species (e.g., crab, shrimp, flatfish, and sharks) on other ecosystem components through competition and predation are poorly known.

Ideally, development of new multispecies fishery management strategies should consider the full range of implications of ecosystem changes on fishery management. In such a new paradigm, the acceptable biological catch for a particular species would not be determined solely by that species biomass, but other considerations would be taken into account, as well, to determine an optimal harvest of a mix of species from the ecosystem. Although fisheries in the GOA and BSAI areas are managed very progressively under a suite of ecosystem considerations (Witherell et al. 2000b), development of a more integrated, formalized approach is likely to be more effective.



Research Needs

Table 3-4 General research needs for fish and invertebrates.

Pressing Fishery Management Issues ↕ Marine Ecosystems Information Needs

Stock Assessment Research and Development

- New methods to assess difficult species (e.g., forage fish, rockfish in untrawlable habitat, Greenland turbot in deep water)
- Catchability/selectivity studies for questioned assessments (e.g., Pacific cod, snow and Tanner crab, some rockfish)
- Incorporation of ecosystem indices in stock assessments
- Spatially explicit stock assessments

Alternative Harvest Strategies

- Effects of fishing on spawning aggregations and reproductive success
- Effects of truncated age/size distributions on stock productivity
- Potential for genetic selection and/or loss of genetic variation by fishing
- Effects of spatial-temporal disproportionate harvest rates on stock dynamics
- Applicability of spawning stock biomass per recruit harvest strategies

Socio-economic Considerations

- Estimates of fixed and variable costs of fishing
- Estimation of aesthetic and non-market valuation of ecosystems
- Socio-economic baselines for regulatory analyses and performance evaluations

Reducing Catch of Unwanted Species

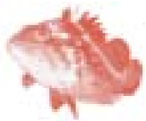
- Mitigation of seabird and marine mammal interactions with fisheries
- New technologies/methods to monitor and reduce catch of unwanted species
- Survival studies of discards

Causes of Perturbations of Major Species

- Role of natural and human impacts on species declines (e.g., crab, shrimp, western Alaskan salmon, Greenland turbot)
- Role of natural and human impacts on species increases (e.g., arrowtooth flounder, other flatfish, sharks, skates)
- Migration, inter-mingling, carrying capacity, and ocean survival of anadromous salmonids
- Increased releases of Asian salmon, that may rear in U.S. waters and may impact Western Alaska salmon survival and production

Implications of Ecosystem Change on Fishery Management

- Effect of habitat disturbance on fish populations
- Effects of disproportionate species removals on ecosystem function
- Potential for fisheries competition with fish, bird and mammal predators
- Biodiversity and implications for fisheries management
- Develop indicators of ecosystem conditions
- Mechanisms for climate-induced regime shifts of fish/invertebrate communities
- Role of pelagic and benthic forage species on upper trophic dynamics
- Ecosystem effects of large fluctuations in abundance and/or distribution of managed species (e.g., flatfish, crab, shrimp, sharks)
- Ramifications of large fluctuations in other ecosystem components (e.g., jellyfish, coccolithophores)



Implementation Strategies

In developing its nearer term implementation plan for fish and invertebrates, the Board will have the advantage of having approved funding for the projects listed in the table below for 2002-2005 (detailed project information by project number is available at http://www.nprb.org).

Current Projects

Project	Project Number
Genetic stock identification of western Alaska sockeye	205
Run-timing analysis for Bristol Bay sockeye	317
Evaluation of alternative reasons for collapse of Kvichak sockeye runs	321
Early ecology of chums in Kuskokwim Bay	327
Survival of Copper River delta sockeye and coho juveniles	310
Open ocean salmon stock structure and tagging in the Bering Sea	204, 303
Environmental spawning cues for herring at Togiak	208
Rougheye rockfish genetics in northern Gulf of Alaska	209
Forage fish assessments in Bering Sea and Aleutians	401
Reproductive ecology of Atka mackerel	417, 522
Ecology of spiny dogfish off Alaska	418, 511
Genetics of juvenile Pacific ocean perch	420, 512
Development of a crab supply and demand economics model	423
Social studies of fishing communities	318
Development of technologies to reduce salmon bycatch in trawls	202
Video monitoring on Bering Sea at-sea processors	325
Causes of bitter crab disease	306
Cultivation of blue king crab larvae	316,507
Health of Pacific herring	319
Thermal habitat preference for Pribilof halibut	314
Modeling of multispecies groundfish interactions	419
Predator-prey relationships for groundfish and forage fish	305
Forage fish studies near Kodiak	308
Estimating movement of eastern Bering Sea pollock	505
Evaluating pollock tagging mortality using a trawl net	506
Female reproductive output of snow crab in eastern Bering Sea	508
Retrospective analysis of Kodiak red king crabs	509
Age and growth determination of Alaskan skates	510
Pollock recruitment and stock structure in Gulf of Alaska	523

Concerning further research on anadromous fish stocks, the Board may seek partnerships with other salmon research initiatives such as the AYKSSI (NRC 2004b), which is developing its own science plan. The salmon resources of the Bristol Bay region are of critical importance and the Board also is supporting an analysis of how and where salmon research funds are being spent. This will give the Board a better idea of the gaps in salmon research that need to be addressed. The Board also will have a better understanding of which hypotheses for the collapse of Kvichak River sockeye runs need to be examined once the current series of NPRB-supported workshops is completed. The Board may also continue to support open ocean salmon research, such as conducted by NPAFC and the BASIS program. Other regional salmon stocks may be included in a call for salmon research that periodically goes out with the request for proposals generated by the Board, possibly placing an annual funding target and time limit of up to two years for a single project.

Concerning groundfish and crab commercial species, the Board will work with the NPFMC, NMFS, and the ADFG to develop research needs and priorities annually. Projects may be limited to 1-2 years duration so that information is made available more rapidly. For other species, the Board will periodically call for proposals, including for halibut, herring, forage fish, and invertebrates other than crab. The Board will strive to develop partnerships in this research with agencies directly responsible for resource management.

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Marine Mammals

Marine Mammals Section Guide

Introduction

Marine mammal concerns were raised at most NRC regional site visits (NRC 2004a). In areas with significant overlap of marine mammal populations and commercial fisheries, such as Kodiak, concerns centered on fisheries interactions and economic impacts of measures designed to protect marine mammals. In Barrow, concerns were raised over sustainability of marine mammals such as bowhead whales used for subsistence. Killer whale predation on marine mammals was identified as an issue at several site visits. The NRC committee observed that predation by such top-level carnivores can have cascading effects through an ecosystem, and that those impacts may be playing out in the Bering Sea with changes in Steller sea lion, harbor seal, and sea otter populations. The committee recommended that NPRB support fundamental research on the structure and function of ecosystems, and encourage proposals on roles and trends of important noncommercial species, such as prey species, indicator species, and keystone species.

The USCOP (2004) observed that while more is known about marine mammals today than ten years ago, little is understood about life history or physiology of most marine mammal species. Further, because the decline of such populations tends to be caused by multiple environmental factors, enhanced research is necessary on a range of subjects to find ways to reduce the harmful effects of human activities and to implement effective ecosystem-based management plans. Specifically for Steller sea lions, the commission noted that the continued decline of some populations highlights the importance of moving toward an ecosystem-based management approach, where such factors as predators, quality and quantity of food, essential habitat, and incidental catch are all weighed when deciding how best to protect a species.

The North Pacific Research Board will consider developing a research program for marine mammals that should help provide a sound scientific basis for resource management decisions in the North Pacific. The research should be particularly useful to the two federal agencies responsible for protecting marine mammals off Alaska: NMFS for cetaceans and pinnipeds, except walrus; USFWS for walrus, sea otters, and polar bears. Following this introduction is an overview of marine mammal populations off Alaska. Next is a description of current issues and concerns about marine mammals and population declines, followed by a listing of research needs for six thematic areas: long-term climate change, population dynamics, foraging success, marine habitat use, fisheries interactions, and other human-related impacts. General implementation strategies then are presented.

Except as noted, the following discussion is excerpted and/or summarized mainly from two comprehensive reports: the ecosystems considerations chapter of the 2004 Stock Assessment and Fishery Evaluation report (Boldt 2003) and the Alaska Marine Mammal Stock Assessments for 2002 (Angliss and Lodge 2002).

Overview

Alaska marine regions support a rich assemblage of twenty-six species of marine mammals from the orders Pinnipedia (seals, sea lion, and walrus), Cetacea (whales, dolphins, and porpoises), and Carnivora (sea otters and polar bears). Most species are present throughout the year, while others seasonally migrate into or out of the regions. They occupy diverse habitats from nearshore to continental shelf to deep oceanic waters off the continental slope, some year-round and others seasonally on feeding migrations. Several species are distinctly Arctic and closely associated with ice cover, including the ice seals (bearded, spotted, ringed and ribbon), beluga and bowhead whales, and polar bears. Beluga whales are not entirely Arctic, of course, and range south and east all the way to Cook Inlet and even the ice seals are found at times in the Bering Sea. Several other marine mammals may be found at various times of the year in the Arctic, but also range across the Bering Sea and Gulf of Alaska, and even further south throughout the North Pacific. For example, gray, fin, and minke whales migrate north into the Arctic Ocean but also frequent the Gulf of Alaska and Bering Sea and Aleutians.

Table 3-5 compares approximate population numbers off Alaska, recognizing that some estimates apply to broader areas. Northern fur seals, a very wide-ranging species, appear to be the most abundant marine mammal off Alaska, followed by walrus and then Dall’s porpoise and harbor seals. Many of these species range throughout the North Pacific and population abundance estimates often are for the larger range.

Recent summer surveys in the central and southern eastern Bering Sea in 1999-2000 have provided the first estimates of cetacean abundance and distribution for direct comparison between those regions (Moore et al. 2002). Until recently, cetacean abundance and distribution information in the Bering Sea largely depended on commercial whaling data (Springer et al. 1996) and high seas driftnet fishery incidental take records (Hobbs and Jones 1993). Direct takes from the North Pacific Ocean and Bering Sea were devastatingly large (Miyashita et al. 1995), especially during 1835-1850 for North Pacific right whales (Webb 1988), during 1965-1979 for fin and humpback whales (Wada 1981), and during the 1980s for Dall's porpoise and pelagic dolphins (Hobbs and Jones 1993). The indirect effects of these removals on the marine ecosystem are largely unknown (Moore et al. 2002).

Table 3-5 Approximate population size for selected marine mammal species in Alaska. (After Angliss and Lodge 2002).

Species	Approximate Numbers	Region
Northern fur seals	942,000	E. Pacific-Alaska
Walrus	>200,000	Alaska
Dall’s porpoise	83,000	Alaska
Harbor seals	80,000	Alaska
Sea otters	71,000	Alaska
Steller sea lions	66,000	Alaska
Beluga whales	63,000	Alaska
Harbor porpoise	43,000	Alaska
Pac. white-sided dolphin	27,000	C. N. Pacific-Alaska
Gray whales	27,000	E. N. Pacific-Alaska
Bowhead whales	8,000	Alaska
Humpback whales	4,000	W. C. North Pacific
Polar bears	>2,000	Alaska
Killer whales	1,000	British Col. - Alaska

Fin whales occur in greater numbers in the central eastern Bering Sea, while harbor porpoises are more common in the southeastern Bering Sea. Minke whale and Dall’s porpoise populations are similar in both areas. Overall, fin whales and Dall’s porpoise are the most common large and small cetaceans, respectively, in both regions. There are an estimated 3,368 fin whales, 810 minke whales, 14,312 Dall’s porpoise, and 693 harbor porpoise in the central eastern Bering Sea alone; and another 683 fin whales, 102 humpback whales, 1,003 minke whales, 9,807 Dall’s porpoise, and 1,958 harbor porpoise in the southeastern Bering Sea (Moore et al. 2002).

Distributions of some species are associated with bathymetric features of the continental shelf (Moore et al. 2002). Humpback whales were seen on the middle shelf, near the 50-m contour where the inner front often develops. In the central eastern Bering Sea fin whales occurred primarily on the outer shelf along the 200 m isobath, compared to the southeastern Bering Sea where fin whales occurred on the middle shelf (50–100 m) and on the outer shelf (100–200 m) near the Pribilof Canyon. Distribution and abundance estimates provided in these surveys indicate that baleen whales are re-occupying productive hydrographic zones in patterns similar to those depicted in summaries (Springer et al. 1999) of commercial whaling harvests (Moore et al. 2002). Commercial whaling records of catch reflect hydrographic patterns associated with abundance of zooplankton and forage fish (Nasu 1974). Like planktivorous seabirds, baleen whale distribution reflects oceanographic structure in the eastern Bering Sea and their presence generally is a good indicator of oceanographic productivity (Moore et al. 2002), since in order to feed efficiently, both birds and cetaceans (Croll et al. 1998; Piatt & Methven 1992) need to find dense and predictable aggregations of prey which are strongly associated with water masses in the eastern Bering Sea (Hunt 1997; Hunt et al. 1998). More recently, in the Bering Sea, fin whales and Dall's porpoise appear to be responding to the comparatively high productivity of the shelf break. Minke whales, Dall's porpoise, and harbor porpoise are finding predictable aggregations of prey in the shallow coastal domain of the continental shelf (Moore et al. 2002).

Several marine mammal species are found in the Chukchi and Beaufort seas. In summer and fall, spotted seals use coastal haulouts regularly, and may be found as far north as 69-72 N. Bearded seals migrate north through the Bering Strait from late April through June and spend summer along the ice edge in the Chukchi Sea. Ringed seals have an affinity for ice-covered waters and are well adapted to occupying seasonal and permanent ice, both in summer and winter. Ribbon seals migrate into the Chukchi Sea for the summer and are found in the open sea and on the pack ice, but only rarely on shorefast ice. Pacific walrus migrate in the summer months into the Chukchi Sea and rely on sea ice as a substrate for resting and giving birth. Of the cetaceans, there are Chukchi Sea and Beaufort Sea stocks of beluga whales, killer whales that migrate into the Chukchi Sea, and harbor porpoise that migrate north along the coast line to Point Barrow. Gray, minke, and fin whales may be found in the southern Chukchi Sea, and bowhead whales are distributed in seasonally ice-covered waters of the Arctic and near-Arctic, generally north of 54 N and south of 75 N in the western Arctic Basin. Finally, polar bears appear to have two stocks in the Arctic, the Chukchi/Bering Seas stock and the Southern Beaufort Sea stock. They are circumpolar in their total distribution and individual bears migrate over extensive areas.

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Issues and Concerns

Climate change and reduced ice cover could have significant impacts on Arctic species of marine mammals that depend on sea ice and shorefast ice for feeding, resting and reproduction. Further south in the Bering Sea, Aleutians, and Gulf of Alaska, the more immediate concern is the potential for intensive direct and indirect interactions with large commercial fisheries. This is particularly true of Steller sea lions and Northern fur seals. Others, such as the large whales, migrate through fishing areas and are subject to entanglement in fishing gear. The following is a discussion of major issues and concerns identified for marine mammals off Alaska. It is based to a great extent on Boldt (2003), particularly the discussion of potential causes of.

Strategic Species

Marine mammals may be identified by NMFS as strategic species (Table 3-6). This designation is applied if a species is listed as threatened or endangered under the Endangered Species Act (ESA). In those cases the species also is designated as depleted under the Marine Mammal Protection Act (MMPA). Alternatively, a species may be designated depleted under MMPA, but not listed under ESA. Species falling into any of those categories and identified as strategic, may warrant special consideration in management and research.

Direct Take and Fishery Interactions

Observable interactions between marine mammals and groundfish fisheries generally are restricted to direct mortality in fishing gear. The ecological significance of individual incidental takes is not measurable, and interpretation of their significance is limited to counting the number of animals killed and assessing subsequent population level responses. Based on recent counts of animals reported taken incidentally in fisheries, none is expected to have significant ecosystem consequences.

Table 3-6 Strategic marine mammal species.

ESA Endangered & MMPA Depleted

- W. Steller sea lion
- Sperm whale
- W. & C. N. Pacific humpback whale
- Fin whale
- Right whale
- Bowhead whale
- Blue whale
- Sei whale

ESA Threatened & MMPA Depleted

- E. Steller sea lion
- SW Alaska sea otter (USFWS proposed)

MMPA Depleted only

- E. Pacific Northern fur seal
- Cook Inlet beluga whale
- Prince William Sound AT1 killer whale

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Resource Competition

Most marine mammal species feed on a wide variety of prey, but typically only 3-6 species comprise most of the energy intake at any one time or place (Bowen and Siniff 1999). Marine mammal diets often vary seasonally and geographically over the species range and may change over time in response to changes in prey availability, such that the species listed in Table 3-7 should be regarded primarily as illustrative of the more frequently eaten species. Some species such as Steller sea lions, northern fur seals, and harbor seals, forage on a wide variety of fish throughout the water column, while others such as walrus and gray whales are mainly bottom feeders. Several species feed very low on the food chain, such as sei, northern right, and bowhead whales, while others such as killer whales prey on both fish and marine mammals.

Often there is overlap in the species and size of primary prey consumed by marine mammals and targeted in commercial fisheries, and recent research on the decline of marine mammals has focused on diet and foraging behavior. One hypothesis is that either direct or indirect competition for food with commercial fisheries may limit the ability of apex predators to obtain sufficient prey for growth, reproduction, and survival (NRC 1996). For Steller sea lions, direct competition for resources may include pollock, Atka mackerel, salmon, herring, and Pacific cod (Calkins and Pitcher 1982; Sinclair and Zeppelin 2002). In the case of Atka mackerel, it is a major item in the diet of Steller sea lions in the central and western Aleutian Islands. The Atka mackerel fishery used to be concentrated in several compressed locations, most of which were adjacent to Steller sea lion haulouts and rookeries, inside critical habitat. Evidence of Atka mackerel localized depletion was presented by Lowe and Fritz (1996) based on reductions in catch per unit effort of Atka mackerel over the course of the fishing season. In 1999-2002, new regulations were promulgated that manage Steller sea lion groundfish fishery interactions consistent with provisions of the ESA and MSA. The new regulations have reduced the catches from critical habitat and addressed the temporal compression problem, thus reducing the likelihood of creating localized depletions of sea lion prey.

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Table 3-7 Prey items identified for selected marine mammal species off Alaska. (After NMFS 2004).

Marine Mammal	Prey Items
Steller sea lions	Schooling fishes such as pollock, Atka mackerel, Pacific cod, flatfish, sculpin, capelin, sand lance, rockfish, Pacific herring, salmon, and cephalopods such as octopus and squid
Northern fur seals	Pollock, capelin, herring, deep-sea smelt and lantern fish, salmon, Atka mackerel, squid, Pacific cod, rockfish, sablefish, sculpin, sand lance, and flatfish
Pacific walrus	Benthic invertebrates (bivalve mollusks)
Harbor seals	Pollock, Atka mackerel, sculpin, greenling, Pacific cod, capelin, Pacific herring, eulachon, Pacific sand lance, flatfish, saffron cod, and minor amounts of Arctic cod, eelpouts, rockfishes, and salmon
Spotted seals	Pollock, capelin, eelpout, Arctic cod, and crustaceans
Bearded seals	Benthic feeders for crabs, shrimp and mollusks, plus fish such as sculpin, Arctic cod, saffron cod, and pollock
Ringed seals	Mostly fish such as saffron cod, smelt, herring, and Arctic cod, but some crustaceans such as shrimps, amphipods, and euphausiids
Ribbon seals	Crustaceans, cephalopods, and fish such as pollock, Arctic cod, saffron cod, capelin, eelpout, sculpins, and flatfish
Sea otters	Benthic invertebrates such as sea urchins, clams, mussels, crabs, snails, octopus, squid, and epibenthic fishes, plus some other fish such as lumpsuckers, sculpin, rock greenling, Atka mackerel, rockfish, sablefish, Pacific cod, and pollock
Blue whales	Mainly euphausiids, but also copepods, pelagic gastropods, pelagic schooling squid, and fish such as sardines, capelin, and sand lance
Fin whales	Planktonic crustaceans, squid, and some fish such as herring, cod, mackerel, pollock and capelin
Sei whales	Copepods, euphausiid, and small schooling fish such as saury and squid
Humpback whales	Euphausiids, large zooplankton, and small schooling fishes such as pollock, Atka mackerel, herring, anchovy, eulachon, capelin, saffron cod, sand lance, Arctic cod, rockfish and salmon
Gray whales	Mainly bottom feeders for benthic amphipods and other invertebrates
Northern right whales	Mainly copepods in zooplankton
Bowhead whales	Crustacean zooplankton, primarily copepods and euphausiids
Sperm whales	Primarily mesopelagic squid, but also octopus, other invertebrates, and fish such as salmon, lantern fishes, lancetfish, Pacific cod, pollock, saffron cod, rockfishes, sablefish, Atka mackerel, sculpins, lumpsuckers, and skates
Beaked whales	Benthic and epibenthic squid, skate, grenadier, rockfish, and octopus, as well as Atka mackerel, sardines, and Pacific saury
Pacific white-sided dolphins	Small schooling fish such as sauries and lanternfish, but also squid
Killer whales	Resident: Fish such as salmon, herring, halibut and cod. Transient: marine mammals such as seals, sea lions, otters, and whales
Beluga whales	Schooling and anadromous coastal fishes such as herring, capelin, smelt, eulachon, cod, and salmon, but also octopus, squid, shrimps, crabs, and clams
Harbor porpoise	Cephalopods and fish such as herring, smelt, eelpout, eulachon, pollock, sand lance, and gadids (based on studies in Washington and British Columbia)
Dall's porpoise	Cephalopods and myctophid fishes
Polar bears	Primarily ringed seals and bearded seals.

For northern fur seals, adult pollock and salmon consumption (Kajimura 1984; Perez and Bigg 1986; Lowry 1982; Sinclair et al. 1994; 1996) conflicts with commercial harvests. Fur seal diet studies conducted since the early pelagic collections of 1958-1974 (Sinclair et al. 1994; Sinclair et al. 1996; Antonelis et al. 1997) indicate that groundfish consumption has increased as forage fishes have decreased (Sinclair et al. 1994, 1996). Some prey items, such as capelin, have disappeared from fur seal diets in the eastern Bering Sea and squid consumption has been markedly reduced. At the same time, pollock consumption has doubled, but the age and size of pollock eaten by adult female fur seals have decreased from predominantly adult-sized fish to age-0 and age-1 juveniles (Sinclair et al. 1994). Commercial fisheries exploit pollock that are mostly age 3 and older. Female northern fur seals may be consuming 2-4 year old pollock during summer in the eastern Bering Sea (Kurle and Worthy 2001).

More difficult to identify and potentially more serious are interactions resulting indirectly from competition for secondary prey resources and the influence of fisheries on marine mammal and prey habitat. Compounding the problem of identifying competitive interactions is the fact that biological effects of fisheries may be indistinguishable from changes in community structure or prey availability that might occur naturally. The relative impact of fisheries perturbations compared to broad, regional events such as climatic shifts is uncertain, but given the potential importance of localized prey availability for foraging marine mammals, they warrant close consideration. Whereas the overall abundance of prey across the entire Bering Sea or Gulf of Alaska may not be affected by fishing activity, reduction in local abundance, or dispersion of schools could be more energetically costly to foraging marine mammals. Thus, the timing and location of fisheries relative to foraging patterns of marine mammals may prove to be a more relevant management concern than total removals. Sinclair and Zeppelin (2002) demonstrated that, for the western stock of Steller sea lions, diet diversity was highest where the population trends were most stable.

Disturbance from either vessel traffic or fishing activities may also be a disadvantage to marine mammals. Vessel traffic alone may temporarily cause fish to compress into tighter, deeper schools (Freon et al. 1992) or split schools into smaller concentrations (Laevastu and Favorite 1988). Preliminary results on the effects of noise produced by a single vessel (no trawl in the water) on pollock school structure suggests that the fish may move down and to either side of the vessel, but return to the undisturbed structure within minutes of the vessel passage. Effects of repeated trawling by many vessels over several days or weeks on fish school structure and the resulting impacts on prey availability to Steller sea lions need to be studied.

Predation

Predation also may account for declines in marine mammal populations. The NRC (2003) noted in their report on the decline of Steller sea lions that the role of predation in population regulation and food web dynamics must be considered when evaluating hypotheses for declines in marine mammal populations. Potential predators include salmon sharks, Pacific sleeper sharks, and killer whales, though it may be doubtful that large sharks could be responsible for much sea lion mortality because of the absence of reports on shark attack or shark wounds on sea lions. The NRC believes that sea lion declines could be explained by remarkably small changes in killer whale foraging behavior based on their energetic requirements. Since there is no direct evidence that increased predation since the 1970s was the primary cause of sea lion declines in the 1980s, the role of killer whale predation in the historical decline remains unknown.

Concerning sea otters, killer whales may be the most likely cause of their decline in the Aleutian Islands (USFWS Proposed Rule of February 11, 2004). That hypothesis is supported by a significant increase in killer whale attacks on sea otters during the 1990s, scarcity of beachcast otter carcasses, and markedly lower mortality rates for sea otters in a sheltered lagoon (where killer whales cannot go) compared to an adjacent exposed bay. The NRC (2003) notes that a switch of fewer than four killer whales to feeding exclusively on sea otters could account for the additional annual mortality in the central Aleutians during the rapid decline of the sea otter population. Other predators on sea otters could include white sharks, brown bears, and coyotes, but that predation is believed to be negligible.

Environmental and Climate Change

Most scientists agree that the 1976-1977 regime shift dramatically changed environmental conditions in the BSAI and GOA (see Chapter 2, Regime Shifts). However, there is considerable disagreement on how and to what degree these environmental factors may have affected both fish and marine mammal populations. Fish productivity of the Bering Sea was high from 1947 to 1976, reached a peak in 1966, and declined from 1966 to 1997. The regime shift may have changed the composition of the fish community and resulted in reduction of prey diversity in marine mammal diets (Sinclair et al. 1994; Piatt and Anderson 1996; Merrick and Calkins 1996). Some suggest the overall biomass of fish was reduced by about 50 percent (Merrick et al. 1995; Piatt and Anderson 1996). Others suggest that the regime shift favored some species over others, in part because of a few years of very large recruitment and overall increased biomass (Beamish 1993; Hollowed and Wooster 1995; Wyllie-Echeverria and Wooster 1998). Hunt et al. (2002) propose that the pelagic ecosystem in the southeastern Bering Sea alternates between bottom-up control in cold regimes and top-down control in warm regimes. In their proposed Oscillating Control Hypothesis, Hunt et al. (2002) hypothesize that when cold or warm conditions span over decades, the survival and recruitment of piscivorous vs. planktivorous fishes are variably affected along with the capacity of fish populations (and arguably, apex predator populations) to withstand commercial fishing pressures.

Research Needs

The above review demonstrates the extensive research that has been completed on many marine mammal species off Alaska. Steller sea lions alone have been the focus of over $120 million in research since 1999 because of their listed status and broad overlap with large commercial fisheries. Despite this infusion of research funds, a wide spectrum of research needs continues to be identified for sea lions. Northern fur seals also are gaining attention because of declines in their abundance and overlap of their foraging grounds with commercial fisheries.

General research needs vary by species groups. For cetaceans, special interest has been expressed in monitoring of population size and distribution using aerial and vessel line transect surveys, photo-identification surveys, genetics studies using biopsy samples to establish stock structure, and for using mark-recapture experiments to estimate population size and to study movements and social dynamics (R. Hobbs, NMML, personal communication). For polar bears, accurate information is needed on population size, sex-specific survivorship, recruitment rates, distribution, and migratory patterns. Importance of the near-shore environment to polar bears and ecological relationships also needs to be assessed. Contaminant studies also are of great interest. For sea otters, population surveys are needed as well as studies of the role of sea otters in structuring near-shore marine communities, their food habits and direct effects on prey removal. Information is also needed on the impacts of killer whale predation, and the productivity, survival, and movements of sea otters (R. Meehan, USFWS, personal communication).

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Research needs have been identified more thoroughly for Steller sea lions than most other marine mammals. For example, the National Research Council provided the following recommendations in its study of the Steller sea lion decline (NRC 2003), summarized as follows:

- Abundance, sex ratio, and survival/productivity rate from recapture patterns of marked animals at geographically diverse rookeries.
- Spatial and temporal patterns of fishing activity (efforts, fishing areas) for all fisheries working in proximity to Steller sea lions.
- Spatial abundance and seasonal distributions patterns of key fishes that are important prey for sea lions in particular areas.
- Long-term sampling and monitoring of population and ecosystem variables such as sea lion and fish population structure and variation, harmful algal blooms, and oceanographic conditions indicative of climate regime shifts.
- Fine geographic scale surveys of sea lions on rookeries and haul-out sites.
- Information from subsistence harvests should include tissue samples, extracted teeth, sex determination, etc.
- Studies of killer whale predation in western and eastern ranges of sea lions.
- Confidential interviews and novel approaches should be used to document current levels of lost catch to sea lions and contemporary responses of fishermen.
- Assess role of infectious diseases through retrospective analyses of archival serum and tissue samples, and test for presence of toxins and pollutants.
- Conduct experiments to assess efficacy of closed and open areas with regard to mitigating fisheries impacts on sea lion populations.

An expert panel (Bowen et al. 2001), established in 2001 by the North Pacific Fishery Management Council to review the November 2000 biological opinion and incidental take statement with respect to the western stock of Steller sea lions, recommended seven main research priorities:

- Monitoring trends in population size and distribution.
- Estimation of vital rates.
- Spatial and temporal scales of foraging.
- Diet studies, such as fatty acid signature analysis.
- Spatially explicit modeling of foraging and reproductive energetics of sea lions.
- Retrospective analysis to investigate the relationship between the rate of change of sea lion numbers at specified sites and contemporary high resolution, spatially explicit data on catch and effort for pollock and Atka mackerel close to the rookery over that period.
- Local depletion of prey and its consequences for sea lions.

Many of these research recommendations, while specific to Stellers, are equally valid for other pinniped species, as well as other marine mammals. Because of the long-lived nature of marine mammals, many aspects of research need to be supported over 5-10 or more years to determine population responses and change. Based on its review of specific research needs, summarized above, the North Pacific Research Board has identified a general list of research needs that fall into six major thematic areas: fisheries interactions, migration patterns and oceanographic habitats, foraging success, population dynamics, long-term climate change, and other human-related impacts. The intersection of fishery and other human-related impacts with selected marine mammal species is shown in Table 3-8. This represents the current views of NMFS, and other scientists may have differing opinions. Overall research themes are summarized in Table 3-9, with specific suggested research activities identified for each thematic area. These will serve as the basis for development of the implementation plan and periodic NPRB requests for proposals related to marine mammal research.

Table 3-8 Fisheries and human-related impacts on marine mammals. (After Angliss and Lodge 2002).

	Steller sea lions	Northern fur seals	Harbor seals	Spotted seals	Bearded seals	Ringed seals	Ribbon seals	Beluga whales	Killer whales	Pacific white-sided dolphin	Harbor porpoise	Dall's Porpoise	Sperm whales	Gray whales	Humpback whales	Fin whales	Minke whales	North Pacific right whales	Bowhead whales	Sea otters	Polar bears	Pacific walrus
LMEs																						
Arctic				x	x	x	x	x	x		x			x		x	x		x		x	x
Bering Sea/ Aleutian Islands	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Gulf of Alaska	x	x	x					x	x	x	x	x	x	x	x	x	x	x		x		
Strategic Species																						
ESA Endangered	**W**												x		x	x		x	x			
ESA Threatened	**E**																					
ESA Candidate																				x		
MMPA Depleted	x	x						**CI**	**ATI**				x		x	x		x	x			
Fisheries Interactions																						
Incidental catch	x	x	x	x	x		x		x	x	x	x			x	x						
Fishing gear entangle-ment/ship strikes									x		x		x	x	x	x		x	x			
Disturbance of prey fields/food competition	x	x																				
Noise disturbance	x	x																				
Impacts on rookeries and haul-outs	x																					
Impacts of fish discards & processing offal		x																				
Other Human-Related Impacts																						
Contaminants impacts, entanglement in debris		x																	x	x		
Illegal intentional kills	x	x	x																			
Noise pollution (Navy sonar, oil explor., etc)															x				x			
Coastal development and disturbance of habitat		x						x												x	x	
Subsistence takes	x	x	x	x	x	x	x	x						x					x	x	x	

Note: CI is Cook Inlet; AT1 is Prince William Sound transient stock; W is western stock; E is eastern stock.

Research Needs

Table 3-9 General research needs for marine mammals.

Pressing Fishery Management Issues ↔ Marine Ecosystems Information Needs

Other Human-Related Impacts
- Contaminants impacts (including tissue samples and archives)
- Entanglement in marine debris
- Coastal development and disturbance of habitat (e.g., on polar bear)
- Subsistence takes
- High frequency sonar

Fisheries Interactions
- Overlap of fisheries and marine mammal habitat
- Incidental catch and development of deterrents
- Mortality/injury from vessel strikes
- Disturbance of habitat and by noise
- Disturbance/depletion of prey fields and competition for food resources
- Impacts on rookeries and haulouts
- Impacts of fish discards and processing offal

Marine Habitat Use
- Development of tracking and tag attachment methods
- At-sea population distribution (including migratory species whose distribution may extend beyond the geographic boundaries of NPRB)
- Benthic habitat requirements

Foraging Success
- Foraging behavior in relation to prey characteristics (availability, abundance, patchiness)
- Individual and population energy requirements
- Factors affecting diets
- Physiological indicators of food limitation
- Effects of competitors on success
- Seasonal and longer-term patterns in foraging behavior (particularly in winter)
- Spatially-explicit modeling consequences of foraging behavior and diets on demography

Population Dynamics
- Development of survey and census methods to estimate population size and vital rates (including photo-identification and mark-recapture)
- Population structure (e.g., genetics, telemetry, mark re-sighting)
- Estimation of population size and trends
- Factors affecting survival probability (e.g., predation, food limitation, disease)
- Factors affecting birth rate
- Spatially-explicit models of factors affecting population dynamics

Long-term Climate Change
- Impacts of reduced sea ice or other climate-related changes on population dynamics
- Impacts on prey availability and demographic consequences

Implementation Strategies

In developing its nearer term implementation plan for marine mammals, the Board will have the advantage of having funded the following projects in 2002-2005 (detailed project information by project number is available at http://www.nprb.org).

Current Projects

Project	Project Number
Ecology of ice seals in the Chukchi and Bering seas	312
Feeding ecology and distribution of harbor seals in Prince William Sound	313, 50
Bering Sea wintering grounds of beluga whales	324
Bering Sea right whale distribution	325, 519
Dietary specialization of Bering Sea and Aleutian Island killer whales	411, 535
Fur seal foraging strategies and consequences	414, 514
Observations of marine mammals during continuous plankton recorder transects	206,409
Sperm whale interactions with longline fisheries off southeast Alaska	309, 412, 527
Winter movement of northern fur seal pups	513
Ice seal movements and stock structure	515
Oceanography and occurrence of endangered whales in Bering Sea	518

The Board will consider a mix of short and long-term marine mammal research in its implementation plan over the next 2-4 years, perhaps focusing on those species, such as northern fur seals and Steller sea lions, that may be at greatest risk from interactions with major commercial fisheries of the Bering Sea, Aleutians and western Gulf of Alaska. The Board will seek to collaborate with NMFS to host a synthesis meeting of Steller sea lion research to appraise current understanding of factors affecting sea lions, map out how funds are being spent, and identify new research directions to be pursued. Concerning cetaceans and other marine mammals, the Board may consider identifying research needs and a commensurate amount of funds for such research as part of annual requests for proposals. As noted earlier, the Board also may support a synthesis and conference effort to assess remote sensing technologies for detecting marine mammal migrations and providing better counts to determine population trends.

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Seabirds

Seabirds
Section Guide

Introduction

Seabirds are distributed throughout the Bering Sea and North Pacific marine ecosystems, and along coastal areas of the Chukchi and Beaufort Seas. They are widely distributed in the marine environment most of the year, but during breeding season, breeding pairs occupy nest areas and colonies, while continuing to forage at sea (Boldt 2003). Some seabird species have been hunted by Alaska Natives for thousands of years and continue to be an important source of meat and eggs in certain communities (Denlinger and Wohl 2001).

In several of the NRC site visits, issues were raised over declines in seabird populations and the impacts of climate change on seabirds and other components of the ecosystem (NRC 2004a). It was noted in Dillingham, for example, that the productivity and diet of seabirds are largely unknown, and that, in the opinion of indigenous elders, changes in water temperature have displaced fish populations and increased mortality of diving birds. The NRC (2004a) recommended that NPRB encourage proposals that include data on roles and trends of indicator species as part of overall, integrated, interdisciplinary studies of entire ecosystems. They further noted that spatial and temporal characteristic of fishing may have important consequences for the dynamics of upper trophic level vertebrates, such as birds and mammals. Seabird breeding chronology, productivity, population trends, and bycatch, have been identified as ecosystem status indicators by Boldt (2003).

This section on seabirds presents an overview of current understanding of seabird populations off Alaska, and then identifies issues and concerns with seabirds, and resulting research needs. The section concludes with some suggested implementation strategies for the near term of the next 2-4 years. Seabirds are managed and protected by the U.S. Fish and Wildlife Service. The following discussion excerpts and/or summarizes information provided in the ecosystems considerations chapter of the 2003 SAFE for NPFMC (Boldt 2003: In particular, contributions on p. 206-238 by S. Fitzgerald, K. Kuletz, M. Perez, K. Rivera, D. Dragoo, and R. Suryan), the Groundfish Final supplemental environmental impact statement of June 2004 (NMFS 2004b), and various USFWS biological opinions and recovery plans as noted.

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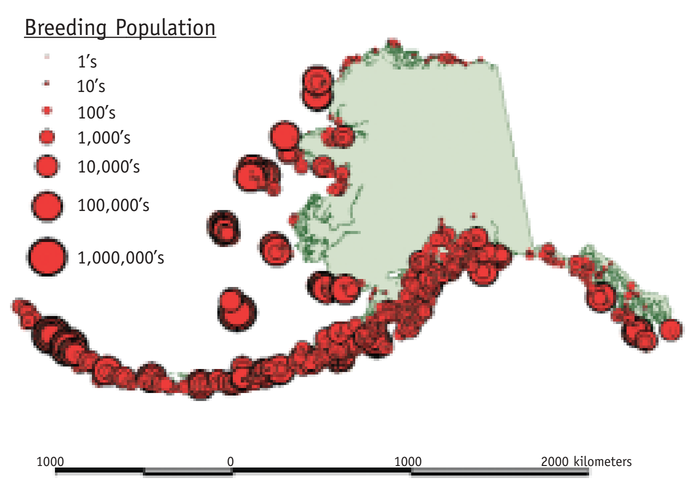
Overview

Seabirds spend the majority of their life at sea. Thirty-eight seabird species breed in Alaska; at least five additional species breed elsewhere but return regularly to Alaska to feed, typically during summer months. Alaska seabirds are represented mainly by three Orders: albatrosses, shearwaters, fulmars, and storm-petrels are in the Order Procellariiformes; cormorants in the Order Pelecaniformes; and gulls (family Laridae) and puffins, murres, auklets, and murrelets (alcids in family Alcidae) are in the Order Charadriiformes. Other bird groups include loons, grebes, phalaropes, and sea ducks, but of those, only sea ducks are discussed here because of their status as Birds of Conservation Concern. It also should be noted that other marine birds and waterfowl such as geese are not discussed here, but research on them may be supported by NPRB as the need arises. For example, the Emperor Goose, which overwinters in the marine intertidal areas of the Aleutians, is a highly valued subsistence resource to coastal communities, but its population has declined significantly, possibly due to stress caused by selenium exposure (Franson et al. 1999, 2002).

Seabird breeding colonies are distributed throughout the Bering Sea, Aleutian Islands, and Gulf of Alaska (Fig. 3-5). During breeding season, pairs occupy nesting areas, but continue to forage at sea. Migrants, juveniles, and adult non-breeding birds occupy the pelagic marine environment while breeding birds nest in burrows, rocky cliffs and crevices, and in open nests on the ground.

Over 1,600 seabird colonies have been documented, ranging in size from a few pairs to 3.5 million birds. The 135 colonies in the southeastern GOA tend to be small, 5,000-60,000 birds, except for two with 250,000-500,000 birds at Forrester and St. Lazaria Islands. The 850 colonies in the northern GOA also are generally small, with larger colonies at the Barren and Semidi Island groups. The Alaska Peninsula (261 colonies) and Aleutian Islands (144 colonies) have larger colonies including several with over 1 million birds and two with over 3 million birds. Large colonies of over 3 million birds are also found on large islands of the Bering Sea, though relatively few colonies are located along the mainland. Some seabird species are highly clustered into a few colonies: 50% of Alaska's seabirds nest in just 12 colonies, of which 10 are in the Eastern Bering Sea.

Figure 3-5 Seabird colonies of Alaska. (From Beringia Seabird Colony Catalog, 2005, USFWS).

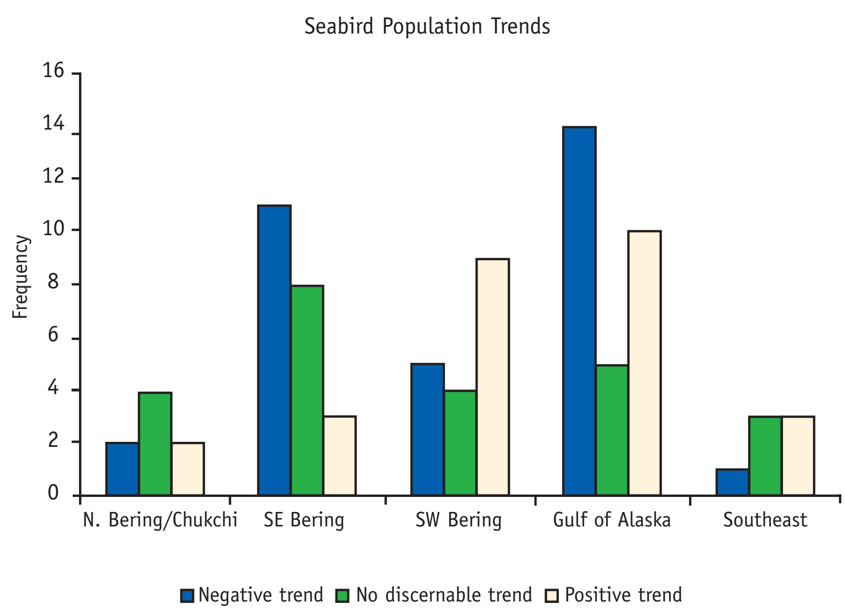


Breeding populations contain about 36 million individual birds in the BSAI and 12 million in the GOA (Table 3-10). Subadults and non-breeders increase population size another 30%. Six additional species (short-tailed, black-footed, and Laysan albatrosses; sooty and short-tailed shearwaters; and ivory gulls) that do not breed here, but visit Alaska waters in summer, contribute another 30 million birds (NMFS 2004b).

Chukchi and Beaufort seas colonies are small and dispersed, however, the coastal areas are the breeding grounds for three of four species of eider ducks (spectacled, king and common or Pacific eider; Steller's eider are rare that far north) that breed in arctic and subarctic areas of the northern hemisphere (BP Exploration 2001). The barrier islands off the North Slope in particular are heavily used by seabirds and waterfowl. For example, many of the most productive aggregations of nesting Pacific eiders occupy relatively high-elevation barrier islands in the flood plumes of large rivers. Thetis Island, Egg and Stump islands, and Cross Island, which lie in the flood plumes of the Colville, Kuparuk, and Sagavanirktok rivers, respectively, are examples (Johnson 2000).

Seabird populations do not necessarily have large annual fluctuations because adults are long-lived and usually return to the same breeding colony (Boldt 2003). Because observed annual fluctuations may not be meaningful, Dragoo et al. (2003) describe population trends using exponential regression models. Recent censes through 2001 indicate that populations of fulmars and petrels (primarily surface-feeding on invertebrates) were stable or increasing at all sites. Cormorants (nearshore diving piscivores) appear to have declined in 9 of 11 samples, though population trends at a given site are difficult to interpret because cormorants sometimes shift nesting locations. Regionally, declining seabird populations were most prevalent in the southeast Bering Sea, including the Pribilof Islands, and GOA. The highest proportion of increasing trends occurred in the southwest Bering Sea (9 of 18 samples). In the northern Chukchi and Bering Sea and in southeast Alaska, most populations were stable or increasing (Dragoo et al. 2003) (Figure 3-6).

Figure 3-6 Seabird population trends at selected colonies in Alaska up to and including summer 2001. Frequency is the number of samples (species x sites) for each region, showing below average, average, or above average productivity rates. (NPFMC 2003, after Dragoo et al., 2003).



Recently, breeding has tended to be earlier than normal throughout the North Pacific, perhaps reflecting climate changes and their affect on spring plankton blooms (Root et al. 2003). If plankton blooms are too early, there may be a mismatch between prey and seabirds, which can affect seabird breeding success (Bertram et al. 2001). Exceptions appear to be storm-petrels in southeast Alaska and puffins in southwest Bering Sea where breeding occurred later in 2003.

Seabird productivity is highly variable, but in most cases, plankton feeders (storm-petrels and auklets) recently have had average or below average reproductive success, whereas diving piscivores (cormorants, murres, murrelets, rhinoceros auklets and puffins) were average or above average. In general, productivity was lower than average in the Chukchi and southern Bering seas. Productivity was above average in the GOA, but more variable in southeast Alaska. Black-legged kittiwakes (surface-feeding piscivores), one of the most frequently monitored species, had below average productivity in most sites from the Chukchi Sea to the southern Bering Sea, but did well at all four sites in the Gulf of Alaska and southeast Alaska. Murres were successful at a few sites in the Bering Sea, but did better in the Gulf.

Seabirds may be grouped in various foraging guilds (Dragoo, D.L. et al. 2001). For example, surface fish feeders include glaucous-winged gulls, kittiwakes, and albatross. Surface plankton feeders include fork-tailed and Leach's storm-petrels. Nearshore diving fish feeders include cormorants. Offshore diving fish-feeders include common and thick-billed murres, rhinoceros auklets, and tufted puffins. Diving plankton-feeders include least, crested, parakeet, and whiskered auklets. While it is convenient to group species in these foraging guilds, a closer look at diet habits indicates that various seabird species depend on a range of prey items, and diets will vary according to prey availability. For example, albatross depend not only on zooplankton, but also on squid and small fish, feeding mainly in the upper 1 m of the ocean surface by seizing and dipping while sitting on the water (Gould et al. 1998). Fulmars feed on a variety of surface species including squid, jellyfish, crustaceans, other invertebrates, and small fish (NMFS 2004b). Shearwaters also take euphausiids and schooling fish, but can dive to deeper waters of at least 60 m. Storm-petrels feed on small fishes, particularly juvenile lantern fish, squid and euphausiids, and sometimes capelin, mainly at night at the surface. Spectacled eiders are primarily bottom feeders, eating mollusks and crustaceans at depths of up to 70 m, but they may also forage on pelagic amphipods that are concentrated along the seawater-pack ice interface (NMFS 2004b). Steller's eiders forage mainly in shallow, near-shore waters dabbling for clams, polychaete worms, snails, and amphipods. More detailed diet information on a variety of species is presented in Table 3-10 (from Boldt 2003).

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Issues and Concerns

Birds of Conservation Concern

The USFWS has management responsibility for seabirds, sea ducks, and other waterfowl, and all species are protected under the U.S. Migratory Bird Treaty Act (16 USC 703 et.seq.). Besides some of these species being protected by the ESA, all are listed as Birds of Conservation Concern. These are species that without additional conservation actions are likely to become candidates for listing under the ESA. The USFWS anticipates that this 2002 List of Birds of Conservation Concern will be consulted by Federal agencies and their partners prior to undertaking cooperative research, monitoring, and management actions that might directly or indirectly affect migratory birds. Species of special concern include:

1. <u>Short-tailed albatross:</u> Listed as endangered under ESA and treated as such since 1970. Critical habitat was not designated because it would not have been beneficial to the species.

2. <u>Spectacled eiders:</u> Listed as threatened under ESA on May 10, 1993. Critical habitat was designated on February 6, 2001 because of severe declines in breeding population.

3. <u>Steller's eiders:</u> Listed as threatened under ESA on June 11, 1997 because of severe declines in the breeding population and range.

4. <u>Red-legged kittiwakes:</u> Designated as USFWS Bird of Conservation Concern 2002 because 80% of its worldwide population nests in only one colony, St. George Island, and because its recent severe population decline has not been explained. It was recently assigned "vulnerable" status on the World Conservation Union's Red List of Threatened Species.

5. <u>Marbled and Kittlitz's murrelets:</u> Designated in 1995 as USFWS Bird of Conservation Concern 2002, because of documented or apparent population declines, small or restricted populations, or dependence on restricted or vulnerable habitats. The marbled murrelet is not listed under ESA in Alaska, but it is listed as "vulnerable" under the World Conservation Union's criteria. The Kittlitz's murrelet was just listed as a candidate species under ESA on May 4, 2004 (69FR24876) because of major and consistent population declines in core breeding areas in southeast Alaska.

6. <u>Black-footed albatross:</u> It was recently assigned "vulnerable" status on the World Conservation Union's Red List of Threatened Species because of reported declines in numbers on their breeding colonies. This criterion is used for species that are deemed to have a high risk of extinction in the wild in the medium-term future (60 years). It also is on USFWS list as Bird of Conservation Concern 2002.

7. <u>Red-faced cormorant:</u> Designated as a USFWS Bird of Conservation Concern in the Alaska Region because of apparent declines at the one monitored colony in Chiniak Bay in the GOA.

8. <u>Whiskered auklet:</u> Designated as a USFWS Bird of Conservation Concern in the Alaska Region due to concerns over its localized breeding distribution on Buldir Island.

Table 3-10 Estimated populations and diets of seabirds that breed in BSAI and GOA. (From Boldt 2003).

Species	Population[1]		Diet[2]
	BSAI	GOA	
Fulmar *(Fulmarus glacialis)*	1.500,000	600,000	Q,M,P, S,F,Z,I,C
Fork-tailed storm-petrel *(Oceanodroma furcata)*	4,500,000	1,200,000	Q,I,Z,C,P,F
Leach's storm-petrel *(Oceanodroma leucorrhoa)*	4,500,000	1,500,000	Z,Q,F,I
Double-crested cormorant *(Phalacrocorax auritis)*[3]	9,000	8,000	F,I
Pelagic cormorant (*Phalacrocorax pelagicus*)	80,000	70,000	S,C,P,H,F,I
Red-faced cormorant (*Phalacrocorax urile*)	90,000	40,000	C,S,H,F,I
Mew gull *(Larus canus)*[3]	700	40,000	C,S,I,D,Z
Herring gull *(Larus argentatus)*[3]	50	300	C,S,H,F,I,D
Glaucous-winged gull *(Larus glaucescens)*	150,000	300,000	C,S,H,F,I,D
Glaucous gull *(Larus hyperboreus)*[3]	30,000	2,000	C,S,H,I,D
Black-legged kittiwake *(Rissa tridactyla)*	800,000	1,000,000	C,S,H,P,F,M,Z
Red-legged kittiwake *(Rissa brevirostris)*	150,000	0	M,C,S,Z,P,F
Arctic tern *(Sterna paradisaea)*[3]	7,000	20,000	C,S,Z,F,H
Aleutian tern *(Sterna aleutica)*	9,000	25,000	C,S,Z,F
Common murre *(Uria aalge)*	3,000,000	2,000,000	C,S,H,G,F,Z
Thick-billed murre *(Uria lomvia)*	5,000,000	200,000	C,S,P,Q,Z,M,F,I
Pigeon guillemot *(Cepphus columba)*	100,000	100,000	S,C,F,H,P,I,G,Q
Marbled murrelet *(Brachyramphus marmoratus)*	Uncommon	Common	C,S,H,P,F,G,Z,I
Kittlitz's murrelet *(Brachyramphus brevirostris)*	Uncommon	Uncommon	S,C,H,Z,I,P,F
Ancient murrelet *(Synthliboramphus antiquus)*	200,000	600,000	Z,F,C,S,P,I
Cassin's auklet *(Ptychoramphus aleuticus)*	250,000	750,000	Z,Q,I,S,F
Least auklet *(Aethia pusilla)*	9,000,000	50	Z
Parakeet auklet *(Cyclorrhynchus psittacula)*	800,000	150,000	F,I,S,P,Z,C,H
Whiskered auklet *(Aethia pygmaea)*	30,000	0	Z
Crested auklet *(Aethia cristatella)*	3,000,000	50,000	Z,I
Rhinoceros auklet *(Cerorhinca monocerata)*	50	200,000	C,S,H,A,F
Tufted puffin *(Fratercula cirrhata)*	2,500,000	1,500,000	C,S,P,H,F,Q,Z,I
Horned puffin *(Fratercula corniculata)*	500,000	1,500,000	C,S,P,H, F,Q,Z,I
Total	**36,000,000**	**12,000,000**	

1. Estimates are minima, especially for storm-petrels, auklets, and puffins. Interpret abundant as > 10^6; common = 10^5-10^6; uncommon = 10^3-10^5; rare < 10^3. There is no single census date, as the table is a compilation of the best available data for all Alaska colonies (or population estimates from at-sea surveys, in the case of non-colonial birds like marbled and Kittlitz's murrelets, or rare birds like Sabine's gull). Some species are represented by hundreds of colonies that could have been counted anytime from the mid 1970s to 2002. Most of the estimates come from censuses conducted in the 1990s, but some of the colony data do go back to the 1980s, and a few to the 1970s. The table is intended to give a general picture of abundance by species and region, based on the most recent available data, but recognizing that some of those data are not very current.
2. Diet components are in order of importance; usually dominated by available one or a few items: M, Myctophid; P, walleye pollock; G, other gadids; C, capelin; S, sandlance; H, herring; A, Pacific saury; F, other fish; Q, squid; Z, zooplankton; I, other invertebrates; D, detritus.
3. Species breed both coastally and inland; population estimate is only for coastal colonies.

Direct Take and Fisheries Interactions

Subsistence Harvest As noted earlier, seabirds continue to be an important source of meat and eggs in certain communities. Seabirds also have been used for clothing and decoration and are important in many cultural contexts. The impacts of subsistence hunts are concentrated during the breeding season and on the colonies most accessible to Native communities.

Incidental Take by Fisheries Many factors affect the incidental catch of seabirds by commercial fisheries, including sea state, time of day, gear type, daily fishing patterns, attraction to vessels, interannual variation, and the bird's age, sex, or breeding status (Jones and DeGange 1988; Melvin et al. 1999; Ryan and Moloney 1988; Tuck et al. 2001; Melvin et al. 2001). Longline, bottom and pelagic trawl, pot, and gillnet fisheries have observed seabird bycatch. In the past, groundfish longlines have accounted for most bycatch. In 1993-2002, for example, the average annual longline take of seabirds was estimated to be 13,345 seabirds in the BSAI and 962 seabirds in the GOA. Longline fishermen have taken major steps to deploy deterrents to reduce bycatch. Freezer longliner, for example, started voluntarily using paired streamer lines in 2002 to reduce bycatch. As a result, the longline bycatch in 2002 was down to 3,835 seabirds in the BSAI and 259 seabirds in the GOA. A longer time series will be needed to determine if these reductions reflect the impacts of deterrents or normal annual variability in bycatch rates (Boldt 2003). Northern fulmars and gulls accounted for the most bycatch in the longline fisheries in 2002, the most recent counts available. Trawls also take seabirds. Annual trawl bycatch ranged from 1,754 to 11,955 seabirds for 1998-2002 in the BSAI and GOA combined, with northern fulmars, shearwaters and gulls the most represented species groups. Trawl bycatch in 2002 ranged from 3,193 to 9,008 seabirds, placing that gear group in the same league as longlines. It should be noted that local bycatch mortality from fishing gears in Alaska waters may represent only a portion of total fishing-related mortality throughout the migratory range of certain species such as albatrosses that make long foraging runs and are subjected to bycatch in other fisheries throughout the North Pacific (Brothers et al. 1999; Lewison and Crowder 2003).

Direct Mortality From Vessel Strikes Seabirds strike vessels, rigging, and fishing gear in flight, sometimes causing injury or death. Recorded incidents mainly involve northern fulmars, Laysan albatross, storm-petrels, crested auklets, and shearwaters, with almost half the birds being killed or injured. Strikes are most numerous during night, storms, and foggy conditions when bright deck lights may disorient the birds. Seabirds also may strike a third wire cable deployed off trawlers to monitor their nets. Sixteen incidents have been recorded involving 79 birds, mainly fulmars and Laysan albatross, with approximately 90% mortality. Third wire and main cable interactions are a source of mortality which is outside the normal observer sample routine. Special efforts are being made to characterize this mortality factor and address it through mitigation measures (S. Fitzgerald, personal communication).

Other Fisheries Interactions Groundfish fisheries may impact seabird colonies even if there is little or no overlap with the breeding season. Fishing operations may physically disturb colonies or important foraging habitat, alter predator-prey relations among fish species, compete for prey, or take juvenile fish otherwise consumed by seabirds. Conversely, a fishery could be beneficial if it removes adult fish predators, such as pollock, on small fish that are prey for seabirds. Seabirds also compete with other upper trophic level consumers, and at a local scale, may impact fish populations, though overall consumption of fish biomass by seabirds is generally low, estimated at <4% (Livingston 1993). The impact may be much greater within foraging range of breeding colonies during summer where 15-80% of the biomass of juvenile forage fish may be removed each year (Boldt 2003).

Provision of Food Resources Catcher/processors and other vessels discharge overboard a steady stream of processing wastes (offal) and discarded fish which attracts feeding seabirds. The extent of this interaction and the dependence of seabirds on offal discharge are not well documented. Generally, vessels that have been steadily processing fish will have hundreds of birds in attendance, primarily northern fulmars, but also kittiwakes, shearwaters, gulls, albatross, and other species. It remains unknown whether recent regulations to reduce discharges have affected bird behavior.

Resource Competition

Most groundfish fisheries occur between September and April (NMFS 2004b), and do not overlap the main seabird breeding period from May through August (DeGange and Sanger, 1986; Hatch and Hatch, 1990; Dragoo et al. 2000, 2001). However, some species, such as pigeon guillemots, and murrelets, may arrive at breeding sites in April. Others, including fulmars, puffins, and murres, are still rearing young in September. Among the latest breeding species are fulmars, which have long incubation and chick-rearing periods and generally fledge chicks in September or early October. Some storm-petrels do not fledge young until October (DeGange and Sanger 1986; Hatch and Hatch 1990; Dragoo et al. 2000). Seabird attachment to the colony is thus most likely to overlap with fisheries effort during the early (pre and early egg-laying) and late (late chick-rearing and fledging) portion of their breeding season. Juvenile birds, generally on their own and not experienced foragers, would also be most abundant at sea during the fall fisheries. Impacts and interactions will vary as fishery seasons are shifted by managers.

Predation

Another threat, particularly to seabird colonies on nesting islands, is the introduction of exotic predators such as arctic fox, red fox, and rats, the latter mainly by shipwrecks. They attack eggs, chicks, and even adult birds. Rats have been introduced to 22 islands including Kodiak and some Aleutian Islands, and now pose the greatest threat to seabirds. Eradication programs have been implemented, at times with great success. The Pribilof Islands currently are rat-free.

Ecosystem Factors

As noted earlier, seabird populations have traits that make them extremely sensitive to changes in adult survival. Fluctuations in fish stock recruitment are likely to affect survival of adult seabirds and seabird reproduction differently. Adult survival is unlikely to be affected by interannual variations common to prey stocks because adults can shift to other prey or forage in other regions. Breeding seabirds, being more restricted to colonies and nearby foraging areas, may be affected by local fluctuations. Local seabird reproduction will fail if food supplies are reduced below the amount needed to generate and incubate eggs, or the specific species or size of prey needed to feed chicks is unavailable (Hunt et. al. 1996).

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Most seabird diet information has been obtained during the breeding season, often by examining the prey that adults bring to chicks. Diets consist mainly of fish or squid less than 15 cm, large zooplankton, or a combination of both. Prey species vary by season, location, and seabird species and stage of maturity. Seabirds use the juvenile age-classes (age-class 0-1) of a variety of commercial fish, including Pacific herring, walleye pollock, Pacific tomcod, salmon, rockfish, lingcod, smelts, and flatfish. Bottom-feeding birds such as scoters, cormorants, and guillemots may also consume juvenile stages of commercial shrimp and crab species. Non-commercial forage fish include juveniles and adults of Pacific sand lance, capelin, Pacific sandfish, greenlings, and several species of lanternfish, or myctophids. Birds feeding near the coast or sea floor also may take sculpins, blennies, octopus, mollusks and small crustacea. Most prey are caught in shallow waters (< 100 m; usually < 50 m) or in the upper water column. Deep-water fish like myctophids are usually taken at night, when they migrate to surface waters.

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Energy content of prey influences growth and reproduction and overall success at the colony level. Fish with high lipid and low water content provide the most efficient food source. Fish with high energetic value to seabirds include myctophids, herring, sand lance, and capelin. Fish with lower energetic value include pollock and most other bottom-dwelling fish (Van Pelt et al., 1997; Anthony et al., 2000). Of the high-valued forage fish species, only one or two typically may be available to seabirds in a given area, for example, sand lance in most of the Bering Sea, pollock and capelin in the Pribilof Islands, capelin and pollock along the Alaska Peninsula, and capelin, sand lance, herring, and pollock in the northern GOA (NPFMC 2000). Though prey species may occur within foraging range, schools or swarms of forage fish must be of sufficient size and density to be exploited efficiently. Ocean dynamics play a critical role, concentrating prey through upwellings, stratification, ice edges, fronts, gyres, or tidal currents.

Competition and predation also may influence prey availability. Links between seabirds and other species could be direct, or extremely diffuse and indirect, and include: competition between seabird species; competition of piscivorous seabirds with other large marine predators such as marine mammals and fish; cannibalism by large pollock on smaller pollock; competition for food among forage species of seabirds, such as small pollock, capelin, sand lance, herring, myctophids, and squid; competition between planktivorous seabirds and whales or planktivorous fish; and even ecosystem links with groups such as jellyfish. Little information is available on the magnitude or direction of these links.

Other Impacts

Oil damages feathers necessary for insulation from cold water, and if ingested may damage internal organs and the immune system. Species at most risk are diving seabirds, which spend more time resting on the water than do surface-feeders. Alcids are considered most vulnerable, followed by diving ducks. Surface and plunge feeding pelagic seabirds (albatrosses, petrels, fulmars, shearwaters, skuas, and jaegers) are moderately sensitive. Gulls and terns generally can avoid being oiled. A second threat is ingestion of plastics, especially by seabird species feeding primarily by surface-seizing or pursuit-diving, such as tubenoses and parakeet auklets. Gulls and most alcids ingest little or no plastic. Plastics are mainly in two forms, pellets and fragments, and are damaging to seabirds when they are consumed in sufficient quantity to obstruct the passage of food or cause stomach ulcers. Other effects may include bioaccumulation of polychlorinated biphenyls, toxic effects of hydrocarbons, diminished feeding stimulus, reduced fat deposition, lowered steroid hormone levels, and delayed reproduction, though those effects rarely can be isolated from impacts of environmental variability and are difficult to document because birds may quickly disappear from sampled populations.

Steller's eiders and spectacled eiders are listed as threatened under ESA. Steller's eider breeding populations were listed because of a severe reduction in their breeding range and disappearance from the Yukon-Kuskokwim Delta, where they historically occurred in significant numbers. Steller's eiders nest in the terrestrial environment, but spend most of the year in shallow nearshore marine waters. The largest numbers concentrate in four areas along the north side of the Alaska Peninsula: Izembek Lagoon, Nelson Lagoon, Port Heiden, and Seal Islands. They forage on marine invertebrates such as mollusks and crustaceans, and after molting, disperse as far south as Kodiak Island and east to Cook Inlet. Potential causes of decline in the population include predation, hunting, ingestion of spent lead shot in wetlands, and changes in the marine environment that could affect food or other resources. Exposure to oil or other contaminants near fish processing plants in southwest Alaska also may be involved in the decline. There appears to be no direct competition for prey and very little spatial/temporal overlap with the groundfish fisheries and marine waters used by Steller's eiders.

Spectacled eiders nest along much of the coast from the Nushagak Peninsula to Barrow, and east nearly to the Canadian border. Between the 1970's and 1990's, the breeding population on the Yukon-Kuskokwim Delta declined by over 96% and only about 4,000 pairs now nest there. The vast majority breed in Russia, on the northern Chukotka Peninsula west to the Lena River Delta, on Wrangel Island, and Novosibirski Islands. Winter surveys in the Bering Sea indicate a worldwide population of about 360,000 birds. Potential threats to spectacled eiders include lead poisoning from spent lead shot, and predation by foxes, large gulls, and ravens on the breeding grounds where predator populations may be supported by year-round food and shelter provided by human activities and garbage dumps. In addition, complex changes in fish and invertebrate populations in the Bering Sea may be affecting food availability during the 8-10 month non-breeding season. They may also be affected by other shifts in the Bering Sea ecosystem, by commercial fisheries, and by environmental contaminants in the sea. Elements known to be toxic to waterfowl (cadmium, copper, lead, selenium, and zinc) have been found at high concentrations in Spectacled eiders relative to other species, but only lead has been directly associated with eider deaths. Because most of the worldwide population gathers during winter in a small area of the Bering Sea, they may be particularly vulnerable to human disturbance (direct or indirect), environmental contamination or, possibly shifts in prey base due to long term climatic changes.

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Research Needs

The Board must pay particular attention to pressing fishery management issues and marine ecosystem information needs, with an overriding goal of enabling sustainable resource management. Therefore, the greatest emphasis for seabird research likely will be on impacts on seabird populations caused by the groundfish fisheries in the Bering Sea, Aleutian Islands, and Gulf of Alaska. They potentially could have far greater direct and indirect impacts than any other human activity, other than a catastrophic oil spill, or an even worse threat, the introduction of predators such as rats to currently uninfested locations such as the Pribilof Islands.

Long-term climate change, mediated through reduced sea ice cover, likely will change the distribution and availability of prey species that in turn could change nesting and breeding cycles and overall population dynamics of seabird colonies. To evaluate such long-term change and identify the relative importance of fisheries impacts, research is needed on seabird abundance and population trends and how they relate to environmental change. This may require development of additional census methodologies, particularly for crevice dwellers, and enhancement of consistent databases that bring together disparate observations compiled from many years of research. Populations should be studied at the local level, and across regions, particularly if a species is doing well in one region, but poorly in another, in an attempt to determine factors primarily responsible for success or failure. Comprehensive, holistic ecosystems studies on key nearshore and fjord areas also would be beneficial.

Foraging success may be key to overall health of species and colonies. Research is needed to identify dominant energy pathways in marine ecosystems, and prey availability and densities. Foraging patterns, diet composition, and energy requirements need to be determined for both piscivorous and planktivorous species, and methodologies developed and applied for identifying food stress. Interspecies competition for prey and habitat also must be assessed.

There is a need to support the development and deployment of tracking technologies that will elucidate migration patterns for seabirds, especially as they relate to variations in the ocean environment. How will these migration patterns be impacted by climate change? To what extent do migrations and foraging activities overlap the presence of major commercial fisheries? What are the pelagic distribution and abundance of seabirds? How can platforms of opportunity and dedicated research vessels be used to gain a better understanding of pelagic distributions?

Commercial fisheries interactions fall into the category of research that addresses pressing fishery management issues. Whereas marine ecosystems research described above applies to most all species of seabird off Alaska, fisheries interactions are more probable with certain species, based on the best information available from NMFS (Table 3-11). This is based on the views of NMFS and other scientists may have differing opinions. Applied research is needed to assess direct impacts such as bycatch of seabirds in longlines, trawls, pots, and other fishing gears, and collisions of birds with vessel rigging or third wires, and potential support for development of deterrents. Other more indirect impacts should be assessed also, such as disturbance of prey fields and habitat, noise disturbance, and the discharge of fish wastes from processing vessels. All these factors could have direct and indirect influence on seabird colonies and their success or failure. In addition, research is needed on other human-related impacts, such as contaminants and ingestion of plastic pellets and fragments, predator introductions in regions of nesting birds, coastal development and disturbance of habitat, and the population effects of subsistence takes, if any.

Based on the review of specific issues and concerns above, and on research needs identified by NMFS (2004b), Boldt (2003), the NPFMC's plan teams and scientific and statistical committee, and in over 30 proposals on seabird research received in 2002-2004, the NPRB has identified a general list of research needs that fall into six major thematic areas: Fisheries interactions, marine habitat use, foraging success, population dynamics, long-term climate change, and other human-related impacts, as summarized in Table 3-12. Specific suggested research activities are identified for each thematic area and will serve as the basis for developing the implementation plan and periodic NPRB requests for proposals related to seabirds.

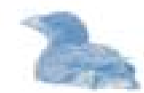

Table 3-11 Fisheries and human-related impacts on seabirds.

	Black-footed Albatross	Laysan Albatross	Short-tailed Albatross	Northern Fulmar	Shearwaters	Storm-petrels	Cormorant, red-faced	Spectacled eider	Steller's eider	Gulls	Red-legged Kittiwakes	Black-legged Kittiwakes	Murres	Marbled Murrelets	Kittlitz's Murrelet	Whiskered Auklet	Other Auklets	Puffins
LMEs																		
Arctic					x			x	x			x	x					
Bering Sea/ Aleutian Islands	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
Gulf of Alaska	x	x	x	x	x	x	x			x	x	x	x	x	x		x	x
Strategic Species																		
ESA Endangered			x															
ESA Threatened								x	x									
ESA Candidate															x			
USFWS Bird of Conservation Concern	x						x				x			x	x	x		
World Conservation Union *Red List*: *vulnerable*	x										x			x				
Fisheries Interactions																		
Incidental catch (possible development of deterrents)	x	x	x	x	x					x	x	x	x	x	x	x	x	x
Vessel strikes, including trawl third wires		x	x	x	x	x										x	x	
Disturbance of benthic habitats								x										
Disturbance of prey fields and food competition										x	x	x	x	x	x			x
Noise disturbance															x			
Impacts on colonies											x	x	x					
Impacts of fish discards & processing offal	x	x	x	x	x					x	x	x						
Other Human-Related Impacts																		
Contaminants impacts, entanglement in debris	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x
Predator introductions and impacts						x					x	x		x	x	x	x	x
Coastal development and disturbance of habitat														x	x			
Subsistence takes								x	x	x	x	x	x	x	x	x	x	x

Research Needs

Table 3-12 General research needs for seabirds.

Pressing Fishery Management Issues ↕ Marine Ecosystems Information Needs

Other Human-Related Impacts
- Contaminants impacts and plastics ingestion
- Predator introductions and impacts
- Coastal development and disturbance of habitat
- Subsistence takes

Fisheries Interactions
- Overlap of fisheries and seabirds habitat
- Incidental catch and development of deterrents
- Mortality/injury from vessel strikes, including trawl third wires
- Disturbance of benthic habitat
- Disturbance of prey fields and competition for food resources
- Impacts on colonies
- Impacts of fish discards and processing offal

Marine Habitat Use
- Development of tracking and tag attachment methods
- At-sea population distribution (including migratory species whose distribution may extend beyond the geographic boundaries of NPRB)
- Benthic habitat requirements

Foraging Success
- Foraging behavior in relation to prey characteristics (availability, abundance, patchiness)
- Individual and population energy requirements
- Factors affecting diets
- Physiological indicators of food limitation
- Effects of competitors on success
- Seasonal and longer-term patterns in foraging behavior (particularly in winter)
- Spatially-explicit modeling consequences of foraging behavior and diets on demography

Population Dynamics
- Development of survey and census methods to estimate population size and vital rates (including photo-identification and mark-recapture)
- Population structure (e.g., genetics, telemetry, mark re-sighting)
- Estimation of population size and trends
- Factors affecting survival probability (e.g., predation, food limitation, disease)
- Factors affecting birth rate
- Spatially-explicit models of factors affecting population dynamics

Long Term Climate Change
- Impacts of reduced sea ice on population dynamics
- Impacts on prey availability and demographic consequences

Implementation Strategies

In developing its nearer term implementation plan for seabirds, the Board will have the advantage of having funded the following projects over the past three years (detailed project information by project number is available at http://www.nprb.org).

Current Projects

Project	Project Number
Commercial fisheries interactions with short-tailed albatross	322, 532
Third trawl wire impacts on short-tailed albatross	323
Seabird observations associated with continuous plankton recorder transects	206, 409
Tufted puffins as bio-indicators of forage fish near Kodiak	413
Feeding ecology of kittiwakes, murres, auklets, and short-tailed albatross in southeast Bering Sea	320
Seabirds as ecosystem indicators	516
Coupled seabird-fish responses to environmental variation	531
Expanding the seabird tissue archive for contaminants monitoring	534

It is likely that the Board will focus on the role of seabirds in the ecosystem. This would commence with project 516 above and inclusion of further research needs in annual requests for proposals. NPRB could support a comprehensive team science approach to study the relationship of oceanography, prey items like forage fish, and seabirds at two to three sites over five years. Part of the strategy could involve comparing areas near major fisheries with areas remote from major fisheries. The Board also may consider supporting studies on sea ducks and their at-sea distribution in order to lay down a baseline for future climate-impact studies.

NPRB also may consider supporting development of new census methodologies and assessment techniques, as well as the application of tracking technologies to seabirds to determine overlap of feeding migrations with major commercial fisheries. Cooperative research with industry on the development of deterrents also could be very important.

Chapter 3
Research Themes

Humans

Humans Section Guide

Introduction

The NRC (2004a) noted that: *one could argue that marine ecosystems and their fluctuations are of interest because of their effect on human societies.* Indeed, important socio-economic issues were raised for potential research at NRC site hearings in rural Alaska, as well as Juneau, Anchorage and Seattle. Therefore, NRC recommended that NPRB pay attention to social, economic and management research in formulating its science plan. Noting that new management systems have been implemented for some fisheries (e.g., Pacific halibut and Bering Sea pollock), and are being contemplated for others (e.g., Bering Sea crab and Gulf of Alaska groundfish), NRC recommended gathering economic and social data on an ongoing basis to evaluate changes that new management regimes have brought or are likely to bring, as well as economic and social research to ascertain the long-term viability of the subsistence economy and the social changes spurred by fluctuating resources and communities.

Similar sentiments were expressed by the U.S. Commission on Ocean Policy (USCOP 2004), when they stated: *Perhaps most important, people must understand the role the oceans have on their lives and livelihoods and the impacts they themselves have on the oceans.* With regard to fisheries, they noted: *In addition to their dietary value, fish are fundamental to the economy, culture, and heritage of many coastal communities in the United States. Fishing has deep cultural, even spiritual roots in many seafaring cities and villages…* They noted that the race for fish and depletion of fishery resources have been major problems in U.S. fisheries, but were quick to point out that *the lack of adequate scientific information has not been the main culprit in most cases of overfishing.* Both how society chooses to utilize scientific information and how it chooses to give users a stake in the outcomes of fishery management are serious objectives for research, as indicated by the Commission in their considerations of implementing a new national ocean policy and with regard to what they term *dedicated access privileges.*

Over the life of this science plan, NPRB intends to fund a variety of social, economic and management research. Motivation for this avenue of research originates with the view that humans are part of sustainable ecosystems, and that human utilization of resources must be balanced with impacts on quality of life, and with the concept of preservation as a value in and of itself (Palmer et al. 2004). Humans interact with marine ecosystems in many ways through culture and ways of life as well as economically. Ecosystems provide for nutrition, subsistence, employment, income, lifestyles, cultural identity, and even spirituality. Whereas ecosystems contribute to human health and wealth, they can also contribute risks to health, e.g., from trace contaminants, and risks to wealth as a result of declines in harvestable marine resources owing to natural fluctuations or inappropriate management measures, although this is less the case in the North Pacific than other U.S. regions. While such benefits and risks have been observed in the past in the Northeast Pacific, they are not well documented and the mechanisms whereby impacts are manifested are not well known. Thus, just as it is necessary to study the dynamics of the ecosystem functions and processes noted in other sections of this chapter, it is also appropriate to study how these processes generate impacts and how they affect individuals and society as a whole. Additionally, the impacts of natural variability and management actions on humans are second or third order effects that are hard to understand in retrospect and even harder to predict for formulation of proactive mitigation measures. Study of how societies adapt to changing environments, ecosystems and management systems is especially important and contributes to the design of resilient management institutions.

At present, little is understood about temporal and spatial scales of physical and biological processes and how they impact humans. As an illustration, it is difficult to account for the failure of a salmon run in one river or region while salmon runs in nearby rivers or regions are abundant. This is especially true in instances where the management approach is consistent across regions or watersheds. Local communities and regions can be differentially affected by such environmentally mediated events. Even within communities, subsistence users can be impacted differently than those dependent on commercial fisheries or other forms of economic activity. Further, at even larger spatial and temporal scales, processes such as the way the global transport of contaminants may be absorbed by Alaskan fish can influence global demand for wild fish. In addition, the interplay of global markets can have distinct local and regional effects, e.g., the price of Pacific cod increases when Atlantic cod becomes scarce. Finally, adjustments in fishery management policies can also influence how effects are felt.

Previous sections focused on natural and human-induced impacts on the ecosystem and its components. The resultant changes in the ecosystem, in turn, can impact human systems and those impacts need to be examined and understood. This section provides a brief overview of the information available to assess impacts on humans, and then identifies general issues and concerns, ranging from fishery policy issues and baseline assessments to human values and resource assessments. These represent cross-cutting themes relative to the human impacts, i.e., assessment of impacts on humans and society and evaluation of human response capabilities. Research needs then are identified and several general implementation strategies are provided that could form the basis for the NPRB research program in the next 10 years. In so doing, management and policy measures are addressed as well as the effects of fishery management and natural ecosystem variability on humans.

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Overview

There are significant differences among the LMEs comprising the North Pacific relative to humans. The Arctic Ocean, in particular, is relatively unpopulated and does not support major commercial or recreational fisheries. Subsistence fisheries are a major source of livelihood and some communities are essentially subsistence-based economies. In the Arctic LME seasonal ice extent shapes the relationship between humans and the environment. In contrast, the BSAI LME also supports subsistence fisheries (and subsistence harvest of marine mammals and seabirds), but is dominated by major commercial fisheries. The commercial fleet and corporate headquarters are based largely outside the region and, in many instances, outside the State of Alaska, though community development quotas provide a bridge between outside interests and local Western Alaska communities. The extensive continental shelf and high abundance of commercial species in the BSAI generate conditions for these large-scale fisheries with largely foreign markets. The GOA provides yet another set of human relationships with the marine environment with small coastal communities prosecuting fisheries in adjacent waters. Subsistence harvests are also important especially where lack of processing or access to markets limits development of commercial fisheries. The GOA also is a major location for recreational fishing by local residents and by tourists. Major issues and concerns warranting research on impacts on humans vary considerably by LME, but one need in common is the collection of good data on a variety of social and economic parameters.

Significant data collection is carried out by the State of Alaska and federal agencies pursuant to census, employment, permits and regulatory analyses. These data are aggregated at various scales from the community or borough, to region or state level, depending on purpose (e.g., Hiatt et al. 2003; NPFMC 1994; and Northern Economics 1998). Specific relationships among the impacts of changing marine environmental conditions and human use of marine resources are not well-documented, nor are appropriate data being collected at relevant spatial scales to analyze changes over time. In general, it appears that research on human impacts relative to the marine environment and resources has received considerably less formal attention than other research areas. In comparison to similar work being performed elsewhere, e.g., within the European Community context (See MegaPesca Lda./Centre for Agricultural Strategy 2000), both the level of information about fisheries that is available and the sophistication of the analyses that it permits are considerably higher in the European Union, than in Alaska or other U.S. regions (NRC 2002c; Pew Oceans Commission 2003; Social Science Review Panel 2003; USCOP 2004).

One illustration of this type of problem is found in the efforts by NPFMC in working with ADFG to develop a management program for halibut fishing from chartered boats (NPFMC 2002). Early efforts to estimate the amount of halibut catch in recreational charterboat fisheries were based on annual creel censuses performed by ADF&G, but these did not sufficiently characterize the nature of the interactions for management decisionmaking.

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Logbooks and other methods were then applied to amplify the data and make them specific to the concerns that were motivating management intervention. Decision making was slow as more than six years passed while gathering adequate information. Similar problems existed with respect to assessing the impacts of the Community Development Program for the Bering Sea (Ginter 1995; NRC 1999b) and development of the Halibut/Sablefish IFQ program (NRC 1999c). With respect to other marine environmental changes and contaminants there remain significant human dimension data and analysis gaps (EPA 2002).

Issues and Concerns

General issues and concerns are identified below that relate to fishery management policy and to impacts on humans. These are not exclusive or exhaustive, but represent concerns where adequate research is lacking and where NPRB funding could make substantial contribution to developing knowledge needed to improve fisheries and environmental management. The general category of impacts on humans is further characterized in terms of the need for baseline assessments, human health and marine resources, human values and resource protection, and climate variability and change.

Socio-economic baselines provide the basis for assessing impacts of regulatory measures as well as impacts of ecosystem change on humans. Systematic monitoring of trends in societies over time in relation to the environment is becoming more and more important as an element of assessments required for decision making as well as for monitoring the performance of such decision processes. Attention to the quality of assessment of each element is critical (Anderies et al. 2004). The ability to assess environmental impacts on humans is especially critical with respect to those peoples who are subsisting on marine resources in the region, but this does not lessen the need to account for impacts on recreational and commercial sectors tied in with the primary natural resource-based economy and the tourist economies.

The spatial scale of the research on impacts on humans brought about by fisheries and environmental management could apply equally to the whole NPRB area or to the specific LMEs. It also should be noted that impacts may extend beyond Alaska and are heavily influenced by factors now occurring in global competitive markets. Temporal scales of human dimension research are primarily dictated by the need to document the present. However, historic information that is place-based or aggregated across the region may be important for understanding some social and economic phenomena. Clearly institutional changes over time have an influence on the nature of decision processes used now.

Fishery Management and Policy

Management of resources and environmental impacts in marine ecosystems depends heavily on the kinds of information that physical and ecological sciences can provide, especially as resource managers move further toward ecosystem-based management. Successful management also requires knowledge of impacts of management decisions on human users of the resources. Of course, humans can speak for themselves in public hearings and through participation in decision-making processes, but there will always remain the need for social sciences like economics, sociology, anthropology, political science and law (including studies of regulatory enforcement and compliance), to provide objective information to decision-makers and governance institutions in order to make decisions that will help sustain resources and society over the long run (Maschia et al. 2003).

Management practices in the BSAI and GOA fisheries are generally considered to be some of the best in the world, and yet resource managers will continue to look for ways to improve management. In developing new approaches to management, there will always be the need to assess the impacts of proposed regulations. However, due to important privacy concerns (e.g., cost data on operations), some desired socio-economic analyses have so far not been possible despite regulatory requirements to assess net economic or social benefits to the nation from proposed or enacted fishery management decisions. Further, there is an obligation to assess impacts on a regional and local level, for example, impacts on fishery dependent communities,

and the methods for doing so are still under development. Relatively little *expost* analysis of the actual impacts of regulatory decisions in fisheries management is performed despite the need to have feedback for developing adaptive management. Further, in the Alaska context there is a dearth of independent policy analysis documentation of management decisions despite the generally acknowledged success (in contrast to failures elsewhere) of fishery management in the region (e.g., USCOP 2004; Ginter 1995; McBeath 2004). Finally, as more formal consideration of multispecies and ecosystem-based fishery management progresses, there are critical elements of the program that will involve research on humans (Witherell et al. 2000b).

A wide range of systematic assessments and policy studies are needed in the Alaska region with particular emphasis on fisheries. This includes attention to the history and development of the fisheries, the role of international agreements, conflicts among regulatory statutes and rulings, management systems, stakeholder participation, role of science in management, and a host of other issues. Research also is needed on the implementation of management plans, the trade-offs among alternative resource protection and utilization measures, and on the impacts of safety measures in fishing.

Baseline Assessments

There is a significant issue of developing appropriate baselines for communities so that their dynamics relative to fisheries ecology and management can be traced systematically over time. This is necessary so that, most importantly, trends in demographic change and effects on individuals and communities can be tracked, but also so the effects of management measures can be assessed in regulatory processes to identify benefits and costs as well as any hardships and inequities that might ensue. In fishery management, for example, one of the federal management objectives is to maximize net benefits to the nation. This objective has been particularly hard to quantify despite major analytical efforts during the inshore-offshore allocation and community development quota debates as well as other more recent actions. Similarly, the current requirements to identify and manage with consideration for fishing dependent communities emphasize the need for detailed, systematically gathered baseline data of high quality. A key element is the ability to understand subsistence fisheries in the different LMEs in Alaska and how these may be affected by natural variability of the stocks, market conditions, and management regulations over time.

Human Health and Marine Resources

There also are significant concerns about the relationship between human health and subsistence and commercial use of marine resources. Subsistence users may be subject to contamination through consumption of traditional foods (e.g., fish, seabirds, marine mammals) and their health may be compromised by substitute diets (EPA 2002). Concern also has been expressed about levels of certain contaminants in commercial and recreationally caught fish such that there could be negative effects on consumer demand and sport fishing services, respectively. Finally, research into the benefits of eating a diet of seafood containing omega-3 fatty acids in Alaskan fish could serve as ways to generate consumer demand for fresh seafood and thereby enhance harvest value and other economic activity. Thus, solid scientific work needs to be done in both the natural and social sciences to assess risks and benefits of seafood consumption and to develop management measures to protect subsistence from harmful consequences and to encourage the healthful use of marine resources.

Human Values and Resource Protection

Global and national concerns about management of fisheries have led to the development of significantly increased interest by new stakeholders who place high value on protection of marine habitats and biodiversity as well as sustainable management of fisheries (e.g., Aley et al. 1999; Giraud et al. 2002; Millennium Ecosystem Assessment 2003; Glantz 2004). These new interests raise important questions about what are acceptable impacts of fishing in the marine environment and how to achieve these levels. Research is underway to identify impacts of fishing but defining what constitutes an “adverse” affect has both ecological and human dimensions. Based on current discourse in the NPFMC arena, there is little agreement on basic definitions or methods of assessment. Research could help to outline areas of agreement and disagreement and thus facilitate development of appropriate management scenarios.

Climate Variability and Change

Climate variability is a key element of environmental change with impacts on marine resources and human dimensions of use. Considerable research is needed at various time and spatial scales to elucidate the atmospheric forcing, ocean circulation temperature response, effect on production at different trophic levels and subsequent impacts on human uses. One of the most tangible anticipated impacts on humans is erosion of coastlines with consequent damage to social infrastructure and the need to protect such facilities or retreat to alternate locations. In addition, there is relatively little known about how climate impacts human uses and how human responses are developed in the marine environment relative to fisheries (Vilhjamsson and Hoel et al. 2004; Overland and Stabeno 2004). Thus, it is worthwhile looking in considerably greater detail at climate variability from a perspective of human dimensions and management implications.

If the regime shift hypothesis is further substantiated, what are the implications for the fisheries off Alaska? A few examples of potential changes illustrate the significance of this information. For the last nearly 30 years the North Pacific ecosystem has been dominated by pollock with relatively limited shrimp, crab and forage fish production compared with the period before the mid/late 1970s when other more cold water-favored species were more prevalent. How robust are management measures to change in the climate regime? In the 1980s effort shifted out of crab and into groundfish as the crab bonanza fizzled and as herring and shrimp stocks declined. What would happen now to the individual and corporate investments in the fishing, processing and distribution sectors if (or perhaps more appropriately, when) crab stocks dramatically increase and pollock and Pacific cod decline? Alternatively, what would happen if circulation and water temperatures developed a previously unobserved condition due to unidirectional change? These are not unreasonable considerations from a LME perspective and management capacity might well be evaluated in terms of its resilience and robustness to such changes. To what extent can adaptive strategies be devised?

Research Needs

Based on review of NPFMC documents, the NRC (2004a) report, the U.S. Commission on Ocean Policy (USCOP 2004) directions and other sources, the NPRB has identified the research needs shown in Table 3-13, presented under the issues and concerns categories outlined above. These research needs should be considered neither an exhaustive nor a prioritized listing of needs, but they do represent topical areas where research is needed to meet the NPRP goals and objectives with respect to providing information that may help with sustainable management of fisheries in the North Pacific ecosystem.

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Research Needs

Table 3-13 General research needs for humans.

Pressing Fishery Management Issues ↕ Marine Ecosystems Information Needs

Fishery Management and Policy

- Role of science in fisheries and living resource management
- Evaluation of precautionary management and its impacts on communities
- Historic and contemporary case studies of management success/performance from the North Pacific
- Analyses of economic factors for decision-making
  - Fixed and variable cost data for fishing and processing
  - Development of integrated multi-species/fisheries models for assessment of major management planning
- Analyses of social factors in decision-making
  - Impacts on communities and fishing sector
  - Impacts on sports fishing and charter fishing sector
- Assessment of fishery management systems (including quota systems), stewardship, and performance (implementation)
- Analysis of impacts of stakeholder participation in governance
- Implications of ecosystem-based fishery management
- Fisheries regulatory enforcement and compliance and analysis of fishing safety
- Elimination of conflicts in statutes, regulations and rulings
- Efficacy and strengthening of international agreements

Baseline Assessment Issues

- Subsistence use of marine resources
- Socio-economic baselines for evaluating fishery regulatory effects / performance
- Development of non-market (e.g., subsistence) valuation methods
- Retrospective analyses of demographic change and economic and social drivers
- Valuation of ecosystem services

Human Health and Marine Resources

- Subsistence user exposure to contaminants and implications for resource management
- Health benefits, concerns, and marketing of commercial harvests of seafood
- Health benefits and concerns for utilization of recreationally-caught fish

Human Values and Resource Protection

- Improve assessment of market and non-market values and trade-offs
- Incorporate competing ethical and social values in resource management
- Understand biodiversity and habitat impacts/trade-offs
- Determination of when the burden-of-proof is met

Climate Variability and Change

- Effects on subsistence users
- Effects on commercial users
- Retrospective analyses of impacts and management decisions
- Implications for design of future management approaches (e.g., incorporation of forecasts, risks and uncertainty)

Implementation Strategies

Human research is a relatively new category for research within the NPRB, however, the following projects have been funded in 2002-2005 (detailed project information by project number is available at http://www.nprb.org).

Current Projects

Project	Project Number
◆ Template for collection and analysis of fishing communities and its application to four key communities	318
◆ Development of an international econometric model of crab supply-demand to estimate relationships affecting prices received for North American crab	423
◆ Socioeconomic baseline information for the Pribilof Islands	528
◆ Valuation of habitat closures	529
◆ Institutions for ecosystem-based management	530
◆ Safety evaluation of fisheries management	533

Historically this area of research has been treated relatively lightly, and therefore a wide range of research is necessary. Early emphasis should be placed on developing baseline information in key areas like subsistence fishing, trends in communities relying on fisheries, effects of environmental change on communities and management policies. Concomitantly, development of better models to assess and evaluate the results of management actions using these and other socio-economic data is necessary. In addition, there is strong need to stimulate research on policies and systems of fisheries management and stewardship of living marine resources including current issues and historical developments. Over time, other research on how humans value the marine environment and its living resources may be instituted to better understand the underlying sources of conflict and possible ways to resolve them.

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Other Prominent Issues

Other Prominent Issues Section Guide

Introduction

The mission of NPRB is to build a clear understanding of marine ecosystems off Alaska that enables effective management and sustainable use of marine resources. Therefore, the science plan to this point has been structured mainly around major components of the three large marine ecosystems off Alaska, particularly as they are utilized or affected by utilization of other living marine resources. As funding allows, the Board may support research on other prominent issues that may arise. Among those identified to date are contaminants, harmful algal blooms, invasive species, aquaculture, and climate change and an ice-free Arctic. Others may be addressed as they arise.

Contaminants

The waters off Alaska are generally perceived as pristine, especially relative to more populated, industrialized areas elsewhere. Contaminant levels vary across the Arctic, being low in some regions, but higher in others. Oceanic and atmospheric transport mechanisms bring contaminants long distances to the marine ecosystem off Alaska. Contaminants can also originate locally from increased mining, fishing, and other industrialized activities within the region, from past and present military operations and installations, from outfalls and run-off in more populated areas, and from sewage releases by cruise ships. These local occurrences likely will increase as population densities grow in coastal areas, and may be exacerbated by climate change and regional warming. According to the Arctic Monitoring and Assessment Program (AMAP 2003), predicting how climate change will alter contaminant transport and disposition is an exceptional challenge. Models predict warming will be more pronounced in polar regions. Permafrost melting and mean annual Arctic river discharge will also increase. Permafrost melting may provide a mechanism for trapped organic mercury, as well as methane, an important greenhouse gas to be released. Increased river runoff especially from heavily contaminated Russian river systems will add more contaminants to the Arctic Ocean. Also, contaminated sites with the Arctic contained by permafrost will become local sources of contamination (AMAP 2003).

Contaminants as a group include a broad range of man-made materials such as plastics, trash, and fishing gear discarded or lost at sea. The Board may support research on the impacts of those discarded materials on the marine ecosystem, but the following discussion focuses on six groups of chemical contaminants identified in the AMAP strategic plan for the Arctic, which, for the U.S., includes all of Alaska:

- Persistent organic pollutants (POPs) that include 12 chemicals: pesticides (aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, and toxaphene); polychlorinated biphenyls (PCBs), and industrial and incineration by-products (dioxins and furans).

- Other persistent chemicals such as polychlorinated naphthalines (PCN), short chain chlorinated paraffins, and current use pesticides, and other persistent chemicals of potential concern, mainly polybrominated diphenyl ethers.

- Tributyltin (TBT).

- Oil and polycyclic aromatic hydrocarbons (PAH).

- Heavy metals (cadmium, mercury, and lead are the major metals of concern off Alaska).

- Radioactivity (mainly isotopes of strontium, technetium, and plutonium).

Other types of POPs are just now being recognized for their potential toxicity in the Arctic: polybrominated diphenyl ethers (PBDEs), belonging to a class of neurotoxic chemicals used as fire retardants in clothing, plastics, and computer parts (EPA 2004). These chemicals are found in and around landfills and leach into surrounding environments. They also reach the Arctic on wind currents from other parts of the world.

POP transport, bioaccumulation, and biomagnification in Arctic food webs appear to be of utmost concern recently (Smolen 2002). Though domestic production of many, but not all, POPs is banned in the U.S., Canada, and some European nations, other countries continue to produce and apply them. They enter the world's oceans and atmosphere and are transported intact long distances from the south and from various riverine systems around the Arctic Ocean that drain broad industrial and agricultural areas of Russia. In particular, the Ob, Yenisey, and Lena rivers contribute significant POP, PAH and radionuclide loads, which then circulate around the Arctic Ocean to the Chukchi and Beaufort seas. Pacific Ocean currents also provide a pathway for contaminants to the waters off Alaska, bringing contaminants from agricultural and industrial sources in Southeast and Central Asia.

Various mechanisms may trap contaminants in Arctic regions: (1) chemical and microbial breakdown is slower under colder temperatures, leading to longer half-lives; (2) soluble organic contaminants such as hexachlorocyclohexanes (HCH: e.g. lindane insecticide) are transported through a combination of prolonged persistence in cold waters and large volumes of oceanic water movement; (3) POPs with lower solubility are transported attached to fine particles in the air or water; (4) colder temperatures encourage condensation or deposition of semi-volatile POPs carried in the atmosphere from warmer regions; (5) contaminants deposited from fog onto sea ice, concentrates at the ice edge as sea ice melts in spring; and (6) reduced solar radiation in the Arctic retards photodegradation of contaminants (BSERP 1998; EPA 2002; Smolen 2002). These conditions, coupled with the uniquely higher latitude annual cycle of prolonged cold, winter darkness, followed by summer warmth and long daylight hours, may lead to a sudden release of POPs that have accumulated in the ice, into the flourishing food chain during the very limited time of peak productive and reproductive activity following the spring melt.

The NRC identified three primary risks from contaminants as they move through the food web: (1) toxicity to individual organisms; (2) toxicity to humans, especially Alaska natives who may depend predominantly on aquatic foods, and (3) contamination of commercially-fished species which may affect marketability (NRC 2004a). In site visits, the NRC committee found that rural residents were particularly concerned with bioaccumulation of toxins in foods important to the subsistence economy, especially seal and whale fat, and shellfish.

Contaminants end up in many parts of the ecosystem. Some are entrained in bottom sediments. However, in relatively shallow areas such as the Bering Sea, shore ice and benthic animals disturb the sediments and re-suspend the contaminants, making them more available to the food web. Animals also incorporate contaminants in their tissues, introducing them to the food web to the extent they are prey for fish, seabirds, and marine mammals (BSERP 1998). Higher in the food chain, cold-water animals that accumulate large amounts of fat will concentrate organic contaminants such as pesticides and PCBs, taking on considerable risk from those contaminants even though concentrations in the surrounding environment may be quite low. In the Arctic marine ecosystem the increase of PCB and chlordane related compounds increases 10-fold at each level of the food chain (AMAP 1998). Survival of all species in the cold Arctic depends on securing and maintaining energy levels, based largely on fat storage and utilization. POPs are lipophilic; as fat is consumed, they are passed efficiently up the food chain to top predators, including humans (EPA 2002). Whereas POPs accumulate in fat, heavy metals generally accumulate in organs and muscle. Adverse effects from exposure to contaminants may result in reproductive, immunological, neurological, and developmental effects and cancer (OWS 2002).

Some concerns identified in contaminants-related proposals received by the Board in 2002-2004 included transport and bioaccumulation of POPs; photo-enhanced toxicity of polycyclic aromatic compounds on fish embryos; contaminant loads and impacts in subsistence, recreational, and commercial fish species; exposure of waterfowl to hydrocarbon contamination through food sources; and marine food web impacts of flame retardants (PBDEs) leaching from landfills.

Certain species are of particular importance because of their role in the marine ecosystem, their importance as subsistence food sources for humans, or their condition as stressed species. For example, polar bears are a key species for monitoring environmental contamination because they are at the top of the Arctic food chain, and valuable to Native subsistence users. There is relatively little recent information on heavy metal and organochlorine contamination in Alaska polar bears. PCBs in adult bears are relatively low compared to high levels found in bears from eastern Hudson Bay, Canada and Norway. Average levels of HCH in Alaska polar bears are among the highest levels reported in the Arctic, but the role of these high levels with respect to health and to human consumers is not known. There is a need to establish baseline levels of trace elements in liver, kidney and muscle, and organochlorine pesticides in fat tissues of adult males and develop a database for tissues (USFWS. Undated).

Beluga and bowhead whales provide a source of food for many Alaska Natives. The muktuk (skin and outer layer of fat) of belugas is considered a choice item for consumption (Hild 2003). POPs are highest in the outer layer of fat, but normal concentrations of POP are similar to Canadian Arctic beluga whales, and much lower than whales from highly contaminated areas of eastern Canada. They are even low in Cook Inlet stocks which reside in one of the most urban areas of Alaska. Bowheads have very low levels of PCBs, perhaps because they are filter feeders, consuming prey from a lower level of the food chain (EPA 2002).

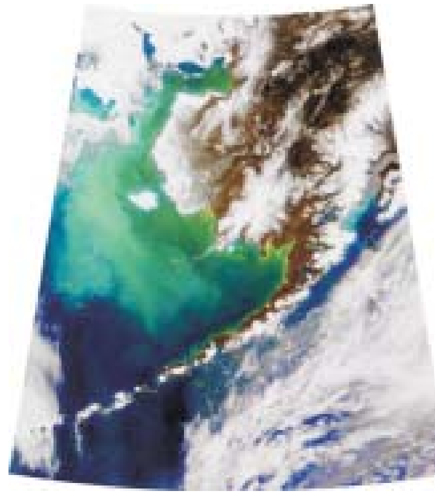
Bearded, harbor, northern fur, and ringed seal blubber samples have been collected and analyzed for POP contaminants (EPA 2002). Harbor seals have low but measurable levels with Prince William Sound specimens having much lower concentrations than specimens from the Pacific Northwest. Some male subadult northern fur seals from St. Paul had higher concentrations than ringed and bearded seals from the Bering Sea or from Prince William Sound. This may result from the long fur seal migrations that occur to areas far south of Alaska where contaminant loads are much higher. Steller sea lion blubber has PCBs as the predominant POP, followed by levels of DDT/DDE (EPA 2002). Higher concentrations are found in sea lions from the Gulf of Alaska than in the Bering Sea. Walrus have been found to have contaminant loads that reflect pollutant concentrations in sediments of the Chukchi and Bering Sea. Levels of organochlorines and aliphatic hydrocarbons are largely below detection levels in blubber collected from Bering Sea walrus in 1991. Any increases in oil and gas development and mining activities within the range of the Pacific walrus could elevate concerns over contamination.

Sea otters tend to accumulate organochlorine compounds from the food chain in the nearshore environment. Analyses of organochlorine and heavy metals in livers and kidneys collected from 65 otters throughout Alaska have shown low levels of PCBs, beta-BHC and dieldrin. Sources and effects of these contaminants are unknown.

Steller's and spectacled eider populations have declined significantly and concerns have been raised over possible impacts of contaminant exposure. Several surveys in Alaska and Arctic Russia have shown that organochlorine levels were very low, but some elements such as cadmium, copper, lead and selenium were surprisingly high compared to published values. Lead appears to be entering the U.S. breeding population via ingestion of lead shot. Sources of other elements have yet to be established. Contaminant levels in spectacled eiders have been fairly well characterized, but routes of exposure remain unknown.

Salmon provide a means of transport for very low levels of chemicals such as PCBs and DDT through their migratory and reproductive patterns. Salmon carry these low levels upstream into fresh water drainages and after spawning, dying, and decaying, release it into the food web. The levels of POPs delivered by sockeye salmon to Alaska interior lakes and rivers have been estimated to be slightly above levels deposited through atmospheric means, although levels are far below those found in fish from the Great Lakes region (EPA 2002).

Ultimately, the impacts of contaminants as they are transported through the food web to human users may be of greatest importance. There has been little research on the effects of potential contaminants in subsistence foods on the health of Alaska Natives, and studies are needed on cumulative affects on humans of a subsistence diet of several species with known concentrations. One study published in 2000 showed increased PCB concentrations with age through the mid-1970s, with greater concentrations in females than men in Alaska Natives from the Aleutians (Middaugh et al. 2000). The sample sizes were so small, however, that few conclusions could be drawn. Because research on the health effects of contaminants in traditional foods has been uncoordinated and undirected, there has been considerable confusion within rural communities on whether traditional foods are safe to eat. As a result, some Alaska Natives have begun avoiding certain traditional foods or certain parts of foods, such as internal organs, because they know it contains contaminants (OWS 2002). EPA (2002) emphasizes that POP levels measured in human populations in Alaska (Aleutian, Pribilof Islands, and North Slope) are similar to those experienced by the background U.S. population, and that there are no known POP levels at this time in Alaska that should cause anyone to stop consuming locally obtained, traditional foods or to stop breastfeeding children. Further assessments and investigation are needed of specific species and foods in traditional diets and to broaden the database across Alaska communities.



Harmful Algal Blooms

Paralytic shellfish poisoning (PSP) is the major harmful algal bloom (HAB) concern in Alaska. Kodiak residents believe the incidence of PSP has increased over the past decade, and many now believe that eating shellfish is dangerous and should be avoided unless shellfish beds are thoroughly tested (NRC 2004a). The following discussion is based primarily on Boldt (2003: particularly see contribution by G. Plumley, J. Matweyou, and R. RaLonde, p. 57-69). Domoic acid, a potent neurotoxic amino acid produced by diatoms off the genus *Pseudo-nitzschia*, also causes significant problems (R. RaLonde, Alaska Sea Grant Marine Advisory Program, personal communication). Plumley et al. (2003) have reviewed the occurrence of PSP in Alaska waters. It is caused by dinoflagellates of the genus *Alexandrium*, primarily *Alexandrium catenella*, though there are some 29 recognized species within the genus, with at least 8–10 toxic species. The toxic species synthesize saxitoxin, a neurotoxin which prevents the uptake of sodium and stops the flow of nerve impulses. Saxitoxin is typically accumulated in filter feeding shellfish that are relatively immune to the toxin, and is transferred through the food chain by secondary consumers. Symptoms in humans include tingling and/or numbness in the lips and extremities, nausea, dizziness, shortness of breath, and in extreme cases, paralysis and death. The toxins are water-soluble and will pass from the system without causing permanent damage if victims are kept alive during the stages of respiratory paralysis. The toxins can also be passed through the pelagic food web via zooplankton and forage fishes, ultimately affecting upper trophic levels, i.e., fish, seabirds and marine mammals.

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Alexandrium has a very complex life cycle, altering between asexual and sexual stages. This enables cells to persist through unfavorable conditions as well as to thrive in a spectrum of habitats and hydrographic regimes. The vegetative cells are able to divide rapidly during favorable conditions, but under nutrient stress, may form a dormant, resting cyst that can survive in sediments for years. Cysts must undergo an obligatory dormancy period during which physiological "maturation" is presumed to occur. Mature cysts enter a quiescent period when they are physiologically capable of germination, but may be prevented from doing so by some environmental factor. Germination requires favorable temperatures, light, salinity, and oxygen conditions. Thus it is commonly assumed that overwintering cyst "seedbeds" provide the inoculum for *Alexandrium* blooms when conditions are favorable. Persistent, reoccurring PSP problems would be expected in "seedbed regions" whereas PSP problems in adjacent areas would depend upon currents and wind conditions. Although cyst seedbeds have not been documented in Alaska, it is well known that some areas have persistent and seasonally recurring problems with PSP toxins, while PSP problems are surprisingly absent in other areas. The seedbed hypothesis remains an attractive, yet unproven, model to explain ecosystem level PSP problems in Alaska. An alternative hypothesis is that low abundance winter populations of *Alexandrium* survive in offshore waters and that these populations provide an inoculum for nearshore habitats when wind and temperature regimes shift in the summer. Further studies that couple biological studies of *Alexandrium* with physical oceanography and climatic events are needed to substantiate which alternative is correct for the marine environment off Alaska.

PSP has significant health and economic impacts. From 1973 through 1994 the Alaska Division of Public Health documented 71 outbreaks of PSP involving 141 people from coastal communities around the state, with cases reported in all months except November and December. A variety of shellfish was implicated in these illnesses. Since 1994, at least 17 additional illnesses from five separate outbreaks have been documented, and many cases are thought to go unreported. Commercially, the loss of revenue due to PSP toxins has been extensive, affecting both the crab and clam fisheries. Some crab processing and handling have been changed from a whole, live product to a sectioned, cooked one due to PSP toxins found in crab viscera. Once a growing industry, the Alaska clam industry today is virtually nonexistent due to the destruction of the market by PSP contaminated product in the 1940's, and remains a large untapped fisheries resource. The difficulties, expenses, and fear of contamination make developing a viable shellfish market a financial risk.

Bitter crab disease, though technically not an HAB phenomenon, also is caused by dinoflagellates related to those that cause PSP. A parasitic dinoflagellate (*Hematodinium* sp.) may play a key role in poor recruitment of *C. opilio* and *C. bairdi* Tanner crab, whose abundance remains low in the eastern Bering Sea. Small crabs may be particularly susceptible to infection: infection rates may exceed 10% for crabs less than 40 mm carapace width in the eastern Bering Sea (Morado et al. 2003. Unpublished data). Effective diagnostic tools are needed to develop information on the pathogen's life history. Monitoring dispersal patterns and timing of infection could lead to predicting areas of potential high infection rates. Such information could influence managers to limit the spread of bitter crab disease or to develop area-specific quarantine procedures. The Tanner crab resource was the basis for a major fishery off Alaska that took the place of the very lucrative red king crab fishery in the early 1980's. Reaching a peak harvest level in 1991, the Tanner crab fishery has generally been in decline. Knowing the role that bitter crab disease plays in the natural mortality of Tanner crabs could aid in the recovery of the population.

Invasive Species

Invasive species are species that are both non-native (alien) to a particular ecosystem and whose introduction causes or is likely to cause economic or environmental harm or harm to human health (Executive Order 13112, February 3, 1999). Invasive species can pose a major threat to Alaska native flora and fauna and result in ecosystem disruptions that could cause severe economic harm. The following discussion is based on the Alaska Aquatic Nuisance Species Management Plan, published by Alaska Department of Fish and Game in October 2002. Relatively few invasive aquatic species have been introduced and become established in Alaska waters compared to other states. This may be due in part to stringent plant and animal transportation laws, but more likely to the geographic isolation of Alaska, northern climate, small population size, and relatively pristine habitat. Alaska is vulnerable to movement of game or bait fish from one aquatic system to another, movement of large ships and ballast water from the U.S. West Coast and Asia, fishing vessels docking at Alaska commercial fishing ports, trade of live seafood, and aquaculture. Ports with high volume marine traffic are especially vulnerable, including ports in Dutch Harbor, Kodiak, Prince William Sound, Cook Inlet, and southeast Alaska. Invasive species from the West Coast of the U.S. and Canada may easily extend their range northward. The problems could be exacerbated if shipping intensifies with recession of the ice pack in the Arctic under global warming.

Currently, the only non-indigenous marine fish species that is considered an invasive species is the Atlantic salmon that escape from fish farms in British Columbia and Washington, and have been found in streams near Cordova, Ketchikan, and Yakutat, and as far north as the Bering Sea. They are a serious threat and would most likely compete with native steelhead, cutthroat trout, Dolly Varden, and coho salmon, and may adversely impact other species of salmon. The other highest potential threat is from northern pike that were introduced from north of the Alaska Range to the Susitna River and the Kenai River drainages and poses a grave threat to valuable salmon stocks. Invertebrates of interest include the northern European green crab which was first introduced about 10 years ago to California and has extended its range north to Vancouver Island. An invasion could severely impact local populations of Tanner, king, and Dungeness crab that use nearshore areas for nursery areas. In addition, the Chinese mitten crab, which has become established in San Francisco Bay, has been found as far north as the Columbia River. Those two invasive species are efficient predators that compete with indigenous fish, shellfish, and birds for food. It is uncertain whether Alaska estuary salinity and temperature conditions are suitable for survival and reproduction of those species. More research needs to be done to assess the risks of invasion. Other organisms that have been identified as potential threats include the New Zealand mudsnail, zebra mussels, signal crayfish, uncertified oyster spat, spiny water fleas, and whirling disease.

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Aquaculture

Currently, Alaska's aquaculture industry includes shellfish farming and salmon ranching. State law restricts aquatic farming to seaweeds and shellfish, and currently there are nearly 60 shellfish farms, mainly for oysters and mussels, operating in the state, mainly in five areas: Kodiak Island, Kenai Peninsula, Prince William Sound, Yakutat, and southeastern Alaska (R. RaLonde. Undated). In order of importance, the following shellfish and aquatic plants are being raised in Alaska: Pacific oysters (*Crassostrea gigas*), blue mussels (*Mytilus edulis*), littleneck clams (*Prothothaca staminea*), scallops *(Chlamys rubida, C. hastata, Crassedoma gigantes*, and *Patinopecten caurinus*), bull kelp (*Nereocystis leutheana*), and *Porphyra* species. Oysters grow particularly well in the cold nearshore waters of Alaska, that provide abundant, high-quality plankton. Cold clean water reduces bacterial contaminaton, thus extending shelf life and assuring safety when eating cultured oysters, especially when eaten raw (ADFG FAQ Sheet on Mariculture). All farmed Alaskan oysters are imported as spat from Pacific Coast hatcheries.

Alaska Statute 16.40.210 prohibits finfish farming, which is defined as growing or cultivating finfish in captivity. Ocean ranching, on the other hand, involves release of young fish into public waters. The salmon become available for harvest by fishermen upon their return as adults. Salmon ranching is done by non-profit hatcheries, primarily owned by commercial salmon fishermen, who support their fisheries with releases of approximately 1.5 billion salmon smolts each year (see http://www.uaf.edu/map/aquaculture/).

A major concern with aquaculture of any type is the introduction of new species to Alaska. Alaska's marine systems are often in pristine condition and highly productive in their natural state. For shellfish or any other aquaculture to be compatible with maintaining the high productivity of the natural marine ecosystem, the problems of interaction between wild and cultured species will need to be addressed. The escape of Atlantic salmon from British Columbia net pens, and their subsequent occurrence off Alaska, is a case in point, and was discussed earlier under invasive species. There is potential for many other issues and concerns to arise if State law is ever revised in the future to allow additional aquaculture opportunities.

Climate Change and Ice Free Arctic

Climate trends over the past 30 years have shown considerable warming and Alaska has experienced the largest regional warming of any state in the U.S., with a rise in average temperature of about 2.8 C since the 1960s, and 4.4 C in winter. The temperature of the entire water column (250 m deep) near Seward has increased by about 0.03 C per year for the past 33 years (about 1 C total) (Royer 2004). There has been extensive melting of glaciers, thawing of permafrost and reduction in sea ice. This is part of a warming trend throughout the Arctic. As noted previously, global climate models predict average annual air temperatures to rise across the entire Arctic region by roughly 3-5 C over land areas and up to 7 C over the oceans. Some models predict a decline of roughly 10-50% in annual average sea ice extent by 2100, and the complete disappearance of summer sea ice by 2040. These climatic changes are projected to include shifts in atmospheric and oceanic circulation patterns, an accelerating rise in sea level, and wider variations in precipitation, with significant impacts projected for water resources, coastal communities, animal and plant species, and human health and well-being. Input from glacial melt water could cease either from lack of glaciers or buildup of glaciers.

Climate change could be particularly devastating to coastal Alaska Native villages. Flooding and erosion already affects 184 out of 213, or 86%, of those villages to some extent (GAO 2003). While many of the problems are long-standing, the GAO found that various studies indicate that coastal villages are becoming more susceptible to flooding and erosion due in part to rising temperatures. Four villages in particular, Kivalina, Koyukuk, Newtok, and Shishmaref, are in imminent danger from flooding and erosion and are planning to relocate. Cost estimates for relocating are expected to be high, estimated at $100-400 million for Kivalina alone (GAO 2003).

Reduced ice cover will influence primary production and types of algae species as well as amount of organic carbon available to faunal communities in the water and sediments. Reduced ice extent also could have serious impacts on marine mammal populations associated with the ice pack and edge, such as ringed seals, walrus, polar bears, and cetaceans, to the extent that ice fields affect feeding and reproductive activities. Climate change may have significant effects on Alaska fisheries (Weller and Anderson 1999). Some fish species such as salmon could shift north with the ice edge. Abundance of some fish species could be reduced while others could increase, changing the patterns and magnitudes of commercial harvests.

Some commercial fisheries may disappear while some new fisheries may develop. Significant changes in harvest levels may occur rapidly and these changes may be felt more strongly in some areas of Alaska, than others. Climate-related stresses on other species, including sea birds and marine mammals, may cause managers to curtail commercial fisheries harvests or change how fisheries are prosecuted. These changes in turn could impact employment and distribution of incomes from fishing activities. There also could be increases in non-fishing activities such as shipping and offshore oil extraction which could impact the environment and affect the health and traditional lifestyles of indigenous people (ACIA 2004).

Implementation Strategies

Research strategies for these other prominent issues have not been identified as clearly as for the preceding topics covered by this science plan. Further work is required in the form of synthesis meetings on each of the topics before a definitive research program can be developed by NPRB. There also may be funding limitations for these programs, considering that the Board must be responsive to its legislative mandate to give priority to research designed to address pressing fishery management or marine ecosystem information needs.

Contaminants NPRB may consider supporting individual studies to determine sources, fates, and trends in concentrations of contaminants, and their how they may influence natural variability of animal populations. A workshop could be funded to further develop a coordinated contaminants monitoring program, and then the Board could determine whether or not to support collection of a time-series of contaminants data at strategic locations for which there are good support data for physical and biological processes. These should include samples of plankton, fish, mammals, people, snow, water, ice, air, surface water, groundwater, and soils. NPRB could partner with other sampling efforts (e.g., Alaska Sea Otter Commission) to develop opportunistic geographic distribution of samples based on voluntary participation of Native subsistence hunters and could support studies to determine how contaminants in living marine resources affect the health of individuals and communities reliant on those resources. And finally, there is a significant need to conduct a risk assessment of contaminants. Technologies to detect contaminants are becoming ever more sophisticated. An emerging issue of great importance is evaluating the actual harm from extremely low concentrations of contaminants, and to what degree populations are at risk from such low, but increasingly detectable, concentrations.

Harmful Algal Blooms Possible research strategies on PSP and bitter crab disease could include support of studies to determine seasonal trends in *Alexandrium* abundance in various regions of Alaska as a predictor of PSP and the environmental variables that may be influencing abundance. Sentinel species of shellfish could be identified and key monitoring sites established around Kodiak and southeast Alaska for oyster farms and geoduck harvests. Also, research is needed on bitter crab disease and its impacts on the shellfish industry.

Invasive Species NPRB will consider addressing research needs on invasive species as they are brought to its attention by the State of Alaska, National Marine Fisheries Service, or other agencies and entities.

Aquaculture NPRB will consider addressing research needs involving aquaculture as they are identified and if funds are available. Of special interest may be potential development of aquaculture outside three miles (e.g., halibut and sablefish) under new federal initiatives. And finally, there is the critical issue of how the introduction of millions of salmon by ocean ranching activities around the Pacific Rim into the marine ecosystem impacts ocean rearing capacity for wild salmon stocks and other species.

Climate Change and Ice Free Arctic Through its other monitoring activities of ocean characteristics and marine life, NPRB will be contributing to the long term record of change over the next 50 years as regional conditions change. NPRB way wish to partner with science programs that are actively engaged in climate change research, such as SEARCH, GEM, AOOS, as well as NSF and federal science programs. Certainly its research initiatives on ecosystem components as described elsewhere in this plan will be on the forefront of helping scientists detect changes in Alaska marine regions attributable to climate change.

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Integrated Ecosystem Research Programs

Integrated Ecosystem Research Programs Section Guide

Introduction

The overall vision of the North Pacific Research Board is to achieve a clear understanding of the North Pacific, Bering Sea, and Arctic Ocean ecosystems that enables effective management and sustainable use of marine resources. As noted in Chapter 1, to achieve this vision, the Board will need to develop integrated ecosystems research programs for each of the three LMEs, recognizing that funding could constrain the exact number that could be supported over the longer term. These IERPs will require interdisciplinary research teams performing well-integrated regional and large-scale investigations into the structure and function of ecosystems in order to understand the populations they support.

Earlier sections of Chapter 3 focused on components of the ecosystems, generally represented in terms of lower trophic level productivity, fish habitat, fish and invertebrates, marine mammals, seabirds, and humans, and on several longer term issues. Research needs and themes were developed for each component, arrayed against the Board's statutory priorities on pressing fisheries management issues and marine ecosystem information needs.

In the following discussion, examples and opportunities of new integrated programs are identified for seven major regions within the three LMEs off Alaska. These are intended to be viewed as guidelines and examples only: Specific regions of study, hypothesis and approaches will be developed through a sequence of synthesis workshops whose attendees should include researchers, managers, shareholders and representatives of the Board and its science and advisory panels. The examples also recognize that current understanding of the three LMEs is insufficient to develop a single IERP for an entire LME. Rather, examples are provided of integrated plans within an LME, which eventually could coalesce into a single integrated LME-wide program as knowledge and understanding mature over the coming years. Last, several implementation strategies are presented as examples of potential next steps in developing a multidisciplinary program within LMEs.

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Examples of Existing IERPs

The Fisheries Oceanography Coordinated Investigations program provides an example of an IERP. FOCI has a species focus on pollock, has enhanced our understanding of the ecosystem in the western Gulf of Alaska and eastern Bering Sea, and continues to provide information to help forecast potential year class strength to the plan teams responsible for providing management advice to NMFS and NPFMC. While most elements in the conceptual model now are part of FOCI, seabirds, marine mammals and impacts on humans were not part of the initial program. The program initially operated within a few hundred kilometers of the western end of Shelikof Strait, on a budget of $1.5 million per year for equipment, personnel and computer time. FOCI was designed on a conceptual model of factors (both physical and biological) important at various life history stages in determining year-class strength of pollock in Shelikof Strait (e.g., Kendall et al. 1996) that suggested the majority of mortality occurred between first feeding and age-0 fish (e.g. Bailey et al. 1996). The overarching hypothesis was that a necessary condition for strong recruitment was that larvae remain on the shelf rather than being carried offshore into the Alaskan Stream. Note that this is not sufficient for strong recruitment: other biological factors (e.g., increased predation by rapidly growing arrowtooth flounder population) could greatly reduce survival even on the shelf, as apparently has occurred after a regime shift (Bailey 2000). Studies included the influence of mountains and gaps on regional atmospheric pressure and wind fields, generation, movement and impact on biota of eddies, development of techniques for assessing larval condition at sea, behavioral determinants of distribution and survival, interannual variability in growth, development and application of a circulation and an individual based model, etc. Scientific products from FOCI span nearly all elements of the Conceptual Model. In the mid-1980's, FOCI began to expand research into the Bering Sea and this was complemented in the 1990's by Minerals Management Service's shelf slope exchange program, NOAA's Coastal Ocean Programs (Bering Sea FOCI and Southeast Bering Sea Carrying Capacity) and the National Science Foundation's Inner Front Study.

Other examples of IERP's in Alaskan waters include the Gulf Ecosystem Monitoring program, the Northeast Pacific GLOBEC program and the developing Bering Ecosystem Study (BEST) program. The BEST program, which has progressed from an idea to a comprehensive science plan that may be funded through NSF in 2005 or 2006, encompasses the elements of the conceptual model, including a specific question on how ecosystem changes impact quality, quantity and availability of resources for commercial and subsistence harvests. BEST, however, does not address issues concerning human impacts to the ecosystem. The draft science plan was developed though two workshops, guided by a planning group and advisors. The development of a NPRB IERP likely would follow a similar path. BEST asks the overarching question: "How will climate change affect the ecosystem of the Bering Sea?" If funded, the BEST program offers an excellent opportunity for partnerships with NPRB programs.

Opportunities for New IERPs

The following discussion provides examples of opportunities for new IERPs, particularly those that would have the greatest payoff in helping the Board achieve its mission of providing information to enable sustainable resource management. They are developed on the basis of the significant issues raised in previous sections on major components of the marine ecosystem. They provide just a starting point and will need considerable guidance and deliberation from managers, scientists and stakeholders with an interest in the regions.

Southeastern Gulf of Alaska

The positive or stable population growth of Steller sea lions and other marine biota in the eastern GOA merits examination of why this is occurring while similar populations are less vital in the western GOA and BSAI. Relatively little is known regarding the atmospheric and oceanographic (including nutrient fluxes) elements of this ecosystem or of how they might influence secondary production. It is possible that enhancing our knowledge of the linkage from atmosphere to forage fish could provide the answer to why higher trophic level populations are stable. Initiating time series of observations from physics to upper trophic levels would be critical to beginning to integrate our understanding of the ecosystem dynamics in this region that has not been systematically studied in the past.

Some questions include: what are the atmospheric and oceanic mechanisms that most influence changes in southeastern GOA ecosystem dynamics and result in abundant and/or stable populations of a number of upper trophic level species (e.g., shrimp, crab, herring, Steller sea lions, etc.); is fish and shellfish recruitment more constant because the spring bloom is more consistent owing to the predominant roles of solar radiation and topographically fixed features that lead to mechanisms (e.g., eddies and gyres) that retain larvae; what are the relative influences of natural and human related factors on the ecosystem?

Northern Gulf of Alaska

The extensive along-shore current system in the northern GOA serves as both an important habitat and as a migratory corridor for a variety of marine organisms. Waters in the northern Gulf are considerably modified, however, by heat exchange with the atmosphere, freshwater discharge from land, and cross-shelf transports (of freshwater, nutrients, heat, plankton, fish eggs and larvae) induced by winds, shelf break eddies, and changes in shelf bathymetry and coastline (Hermann et al. 2002; Stabeno et al. 2004; Weingartner et al. 2005). These modifications eventually influence the western GOA ecosystem, provide a changing environment for organisms moving through the region, and affect Prince William Sound (Niebauer et al. 1994). The Sound's unique ecosystem is a critical component of the northern GOA ecosystem in supporting a variety of species of commercial and/or subsistence value (Cooney et al. 2001a, 2001b). The structure and function of the northern GOA ecosystem depend critically upon abiotic and biotic exchanges between the Sound and the adjacent shelf and slope. Some important questions include: how resilient is this ecosystem to changes in physical forcing and to alterations in upper trophic level community composition; e.g., what are the relative roles of bottom-up and top-down forcing in shaping this ecosystem; what are the major atmospheric and oceanic mechanisms including exchanges between Prince William Sound and the adjacent shelf and slope that affect northern GOA ecosystem structure and function?

Western Gulf of Alaska

In the western GOA, shifts in atmospheric and oceanic forcing can impact transport and the presence of eddies in the Alaskan Stream, thus affecting the flux of nutrients and plankton onto the shelf and larvae off the shelf. Fluctuations of strength and eddy behavior of the Alaska Coastal Current, together with its role as a source of nutrients, also may impact ecosystem dynamics, including recruitment of fish species (Kendall et al. 1996). From the top-down, commercial trawl fisheries and predators (e.g., arrowtooth flounder) may exert population control on pollock and other forage fishes, which may play a role in the decline of Steller sea lions and other marine biota. Some issues are: what are the physical mechanisms that most influence ecosystem change through impacts on the nutrient-phytoplankton-zooplankton production sequence and/or larval retention on the shelf; how do these factors, together with impacts of removal by predators (including commercial fishing) affect the regional ecosystem (e.g., pollock abundance, species mix and trophic structure), and are these factors (predation and bottom up forcing) related to declines at upper trophic levels (e.g., sea lions, harbor seals, some bird populations, Pacific cod)?

Aleutian Islands

The Aleutian Island ecosystem is influenced by transport of heat, salt and nutrients from the Alaskan Stream into the Bering Sea, and climate change will influence the associated processes that may affect the ecosystem. Two issues of major importance in the Aleutian Islands are the decline of the Steller sea lion and potential impacts of major fishing activities (trawling, longlines, and pots) to the benthic habitat, which has a highly diverse and abundant coral and sponge community. Summaries of historical survey data and recent observations indicate that the Aleutian Islands may harbor the highest diversity and abundance of cold-water corals in the world, and these communities likely provide important habitat for a variety of fish and invertebrate species (Heifetz et al, in press). Within the Aleutian Islands there is an increase in diversity of corals west of about longitude 169 W, consistent with the hypothesis of an ecological boundary near Samalga Pass (Ladd et al. in press). The potential need to protect the coral gardens because of their uniqueness and contribution to biodiversity and fish habitat, together with the requirement to protect endangered Steller sea lions (and soon sea otters), and an emergent pollock fishery in the Aleutian Islands near Adak, make this a potentially important region for an integrated ecosystem research program. Some important issues in the Aleutian Islands include: what drives the subarctic gyre and how will changes to nutrient, heat and salt fluxes through the passes impact ecosystem function and structure; what is the role of coral in the ecosystem and what are relative impacts from commercial fishing gear and climate on coral; is predation of sea lions and otters by killer whales a significant factor in their population trends; and what management strategies could be most successful at sustaining ecosystem services?

Southeastern Bering Sea

Ecosystem-level changes in the Bering Sea have been clearly documented over the past 30 years (e.g., PICES 2004). In the southeastern Bering Sea, changes have occurred in both the benthic and pelagic community structure (NRC 1996, 2003) including an increase in zooplankton biomass (Brodeur et al. 2002), invasion by warm water species, a ten-fold increase in gelatinous zooplankton between 1979-97 and subsequent crash after 2001-2003, more frequent blooms of coccolithophorid phytoplankton, and declines in various marine mammal and bird populations (e.g., NRC 2003; Boldt 2003). Similar ecosystem-level change has been observed in the northern Bering Sea, with declines of benthic biomass and mean sizes of the dominant bivalves south of St. Lawrence Island, in the Chirikov Basin, Bering Strait and the southern Chukchi Sea (Grebmeier and Cooper 2002). Commercial fishing may play a role in the dynamics of the southeastern Bering Sea shelf through removal or redirection of nutrients or changing the relative dominance of various species.

The reduction of the king crab fishery is an issue in the eastern Bering Sea. Dew and McConnaughey (2003) hypothesized that alternating, sex-specific sources of fishing mortality were the main cause in the crash of the red king crab fishery in the southeastern Bering Sea. Natural causes such as physical forcing on larval crab recruitment (Zheng and Kruse 2000) have also been discussed. The causes for the collapse of the red king crab, however, have not definitively been identified. An ecosystem study in this region would also involve examination of the impacts of flow through Unimak Pass and its attendant impacts on other species, including larval pollock and the populations of marine mammals and birds associated with the Alaskan Peninsula. This region is also the pathway of salmon migration to Bristol Bay watersheds. Some issues include: what are the environmental conditions that promote or inhibit groundfish and red king crab population growth, what management strategies might facilitate restoration; what are the major pathways through which the coupled atmosphere-ocean-ice system impacts the habitat of the red king crab, its predator and prey fields and other marine populations in the ecosystem?

A rich foundation of science plans and research programs already exists for the southeast Bering Sea. As identified in the BEST Science Plan (BEST 2003), one of the largest challenges is the current lack of knowledge about organism-organism interactions (i.e. predation and competition). The food web contains important organism level linkages, some being more susceptible to impact by climate change than others. Without detailed knowledge at the level of organism-organism interactions, it will be difficult to know how changes in the physical environment might cascade through the food web, and hence impact the entire ecosystem. In a synthesis of the southeastern Bering Sea Carrying Capacity (NOAA's SEBSCC) program and the Inner Front

program (NSF), Macklin et al. (2002) note that future research will need to examine the processes that link atmospheric forcing and processes that control the amount and fate of production. Some issues include: what are the major pathways through which the physical environment impacts production; what are the major processes (e.g., cannibalism, selective micro-zooplankton grazing, etc.) within the flora and biota elements that cause changes in production of higher trophic levels (groundfish, marine mammals and seabirds); how will this system respond to climate change?

Northern Bering Sea

High ecosystem production over the northern Bering Sea shelf is a function of the availability of nutrients and extensive amounts of sunlight from the long summer days. Recent work shows that productivity has been decreasing over the past decade: system productivity (Schell 2000), and amphipod biomass (Highsmith and Coyle 1992) are declining, possibly due to declining carbon flux to the benthos, and gray whales are moving north of Bering Strait to obtain their food (Moore et al. 2003). A similar decline in bivalve populations south of St. Lawrence Island may lead to decreased prey abundance for the diving spectacled eider. It has been suggested that a change in hydrographic forcing and nutrient supply is limiting primary production in the region (Grebmeier and Cooper 2002), which in turn may be related to decadal-scale atmospheric/sea ice/oceanographic processes, which reflect regime-induced climate changes in the western Arctic. Since the Inner Shelf Transfer and Recycling (McRoy 1999) study in the early 1990's, there has not been an integrated ecosystem program in this region. Some issues are: what is the time-space nature of the nutrient flux that provides the fuel for the high productivity, and what processes are causing the present changes in flora and biota; how will upper trophic level species respond to the changes; what are the "downstream" impacts of changes over the northern shelf to ecosystem dynamics in the Chukchi and Beaufort Seas (including human use of resources)?

Chukchi/Beaufort Seas

Atmospheric climate variation and its impact on circulation, heat, salt and nutrient content of shelf waters and sea/shore fast ice formation are central issues in the Arctic seas. It is unlikely that ecosystem change will be understood until more studies examine the Arctic Oscillation-ecosystem interactions (NRC 2004a). Understanding the proximate and ultimate controlling factors of various trophic level standing stocks and production rates is essential for interpreting ecosystem change occurring presently in the Arctic (Aagaard et al. 1999). The impacts of climate change to the ecosystem are commonly thought to be from the bottom up through the nutrient-phytoplankton-zooplankton sequence, while human impacts are top down (Carmack and Macdonald 2002). However, the presence of sea ice as habitat for top-level predators such as polar bears means that climate change will act top down as well. An added element of the ecosystem in Arctic seas is fast shore ice and its attendant phenomena (turbulence under ice, formation of freshwater pools due to blockage of river inflow).

Issues for the Chukchi Sea include: how do the variations in the flux of heat, salt and nutrients from the Bering Sea impact the Chukchi Sea ecosystem? What are the long-term impacts of variations in shelf-slope exchange on this ecosystem; which processes provide the major influence on the distribution, magnitude and seasonal variability of primary production and secondary production, and on variations in abundance of higher trophic organisms? While for the Beaufort Sea the following issues may serve as guidelines for developing an IERP: what are the atmospheric and oceanographic factors that contribute to production on the Beaufort Sea shelf; what is the relative contribution from ice-associated algae versus phytoplankton and are the pathways to higher trophic levels the same; what establishment of buoyancy driven costal flow; how will fish, marine mammals and seabirds respond to ecosystem change related to reduced ice cover?

Implementation Strategies

The Board will consider providing a general framework that permits the creativity and experience of interdisciplinary teams to establish reasonable (in terms of total costs and attainability) objectives and define detailed scientific approaches to developing IERPs for consideration of the Board for long term funding support. This could be similar to the approach successfully used by such programs as GLOBEC and BEST, which includes: conducting workshops that produce proceedings containing detailed hypotheses/questions, program objectives, field/model approaches, and products (e.g., indicators of ecosystem status, suitable ecosystem models, etc.) that act as metrics to gauge ongoing success. The process should begin in spring 2005 and adhere to a schedule that has the necessary information available for input into future requests for proposals.

Examples of potential integrated ecosystem research programs were presented above. A typical approach would be to have presentations by representatives of all shareholders (scientists, resource managers, resource users, etc.) to establish a common language and level of understanding. Participants then would form small groups that address workshop objectives and present their deliberations. The final product would be a workshop proceedings that includes a set of potential IERPs for that LME.

The next step would be to select one or more of the IERPs for further consideration. The merits of all potential IERPs would be evaluated, and they would be prioritized based on various criteria (e.g., likelihood of success, leverage from other programs, in-kind contributions, relevance to pressing fishery management and ecosystem information needs, etc.), and the results presented to the Board. The final step would be to develop a request for proposals that would lead to open competition for funding an IERP. Because funds are a factor in creating interest among researchers, the Board may consider 'banking' a substantial amount of funds for an IERP at the same time the above process begins. Knowing that such funds exist not only makes participation in the workshops more valuable to researchers, it also provides the start-up funds that are often essential in the first year of a project for the purchase of field equipment, funding graduate student positions, development of technologies, etc.

To actually conduct an IERP would require investigations in all five of the major research activities: monitoring, process-oriented studies, retrospective studies, modeling and development of new technologies and analytical methods. In establishing new monitoring schemes, the locations of monitoring sites must be well considered (NRC 2004a), focusing on pulse points of the ecosystem. The monitoring plans also must include key species. The process-oriented studies must be integrated to fit with other activities and have flexibility to change focus based on new results. With respect to retrospective studies, there is much left to learn from existing time series of observations, particularly if viewed from an ecosystem-wide perspective and using new analytical tools.

A modeling component is essential to an IERP. Often the initial planning and implementation are partially based on results from model simulations. Modeling efforts have been conducted in all three of Alaska's LME's. Models already developed for the Alaskan region include three-dimensional (3-D) circulation models typically driven by model wind field, 3-D ocean models coupled with a nutrient-phytoplankton-zooplankton sub-model (e.g., Hinckley et al. 2001) and coupled transport and cannibalism models (e.g., Wespestad 2000; Ianelli 2004). A summary of physical and biological modeling in the North Pacific (BSAI and GOA LME's) was prepared for the Gulf Ecosystem Monitoring program by Aydin (2002). That document provides narrative descriptions of the hypotheses embodied by each model followed by details of the model, including geographic areas covered, time periods addressed, units, status of development, and inputs and outputs. Results from models have been used to assess biological and physical factors that influence pollock recruitment in both the Gulf of Alaska (Megrey et al. 1995) and eastern Bering Sea (Wespestad et al. 2000).

A challenge to using model simulations as tools often occurs because most models lack utility, i.e., not all the researchers can conduct simulations. It is critical that IERP participants decide early on how to handle this challenge, e.g., if many researchers want to have hind-casts of circulation patterns, is there a time-space averaging that would accommodate most applications and could be made available on a web site? Another challenge deals with human interactions, as noted by Kashiwai (2003): *Among marine biologists and even among ecosystem modelers, there is recognition that ecosystem models are special tools for ecosystem modelers only*. *This is the largest obstacle for models to be the core of program integration*. To overcome these challenges, it is essential that a team of researchers who have the ability to cooperate and focus on the overall program goal conducts the IERP.

Accompanying these types of research activities should be the development of appropriate new technology/methods if necessary to answer important scientific questions (NRC 2004a: Recommendation 4-4). For example, the NPRB is presently funding research to develop better assessment methodologies for forage fish populations (project #401), a crucial element of any IERP. Importantly, such development of technologies or methods is not necessarily region specific and should have the potential to be applied in other regions.

Regardless of the exact approach, the NPRB should be very responsive to the NRC's (2004a) strong encouragement to move away from more traditional research initiatives on individual components of the ecosystem. Integrated ecosystem research programs will be critical to providing the more holistic understanding that will enable true ecosystem-based management. Such programs should be pursued vigorously by the Board.


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Chapter 4

Other Research Approaches and Partnerships

Local and Traditional Knowledge

Introduction

Local and traditional knowledge (LTK) offers many things in the context of North Pacific research, including more and better information, new perspectives and paradigms for understanding the marine ecosystem, and greater involvement of those who live and work in the area. This chapter describes LTK and identifies general strategies NPRB will consider to gather and utilize LTK and to engage its holders in the Board's science program.

LTK and its Holders

LTK refers to an array of information, understanding, and wisdom accumulated over time based on experience and often shared within a group or community (Huntington 1998; Berkes 1999). This knowledge may be the product of an individual's time on the land or sea (local knowledge) (e.g., Newell and Ommer 1999), or it may be accumulated over generations and perpetuated within a culture (traditional knowledge) (e.g., Kawagley 1995). As described by some Alaska Natives, traditional knowledge is *a way of life* and *practical common sense… passed on from generation to generation,* and in other ways (see nativescience.org/html/traditional_knowledge.html). For purposes of this plan, LTK is defined broadly and inclusively to incorporate all relevant knowledge and insight derived other than through scientific research (see also Ford and Martinez 2000).

Those who hold LTK are similarly diverse. Although this chapter combines local knowledge and traditional knowledge because they can be gathered and utilized in similar ways, the two are not identical. Traditional knowledge is the product of many generations of experience and the passing on of knowledge and wisdom. Therefore, traditional knowledge may be characterized as dynamic and ever expanding from generation to generation. It has a cultural basis, is often regarded as belonging to a community, and is typically held by Native peoples who have lived in an area for centuries and millennia. A community of knowledge holders, as used here, may have a geographic, cultural, occupational, or other basis. Local knowledge is the product of individual experience, shared perhaps with colleagues and neighbors, but lacking the cultural basis and time depth of traditional knowledge. Local knowledge is typically held by those who live and work in a region, such as commercial fishermen. The depth and extent of both forms of knowledge will, of course, vary greatly as will its relevance to any particular question or topic. Collectively, however, the holders of LTK have a great deal to offer to the NPRB research program, both through the contribution of their knowledge and through their involvement in the research program overall.

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It is important here to distinguish between research involving LTK and the larger question of community involvement in the research program. The contribution of LTK is only one of several ways in which communities and individuals can be involved. LTK research should, therefore, not be taken as a substitute for other avenues of participation. Similarly, LTK research is a field of scientific investigation, not simply an outreach effort, as will be discussed below under standards and expectations.

Strategies

A number of approaches have been used to study and otherwise engage LTK in scientific research (Ford and Martinez 2000; Huntington 2000a). While they are a valuable resource and demonstrate the potential of LTK, by themselves they do not address the question of how LTK can best contribute to the NPRB science program. To answer that question, the Board will consider the following approaches to implement the LTK component of the science program. They may be addressed separately or in combination depending on area and the circumstances of the project or effort in question. Approaches that have been used in the past include workshops, collaborative field research, key informant interviews, surveys, and literature reviews. Those described below should not be considered all inclusive. Other innovative approaches may be considered for funding as well.

Generating research hypotheses. Regional residents and fishermen are not merely passive holders of knowledge, but also are active analysts and processors of that information. As such, LTK holders often have questions they would like to see addressed and theories about the marine environment that can be tested. Helping them to generate appropriate research hypotheses can draw on LTK at the formative stage of research and research planning. This community-driven process is more than recording questions. It is a way of engaging LTK holders in thinking analytically and creatively about what should be studied and how. The resulting hypotheses may then be addressed by further LTK research, by other scientific research, or a combination of both.

Documenting existing LTK. Documenting existing LTK is a powerful means of accessing information that is otherwise available only to those who hold it. This approach is largely retrospective, focusing on what is known and what LTK holders have observed in the past. Results of documentation efforts typically are published (e.g., Huntington et al. 1999; Brown et al. 2002), but also may be stored in a database (e.g.,http://nativeknowledge.org/start.htm). A standardized database should be considered, along with protocols for gathering and accessing information.

Recording observations. Fishermen and local residents in the North Pacific region spend a great deal of time observing the marine environment. Their observations and interpretations provide a vast potential contribution to research and monitoring. The Board may consider developing a system for recording observations, which could include descriptions of conditions or events as well as accompanying interpretations, explanations, and questions. Some systems of this kind exist or are being developed (e.g., the Local Fisheries Knowledge Project in Maine: http://www.st.nmfs.gov/lfkproject, and the proposed Alaska Coastal Community Observer System), which can provide lessons and perhaps a structure on which NPRB may build. This approach is prospective and the benefits may take time to realize as sufficient observations are recorded and linked to areas of interest and priorities for research.

Fostering collaborative analysis. As analysts of information, LTK holders also can contribute to the later stages of the research process. With some or all of the available data in hand, researchers and LTK holders can work together to try to explain various phenomena and determine which interpretations seem most plausible (e.g., Huntington et al. 2001, 2002). This approach may be applied both to projects that have an LTK emphasis and to those that otherwise do not.

Collaborating on specific projects. There are many potential roles for LTK and LTK holders in individual projects, some of which are currently being carried out in NPRB-funded projects. NPRB could continue to encourage applicants for funding to consider how LTK may benefit their projects and to generate support for their efforts to incorporate LTK and its holders as appropriate.

Exploratory research. The strategies outlined above cover the basic areas of research: asking questions, gathering information, and interpreting results. Within each area, there is considerable room for innovation in how LTK can be incorporated. Additionally, there may be other approaches outside this template that are worth attempting. Some funding may be set aside to allow for exploratory research of this kind.

Standards and Expectations

For LTK to contribute substantively to NPRB's science program, the LTK effort must meet standards as high as those applied to the rest of the scientific program. LTK projects should meet the normal requirements for scientific rigor: clear goals, sound methods, appropriate scope, qualified personnel, and an adequate budget. Additionally, LTK projects require a strong community role to ensure that the approach respects community interests and rights (e.g., intellectual property rights), that any information that is disseminated has been reviewed for accuracy and potential harm, and that LTK holders are appropriately involved and credited throughout the project (e.g., Wenzel 1999; Krupnik and Jolly 2002). With this in mind, the Board may consider criteria such as the following in evaluating LTK projects:

- A substantive and well-defined community role throughout the project, with specific tasks associated with specific community organizations.
- Community oversight of implementation.
- Community review of results and information prior to dissemination.
- Statement of research questions/goals/hypotheses.
- Methods.
- Research design.
- Personnel.
- Budget.
- Connection to the NPRB science plan and specific requests for proposals.

Proposals should clearly address all of these points, and reviewers should be selected who have the experience and expertise to evaluate proposals accordingly. The LTK effort is intended to be a substantive part of the NPRB science program. To achieve this goal, LTK work must be treated seriously, proposals must meet high standards, reviewers must be chosen who have the expertise to evaluate the merits of LTK projects, and the Science Panel must have individuals capable of assessing those reviews and determining how the proposals address the NPRB mission.

Coordination and Partnerships with Other Entities and Programs

Introduction

Enabling legislation calls for NPRB to seek to avoid duplicating other research activities and to place priority on cooperative research efforts. NPRB has adopted mission and goals statements to conduct its work through coordination and cooperation among research programs. The NRC (2004a) noted that NPRB has finite resources and its mission overlaps those of other agencies and programs. Therefore, NRC recommended that NPRB appoint liaisons with other research entities whose missions relate to those of NPRB; form partnerships as possible to leverage maximum benefit from available funds; and conduct annual principal investigator workshops to foster project collaboration and share data.

Role of NPRB

NPRB intends to provide a leadership role in working with other agencies and entities to identify science, management, and monitoring needs, and to provide a hub of marine research off Alaska, viewed as a source of unbiased, high quality, science information. NPRB members represent a broad array of federal, state, and other entities involved in research off Alaska; by its very composition and nature, NPRB is in a position to provide coordination among research programs and entities. NPRB already has signed memoranda of understanding with the Alaska SeaLife Center and NMFS (June 29, 2001), with EVOSTC and UAF (May 21, 2003), and with AOOS (February 17, 2004), that foster coordination and joint planning and sharing of resources; established science and advisory panels that foster coordination and communication; and co-sponsored the Alaska Oceans and Watersheds Symposium (June 2002), and joint science symposia in January of 2003, 2004, and 2005.

Strategies

NPRB intends to respond to the recommendations of the NRC, within budget constraints, by doing the following:

- Engage staff in coordination and communication activities with other programs.
- Facilitate meetings with research program managers to learn about their programs.
- Co-sponsor annual science symposia and meetings of principal investigators.
- Develop synoptic descriptions of research programs and expenditures in Alaska.
- Seek partnerships with other entities to support joint research and funding of projects of mutual interest.
- Develop process for identifying important research gaps that need to be addressed, including engaging communities and other interested parties as appropriate.

The following agencies and entities have been identified for coordination and cooperation. A guide to acronyms may be found in Appendix B:

- State: ADEC, ADFG, AKFIN, ANSC, AOOS, ASLC, AYKSSI, Alaska Sea Grant, GEM, Native organizations, North Slope Science Initiative, Norton Sound SSI, NPMRI, PCCRC, PWSSC.
- National: ARC, ARCUS, CMI, EPA, FWS, GOOS, IARPC, IOOS, MMS, NOAA, NSF, ONR, USGS.
- Regional: BASIS, BEST, EFOCI, GLOBEC, NPFMC, SALMON, SEBSCC.
- International: COML, IPHC, IPY, Northern Fund of Pacific Salmon Commission, NPAFC, PICES, SEARCH, WWF (as appropriate, also include Russian, Japanese, and Korean programs outside these established organizations).

Cooperative Research with Industry

Introduction

Most fisheries research projects would benefit from some level of cooperation with industry. This was the first finding of the National Research Council in their report titled *Cooperative Research in the National Marine Fisheries Service* (NRC 2004c). Fishermen in general will be very knowledgeable of fishing gear, fishing grounds, and fish behavior, and this knowledge can be incorporated in most forms of research and the formation of hypotheses to be tested. Indeed, the Magnuson-Stevens Fishery Conservation and Management Act requires in Section 404(b) that the NMFS strategic plan for fisheries research provide a role for commercial fishermen in research, including involvement in field testing (P.L. 94-265, as amended). The following discussion is based mainly on the NRC report.

Commercial fishermen offer a significant opportunity to collect scientific information on the fisheries and marine ecosystem. They provide field experience, practical knowledge, and platforms for collection of data. They are expert at deploying their gear and have the knowledge to increase their efficiencies and lessen their impact on non-target fish stocks. Their expertise can be important in making sure that survey fishing gear is operated as efficiently as designed or that the geographic range of the survey is consistent with the geographic range of the fish. Use of fishing gear in research helps scientists better understand the impacts of that gear, not only on the fished population, but also on the surrounding habitat. It also allows inter-calibration of gears used by scientists and fishermen. Other commercial enterprises, such as oil and gas-related activities, also provide opportunities for cooperative research.

Scientists bring experimental design, the scientific method, and data synthesis. By bringing together the knowledge and skills of these two groups, the quality, quantity, and relevance of research may be improved. Working together may help to build a better understanding between science and industry, and greater confidence in the products of research and in the regulatory process. Cooperative research efforts must ensure the scientific integrity, practicality, and cost effectiveness of the experimental design and facilitate the ready application of the results to alter fishery management if the results suggest that such alteration is beneficial or required. Cost effectiveness, practicality, acceptability, and utility must be key design criteria.

Forms of Cooperative Research

Cooperative research may take a variety of forms:

- Industry may assess a tax on their landings and directly fund research, possibly in partnership with other entities.
- Industry may provide vessels and crew for charter by research scientists, which may reduce costs of research and augment ship time available on federal research vessels. The vessel crew adds their expertise including seamanship, fish finding and gear handling. IPHC and NMFS charter vessels to survey halibut and sablefish, respectively.
- Industry may participate in experiments to modify gear to reduce bycatch. Participation of the North Pacific Longline Association and the Fishing Vessel Owners Association in seabird deterrent research, Groundfish Forum work on bycatch reduction gear through exempted fishing permits, and NPRB-funded research on salmon bycatch reduction, all are good examples of this cooperative approach. The direct cooperation between industry and government or university scientists provides a realistic setting for testing gear modifications, reducing costs, and making the results more believable to industry. Parties work together to formulate, secure funding, execute and analyze a project. Either the industry or the scientists may initiate the project.
- A group of fishermen may get together to do a study or survey, consulting a scientist as needed to ensure scientific validity.
- Fishermen can maintain logbooks to provide information on catch, bycatch, and other aspects of the fishery. They also can retrieve tags from tagging studies.
- Vessels can and do take observers that provide a variety of catch and other information. For example, all vessels over 60′ fishing groundfish off Alaska are required to have one or more observers on board.
- Fishing (and other commercial ships of opportunity) vessels can take scientific data collection instrumentation packages such as continuous plankton recorders, ferry box systems, or other oceanographic data packages to collect information over a wide region.
- Fishermen can contract with outside scientists with no affiliation to the management agency that governs their fishery. One purpose for this can be to improve on methods or assumptions affecting stock assessments or other scientific reports relevant to fishery management decisions.

Elements of Success

Successful and popular cooperative research tends to cluster around projects where fishermen's vessels, gear, and expertise can be readily employed, and research results may substantially change assessments and regulations to provide short- and long-term economic benefits to fishermen. Other substantial objectives include improving stakeholder trust in the fishery science and management system, improving research methods and administration, and co-educating scientists, industry, and managers. Cooperative research tends to work best when scientists and fishermen acknowledge early on that a problem needs to be addressed and that working together cooperatively will be the most effective way of proceeding. They must realize that each bring valuable tools and experience to the objectives of a research project, and that they should use each other's expertise in science and on the fishing grounds to design the most appropriate and practical research protocol. Participants must understand that they are involved in scientific research and must meet scientific standards for the results to be credible and useful for management decisions. Finally, they must properly interpret and timely distribute the results of their project to affected parties and management agencies.

In summary, elements of successful cooperative research projects include:

- Substantial incentives and benefits to research partners.
- Rigorous co-engagement in most elements of the scientific process.
- Complementary skills and abilities.
- Honesty, trust, and mutual respect.
- Adequate financial, administrative and scientific support.
- Ongoing funding sources and in some cases, an institutional framework dedicated to cooperative research that helps in setting long-term objectives, structuring partnerships, developing efficiencies in proposal development and evaluation, and coordinating and developing long-term partnerships where appropriate and desirable.

Most cooperative research funds should be allocated through a competitive review process. The resulting data, analyses, and reports must undergo peer review. Commercial fishing vessels used for cooperative research should meet all U.S. Coast Guard requirements for operation and manning to ensure safe operations, and should have all required federal permits. There should be appropriate liability insurance to protect the financial interests of all participants involved in cooperative research. Agreements and contracts should include project design, project implementation, contingency plans, data collection analysis and communication responsibilities and decision-making authority. And last, there should be a communications plan for outreach, progress reports, and dissemination of final results, while respecting the confidentiality and ownership of some forms of data and information. Rules governing vessel charter arrangements and exempted fishing permits often affect confidentiality of data, the degree to which gear innovations and technologies developed in the research can remain proprietary, and the disposition (including sale if allowed) of fish harvested during field work. Recognizing these limitations, care should be taken from the outset to select a cooperative research vehicle that meets the short- and long-term expectations for all parties in the research.

Strategies

The NPRB will consider the following strategies and others as appropriate, in developing a cooperative research component to its science program. They extend beyond the fishing industry to other users as well, such as the oil and gas industry.

- Seek opportunities to partner with industry-funded research entities.
- Identify ships of opportunity to collect oceanographic and other data over a wide region.
- Establish a registry of commercial vessels potentially available for research charters.
- Support development and deployment of cost-effective instrumentation packages.
- Use commercial vessels as a cost-effective way to do ecosystem monitoring.
- Convene workshops with industry and scientists to identify research needs, develop hypotheses, and establish ways to partner.
- Encourage conservation engineering projects (e.g., bycatch reduction research) in RFP.
- Sponsor training in fisheries science and collection of scientific data to enable fishermen to participate in all facets of fisheries research, from identifying research questions, to developing project procedures and protocols, collecting data, and peer review of results.
- Help establish for Alaska a central cooperative fisheries website such as http://www.fishresearch.org.
- Establish a formal cooperative research program to develop long-term funding sources, develop cooperative partnerships and relevant expertise, and foster development of cooperative research where appropriate.

Education, Outreach and Community Involvement

Introduction

The NPRB aims to support research that is useful to those who live and work in the region. Similarly, NPRB goals and research priorities are informed in part by the interests of those stakeholders. Education, outreach, and community involvement thus are crucial, albeit distinct, elements of an effective science plan. Indeed, the NRC (2004a) found that …*incorporating public input and informing the public of program findings are important NPRB duties*. The committee recommended encouraging outreach and education by principal investigators as part of their proposals or as independently funded activities. The committee also recommended that NPRB facilitate scientist-stakeholder communication and continue site visits to foster understanding and receive public input on research initiatives.

It is important to distinguish between education and outreach and community involvement. Education and outreach include efforts to disseminate research findings and other information to various groups and individuals. These efforts may be general, for example, through a web site or other broadly distributed media, or they may be specific, for example, by presentations in schools or to meetings of stakeholders such as fishermen. Education and outreach also provide opportunities for stakeholders and the public to provide feedback to the NPRB, but the emphasis is on the dissemination of information generated by or under the auspices of the NPRB.

Community involvement is broader, describing not simply the flow of information, but the relationship between communities and the NPRB. Effective community involvement provides a substantive role in helping shape NPRB activities, from research to education to program guidance. There are many mechanisms by which communities may be involved, as described below. Different mechanisms are likely to be required for different communities, but the underlying principle is that communities should be aware of what the NPRB is doing and why, and their voices heard. The Board will strive to field a comprehensive education, outreach, and community involvement program as generally outlined below. It will be revised as necessary through a separate implementation plan reviewed annually by the Board.

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Education and Outreach

The education and outreach program is directed at a broad and diverse audience, including the scientific community of marine researchers; agencies responsible for managing North Pacific marine resources; Alaska residents, including Alaska Native communities, who depend on marine resources for subsistence or employment; teachers and students of all ages and academic levels; and the general public in Alaska and beyond, including tourists with high interest in marine mammals and seabirds. The objective is to translate detailed scientific information into understandable terms, and package it for maximum accessibility, exposure, and impact. The Board has an exciting opportunity to provide students - the leaders of tomorrow - with a long-term understanding of the ecosystem around them.

Strategies for education and outreach will include different products and mechanisms for each of the groups mentioned above, capitalizing on existing partnerships and responding to new opportunities. The NPRB's requests for proposals released in 2002-2004 included requirements for researchers to identify in their proposals $500-2,000 for education and outreach materials to help interpret their project to the public. In 2004, NPRB went a step further and contracted with the ASLC to develop an outreach program and hire an outreach coordinator to work directly with NPRB staff and researchers to formulate an implementation plan and direct outreach activities. As an employee of the ASLC, the outreach coordinator will have access to public relations experts and their existing media contacts, to educators who develop and deliver programs for teachers and students in grades K-12, and to equipment necessary for producing high-quality graphics and video. Having an employee to coordinate activities will relieve the burden on researchers to develop their own educational products, and will provide opportunities for economies of scale by bringing related projects together to present a coherent view of NPRB efforts. The following discussion focuses on the different "customers" for NPRB information and the various ways in which the education and outreach program can serve them, recognizing that many of the methods for disseminating information may serve more than one audience.

Marine Researchers and Resource Management Agencies For scientists and resource managers, NPRB can share marine research techniques and results through colloquia and conferences, some of which may depend on distance delivery to reach across geographical boundaries. The NPRB web site also can include access to abstracts, publications, proposal requests and guidelines, data sets, and photographs or videos of work in progress. Much of this information will come directly from the scientists through their proposals and reports, but when possible, the ASLC exhibits staff can provide expertise in digital photography, videography, and video editing. Information from NPRB-sponsored research also must contribute to analyses provided to resource managers in their decision process. These analyses include such required documents as environmental impact statements, environmental assessments, biological opinions, and stock assessment and fishery evaluation reports, among others. Having that information available will enhance the ability of resource managers to manage for sustainability.

Commercial and Subsistence Users The economic and cultural importance of marine resources in the North Pacific and Bering Sea makes sustainable management critical. Partnerships with resource management agencies and Alaska Native organizations that co-manage marine mammal populations, particularly the NMFS, ADFG, FWS, NPFMC, the Alaska Native Harbor Seal Commission, Alaska Steller Sea Lion and Sea Otter Commission, the Alaska Whaling Commission, and the Alaska Walrus Commission, can make outreach efforts more effective and far reaching. Commercial fishermen recognize that effective resource management depends on reliable scientific data, especially in determining whether protected species depend on the same prey targeted by fisheries. Subsistence users want to know that their harvest is healthful and free of unsafe contaminants. NPRB can work with agencies to bring relevant information to Alaska Natives and fishermen through community outreach and through organizations like NPFMC and others represented on the Board. The NPRB outreach coordinator will work with board members who also represent different Native and industry groups to determine effective methods for reaching their constituents.

Teachers and Students The NPRB web site provides a valuable tool for reaching educators and students worldwide, especially at the secondary and post-secondary level. The outreach coordinator will seek additional opportunities for NPRB researchers to present talks in classrooms, via videoconference and through other distance education technologies. To reach K-12 teachers and students, the Alaska Sealife Center's education department hosts workshops and programs for over 10,000 students per year, and is beginning to build a distance learning program that will extend its reach far beyond Alaska's borders. Since the outreach coordinator will maintain close contact with the ASLC education director in Seward and its outreach educator in Anchorage, he or she will have an opportunity to incorporate NPRB research information into existing and newly developed educational programs. Over the past five years, the ASLC has also developed a thriving student internship program for college juniors, seniors, and graduates, and employs graduate students as research technicians. The internship program and methods for recruiting qualified research staff may serve as models for similar programs at NPRB, which give students hands-on education and experience while providing low cost labor for scientists. Another way to reach students and teachers is through the Alaska Rural Systemic Initiative through UAF. Other Alaska Native internship programs include those offered by the Alaska Native Tribal Health Consortium and the Alaska Native Science Commission.

General Public While some citizens will learn about NPRB projects through public exhibits and conferences, using the media to disseminate information has proven very effective at reaching large numbers of people at extremely low cost. The outreach coordinator will contact the principle investigators of each NPRB project and produce engaging and easily understood fact sheets to make research projects and information accessible to the public. The fact sheets will be available on the NPRB web site, along with updates and "spotlight" stories that focus on projects likely to generate the most attention from print and broadcast media. The ASLC's existing contacts with state and national press will allow the outreach coordinator to highlight the NPRB and its progress in marine research. When researchers are working in remote areas or the media cannot send reporters to research sites due to limited resources, the ASLC can help produce short video clips ("b-roll footage") and send out digital photographs of high public interest. When possible, the outreach coordinator will work with NPRB researchers working aboard ships or in remote field sites to gather digital or video images and send them back to Anchorage, since weeks or even months of marine research can pass before they have an opportunity to capture a dramatic event on camera. The coordinator also can identify NPRB researchers willing and able to speak effectively about their projects in layman's terms, and help arrange public presentations and interviews. The coordinator also will help develop a newsletter that is distributed widely to agencies and interested public. In addition, final reports for NPRB-funded research should include both a technical and a lay summary that will be invaluable as a means of public information about NPRB's mission and activities.

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Community Involvement

Community involvement means providing a meaningful role for communities in all aspects of the NPRB program. For this purpose, "community" is defined as a group with a common geographic, occupational, or other base. For example, a city or village is defined by its location. Members of a particular fishing fleet share a common occupation. Alaska Natives share a cultural connection to the North Pacific. The activities of the NPRB can be grouped in three categories for the purposes of describing what is required to achieve effective community involvement: development of the NPRB program, awareness of NPRB research, and participation in NPRB research.

Development of the NPRB Program The NPRB program should be broadly responsive to the interests and concerns of communities in the region. The Advisory Panel is a formal and vital means of involving representatives from many communities in the work of the NPRB. The NPRB should also take note of the various research agendas, statements of priorities, and other products of the many regional and community meetings that are held. This input can provide a valuable basis for considering and developing new programs or re-shaping existing ones. At times, the NPRB may wish to convene special working groups to address particular topics and develop community-based ideas and recommendations, or to visit particular communities.

Awareness of NPRB Research In addition to the dissemination of results and information described above under education and outreach, community members may want and need additional information about research being planned or underway. Community knowledge and interest regarding natural resources extend beyond physical boundaries of the communities themselves to harvest areas and beyond. Researchers should advise communities and people involved or affected by the studies of the purpose, goals, and time-frame of the research and its potential positive and negative implications. Such contact should include an invitation to provide relevant information back to the researchers and, where appropriate, a plan for continued communication during and at the end of the research project.

Participation in NPRB Research Communities and community members can make substantial contributions to NPRB research. Projects involving LTK are one example, and there are a number of other collaborative approaches that can be taken, including responsiveness to community-based research needs and priorities and the use of local research assistants. Another example is the Fishermen and Scientists Research Society (see http://www.fsrs.ns.ca). Some projects will require the participation and cooperation of community members, for example, in interviews or in health studies. In keeping with established ethical principles for research, proposals involving work in specific Alaska Native communities or on health issues should have a letter or letters of support from the appropriate community and/or tribal governing bodies. Further capacity for community-based research and community participation in research can be built through mentoring programs, research partnerships, internships, and other ways of encouraging community members to plan, participate in, and lead research projects.

Capacity Building Capacity building is a process by which rural residents and Tribal organizations develop individual and collective abilities to participate in scientific research on par with other research institutions. Example programs in Alaska include the FWS program *Partners for Fisheries Monitoring Program* that has the goal of building capacity and expertise of Alaska Native and rural organizations to participate in subsistence fishery management and research, and two new and emerging programs aimed at providing technician certification. The program first started in 2001 when ADFG awarded $200,000 from the NOAA/Pacific Coastal Salmon Recovery Funds to the University of Alaska Southeast/Ketchikan Campus to develop a fisheries technician degree program. More recently, UAS has launched its new *Fisheries Technology Program*, offering a one-year certificate and two-year associate of applied science degree designed to teach job-related skills and knowledge in the field of fisheries and hatchery technology. A second example is the NOAA Educational Partnership Program and National Center for Coastal Ocean Science, working with the Interior Aleutian Campus of UAF's College of Rural Alaska in partnering with the Chugach Regional Resources Commission to begin developing a pilot marine and fisheries technician training program designed to meet the needs of students living in remote villages. The Board may consider these types of approaches as well as others in potentially developing a capacity building program. These considerations are in the very preliminary stage and implementation steps have not been clearly identified.

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Chapter 5
Policies and Procedures

Scientific Quality and Integrity

Introduction

The science program must be of the highest quality, with results viewed as unbiased, based on sound science, and useful to resource managers, such as NMFS, NPFMC, FWS, and ADFG, among others. National Standard 2 of the Magnuson-Stevens Fishery Conservation and Management Act calls for fishery management and conservation decisions to be based on the best scientific information available. Failure to use such information has been the basis for many lawsuits brought against the regional fishery management councils and NMFS (NRC 2002c). To maintain high quality research, NPRB has implemented procedures for (1) reviewing proposals, (2) avoiding conflicts of interest, (3) reviewing final reports, and (4) protecting confidential information. They are published in NPRB's standard operating procedures and will be revised as necessary.

Proposal Review Process

Initial Screening of Applications Upon receipt, staff will screen applications for conformance with requirements in the RFP. The review will consider whether the proposal meets structural requirements and whether it responds to NPRB enabling legislation and criteria and adequately addresses one or more research priorities listed in the RFP. The Exucutive Director will request an ad hoc committee of available Science Panel members to help in the initial screening. Those proposals that are found by the Executive Director and the ad hoc committee to not comply with the requirements of the RFP will be rejected without further processing.

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Consultation with Interested Parties NPRB may consult with federal and state agencies, the NPFMC, and other entities, as appropriate, in reviewing proposal content.

Independent Technical Evaluations All proposals that pass the initial screening will undergo independent, anonymous, technical review, conducted by regional, national and international experts. They will be asked to comment on technical aspects of proposals, as follows (weightings by component will be determined annually):

- Project Responsiveness to Research Priorities: Does project clearly respond to legislated criteria and research priorities?
- Soundness of Project Design/Conceptual Approach: Applications will be evaluated on the applicant's comprehension of the problem(s); the overall concept proposed for resolution; whether the applicant provided sufficient information to evaluate the project technically; and, if so, the strengths and/or weaknesses of the technical design relative to securing productive results. Particular attention will be given to the inclusion of a clear statement of hypothesis to be tested or objectives to be addressed, the presence of a detailed experimental design, and a list of data sources or requirements.
- Project Management: The organization and management of the project, and the project's principal investigator(s) and other personnel in terms of related experience and qualifications will be evaluated. Applicants must demonstrate how they will coordinate and collaborate with other projects, and leverage their proposals with support from other sources. Applicants must seek to avoid duplication of other research efforts. How the applicant plans to disseminate the research results also will be considered.
- Project Costs: The justification and allocation of the budget in terms of work to be performed will be evaluated. Cost effective projects will be encouraged.

Science Panel Review All proposals and their accompanying technical evaluations will be reviewed by the Science Panel, which will score proposals based on the above criteria and assigned weightings, and develop funding recommendations for NPRB's consideration. Outside experts may be invited to join the Science Panel as necessary to provide additional expertise.

Board Review The NPRB will review responsive proposals, consider technical evaluations, panel recommendations, and other factors as appropriate, and decide which proposals to fund. Public comment will not be taken from current applicants when NPRB makes final funding decisions.

Secretary of Commerce Review By law all recommendations of the Board are subject to the approval of the Secretary of Commerce.

Conflict of Interest Procedures

The scientific community, resource managers, Congress, and general public must have confidence in the integrity, effectiveness, and evenhandedness of NPRB's decision-making process, and it cannot be seen to be compromised by real or perceived conflicts of interests.

Science Panel Members and Independent Technical Reviewers They must consider potential conflict situations that may arise in their review of research proposals and in other activities related to the Board. An individual may serve on the Science Panel despite a personal conflict, but must recuse him/herself from voting under three broad affiliations characterized below. The member may remain in the meeting for discussion purposes for all affiliations except item 2, bullet 4, wherein the member must leave the room during discussions and voting. Independent technical reviewers should refrain from evaluating proposals if any of the following circumstances apply.

1] Affiliation with an applicant institution

- Current employment at the applicant institution or agency within the specific department of the applicant, or being considered for employment in that department.
- Ownership of the institution's securities or other evidences of debt.
- Current membership on visiting committee or similar body that directly relates to the proposal.
- Current enrollment as a student at a department or school submitting a proposal if the proposed project will be of direct professional or financial benefit.
- Received and retained an honorarium or award related to work or activities in the specific department of the applicant within the last 12 months.

2] Affiliation with investigator, project director, or other person with personal interest in the proposal

- Known family or marriage relationship, if relationship is with a principal investigator, collaborator (if curriculum vitae is included in proposal) or project director.
- Business or professional partnership.
- Past or present association as major thesis/dissertation advisor or thesis/dissertation student to one of the principal investigators.
- Science Panel member is a principal investigator on a proposal or is listed as a collaborator and a curriculum vitae is included in the proposal package (for this case only, the panel member must leave the room during discussion and voting on that particular proposal).
- Technical reviewers who have submitted a proposal may be called on to review other proposals, but only if there is a shortage of available reviewers.

3] Other affiliations or relationships

- Interests of the following persons must be treated as if they were that of the Science Panel member or technical reviewer: any affiliation or relationship of member's spouse or minor child or sibling, of a relative living in the immediate household or of anyone who is legally a partner of the member, that would be covered by the affiliations listed above.
- Other relationship, such as a very close personal friendship or open antagonism that might tend to affect a member's judgment or be seen as doing so by a reasonable person familiar with the relationship.

NPRB Members NPRB members must refrain from voting under three circumstances: (1) on approval of funding for a research project if the member is listed as a principal investigator or collaborator whose curriculum vitae is included in the proposal, (2) if the decision would have a significant and predictable effect on their financial interest, or (3) if the Board member believes he/she has a conflict of interest. Examples of instances covered under (3) include:

- Current employment in the specific department of the applicant for research funds.
- Ownership of the institution's securities or other evidences of debt.
- Known family or marriage relationship, if relationship is with a principal investigator or collaborator whose curriculum vitae is included in the proposal.
- Business or professional partnership with a principal investigator or collaborator whose curriculum vitae is included in the proposal.

Independent Review of Final Reports

Final project reports may be subjected to independent review, with the expectation that principal investigators will respond timely to peer review comments and revise the final report in accordance with peer review decisions. Principal investigators should strive to submit research results for publication in an appropriate scientific journal within one year of project completion.

Confidentiality of Information

Research proposals shall be deemed proprietary and confidential until the Board approves them for funding. Funded proposals may be released to the public. Unfunded proposals remain proprietary and confidential, however, project title, author(s), funds requested, duration, and proposal summary pages will be made public.

Data Management and Quality Control

Introduction

The NRC (2004a) noted that an effective data management and dissemination strategy is vital to ensuring success of NPRB and recommended that NPRB instruct principal investigators to place data in the public domain after no more than two years and share data within interdisciplinary programs as soon as possible to maximize dissemination of knowledge even before archival publication. The NRC also recommended that the Board establish a data manager position and maintain an easily-navigable web-based archive of data.

The Board already has satisfied some of these recommendations. Project reports are posted on NPRB's web site and a data manager has been hired. The RFPs require principal investigators to have a data management and information transfer plan and report their data to an agreed-upon system (NODC or USGS information infrastructure), and to the North Pacific Ecosystem Metadatabase (see http://www.pmel.noaa.gov/np/mdb/index.html). Principal investigators must agree that data gathered or analyses performed are not proprietary, that timely publication requirements are met, and that results are made available to the public and other researchers as requested by the NPRB. The NPRB also is developing an Alaska marine information system that will entail an enhanced web site and access to project-generated datasets, other biogeographic datasets, and navigational tools to relate information to geographic areas and oceanographic features.

Data Policy Guidelines

The NPRB expects significant findings from its research activities to be promptly submitted for publication, with authorship accurately reflecting contributions of those involved.It expects investigators to share with other researchers, at no more than incremental costs and within a reasonable time, the data, samples, genetic baseline data, physical collections and other supporting materials created or gathered. It also encourages grantees to share software and inventions or otherwise act to make the innovations they embody widely useful and usable. Adjustments and exceptions, where essential, may be allowed to safeguard the rights of individuals and subjects, the validity of results, or the integrity of collections or to accommodate legitimate interests of investigators. (These guidelines are based largely on NSF policy at http://www.nsf.gov/pubs/2004/nsf04004/print_toc.htm.)

Data Submission Principal Investigators are required to submit data collected using NPRB funds to NPRB and the designated National Data Centers (see below) as soon as possible, but no later than two years after the data are collected. They also will be encouraged to submit data as appropriate to the Ocean Biogeographical Information System (OBIS). Inventories (metadata) of all marine environmental data collected should be submitted to the designated National Data Centers within sixty days after the observational period/cruise. The NPRB also requires the submission of basic data to allow for reprocessing later if necessary and appropriate. For continuing observations, or for long-term (multi-year) projects, data are to be made public annually (based on April 2002 policy of NSF Division of Earth Sciences). Principal investigators and their institutions, and ship-operating institutions are responsible for meeting all legal requirements for submission of data and research results if so imposed by foreign governments for granting research clearances. Where no data repository exists for the collected data, metadata must be prepared and made available, and the principal investigators must describe in their proposal, alternative strategies for complying with the general philosophy of sharing research products and data.

Reporting Requirements Annual reports, required for all projects, should address progress on data and research product sharing. Final reports must document compliance or explain why it did not occur. In cases where the final report is due before the required data submission, the principal investigator must report submission of metadata and plans for final submission, and then notify NPRB by e-mail after final data and/or sample submission.

National Data Centers For most ocean data there are designated national data centers where data must be deposited. These centers and a brief description of the data they support are described below:

1] National Oceanographic Data Center (NODC)

- Ocean physical data: temperature, salinity, light transmission or attenuation, currents, waves, pressure, sea level, and sound speed.
- Ocean chemistry data: nutrients such as phosphates, nitrates, nitrites and silicates; chemical tracers such as helium, tritium, freon and argon; pollutants such as petroleum hydrocarbons, organochloride and organophosphorus pesticides, polychlorinated biphenyls and heavy metals. Data may represent chemicals in water samples or biota.
- Ocean biology data: primary productivity; concentrations of pigments in phytoplankton, such as chlorophyll-a; species lists; biomass of phytoplankton, zooplankton, benthos and nekton; and bioluminescence.
- Reference: http://www.nodc.noaa.gov/.

2] National Climatic Data Center (NCDC)

- Surface meteorological data: meteorological data in appropriate World Meteorological Organization formats as part of the Voluntary Observing Ship program: air temperature, sea-surface temperature, dew point temperature, pressure, wind speed and direction, wind and swell waves, weather, short- and long-term radiation, visibility, cloud cover and type, and ice accretion.
- Reference: http://lwf.ncdc.noaa.gov/oa/ncdc.html.

3] National Geophysical Data Center (NGDC)

- Geophysical, geological and geochemical data: bathymetry, magnetics, gravity, seismic and other quantitative geophysical data; geological data including station locations, collection/storage locations, preliminary descriptions of seafloor samples recovered, and all descriptions and analytical data, including geochemistry, derived from sediment and rock samples, including data from the Ocean Drilling Program.
- Reference: http://www.ngdc.noaa.gov/ngdc.html.

4] National Snow & Ice Data Center (NSIDC)

- Sea ice and other glaciological data: sea ice, icebergs, ice shelves and associated physical oceanographic and meteorological data.
- Reference: http://www-nsidc.colorado.edu/.

5] Carbon Dioxide Information Analysis Center (CDIAC)

- Carbon dioxide data: archival data for the World Ocean Circulation Experiment and the Joint Global Ocean Flux Study CO_2 measurements.
- Reference: http://cdiac.esd.ornl.gov/home.html.

Data Management and Quality Assurance/Quality Control

All projects and proposals must provide a statement describing data management and quality assurance/control processes that will be used to ensure the integrity of the data and match data types to project objectives. This statement must present the information listed below, or should cite relevant procedures adopted by the principal investigator's research organization.

1] Study design, including sample type(s) and location requirements, statistical analyses used to estimate types and numbers of physical samples required, or equivalent information for studies using survey and interview techniques. Description of metadata essential for interpreting results.

2] Criteria for determining acceptable data quality for accomplishing project goals.

3] Characteristics of data produced: Metadata must meet minimum requirements of the Federal Government Data Committee (FGDC; see http://www.fgdc.gov/metadata/metadata.html). Quantitative datasets can generally be grouped into three categories: physical measurements, species specific measurements and taxonomic sampling. Physical measurements pertain to non-biological oceanographic readings harvested from devices. Species specific datasets are composed of biological analyses limited to a predefined species group or inclusive hierarchical taxonomic structure. Taxonomic sampling datasets consist of information which attempts to characterize various flora and fauna captured/observed during a sampling project. Quantitative data must be categorized within those three major data types and a list of fields identified.

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4] Definition of algorithms to be used to convert signals from sensors to observations. Examples of algorithms of interest would be the conversion of pressure to depth and the conversion of integrated voltages to biomass at depth.

5] Procedures for handling and custody of samples, including sample collection, identification, preservation, transportation and storage.

6] Procedures for calibration and performance evaluation of all analytical instrumentation and all methods of analysis to be used during the project.

7] Procedures for data reduction and reporting, including a description of all statistical methods, with reference to any statistical software to be used, to make inferences and conclusions. Discuss any computer models to be designed or utilized with associated verification and validation techniques.

Other Policy Issues

Confidentiality of Video and Photographic Information

The NPRB contracts with principal investigators have the following stipulations on provision of data:

The NPRB reserves the right to distribute any and all information pertaining to the data and analyses found in and deriving from programmatic reports. None of the data gathered or analyses performed with funds from NPRB is proprietary in nature. Research results shall be published and made available to the public and other researchers as requested by the NPRB.

Data must be reported in an agreed-upon system, in accordance with specifications in a data management and information transfer plan, which will be developed by NPRB, in consultation with the applicant. It will specify, among other requirements, the storage media and formats, month and location for reporting, and other relevant information, such as metadata, that may be required by the circumstances of the project.

NPRB is exploring the issue of confidentiality of video and photographic information collected on commercial fishing vessels. Fishing companies that are cooperating in research have raised concerns that the above stipulations raise the specter of the possibility of Freedom of Information Act requests for the raw data (such as video footage) by non-governmental organizations and the public for a variety of unintended purposes (such as video editing for negative public relations or evidence for personal injury cases regarding injured crewmembers).

Specimen Archives and Universal Protocol

The NRC (2004a) noted that an effective sample archival program is vital to ensuring success of NPRB and documenting biodiversity, and recommended that NPRB join a sample archiving program to provide safe storage and easy retrieval. Within constraints of available funding, NPRB will seek to establish local, regional, and national partnerships for archiving tissue and organisms and other types of samples and ensuring they are properly curated to preserve their quality.

Marine Geological Samples Principal investigators are required to archive and curate sediment, core, and dredge samples and to make them available to other investigators as soon as possible but no later than two years after the samples are collected. They must describe in their proposals how their geological specimens will be archived.

Biological Samples Academic, private, and community facilities have traditionally been sites where biological materials are curated. Not all material can (or should) be accommodated in these facilities. Principal investigators should archive voucher and type specimens as dictated by community standards and practices, as required by journals for publication, and as appropriate to support research results. Sharing of valuable sample material is highly encouraged and can be facilitated by providing metadata, indicating that samples are available early in the development of a research program.

Collections of biological specimens are necessary for many types of research in biological sciences, including one of the most essential activities, species identification. The National Science Foundation is the principal source of federal support for enhancement of these collections, principally by helping make improvements in infrastructure and computerization of large and disparate datasets. Typically, collections are housed at institutions with programs in systematics and other biodiversity-related research, and the collections have been built over many years and contain thousands or even millions of specimens. Natural history collections contain records of life on earth that are unique and irreplaceable, including specimens of extinct species and temporal information on changes in the ranges of native and introduced species. Such collections provide materials necessary for research on biodiversity, including evolutionary relationships, ecosystem functioning, and biological conservation.

The NPRB will strive to develop partnerships with institutions and the National Science Foundation in establishing specimen archives for NPRB-funded collections. Collections must deal directly with specimens of organisms, parts of organisms, or direct artifacts of organisms (e.g., recorded sounds, fossilized parts), or may be organism-based collections that maintain associated specimens and data documenting the environmental context of the primary organism (e.g. water samples, temperature, specimen-based geographic information) or the genomic context of the organism (e.g. frozen tissue, DNA). In considering support for specimen archives, NPRB will consider the taxonomic breadth of the collections, numbers of specimens or lots, numbers of species, and information on geographic areas, oceanographic regions, or stratigraphic horizons where specimens were collected, and their value for scientific research and resource management.

Protection of Intellectual Property Rights

The NPRB will comply with federal requirements for protection of intellectual property (including patents, inventions, and copyrights), as promulgated in Title 35, Chapter 18, of the United States Code. The requirements are based on the Bayh-Dole Act for which the Department of Commerce is the lead implementing agency. Chapter VII, Section 730, of the NSF Grant Policy Manual incorporates the federal requirements. The Patent Rights clause in section 731.3 will be posted on the NPRB web site and there will be reference to it in all contracts with research entities and principal investigators (including entities not affiliated with universities). It applies to all inventions conceived or first actually reduced to practice in the performance of a federal grant, contract, or cooperative agreement, even if the Federal government is not the sole source of funding for either the conception or the reduction to practice. The provisions do not, however, apply to federal grants primarily aimed at training students and postdoctoral scientists.

In general, a university is obligated to have written agreements with its faculty and technical staff that require disclosure and assignment of inventions, and must disclose each new invention to the federal funding agency within two months after the inventor discloses it in writing to the university. The decision whether or not to retain title to the invention must be made within two years after disclosing the invention to the agency. This time may be shortened, if, due to publication of research results or public use, the one-year U.S. statutory patent bar has been set in motion. Under such circumstances, the university must make an election at least sixty days before the end of the statutory period. If the university does not elect to retain title, the agency may take title to the invention.

Upon election of title, the university must file a patent application within one year, or prior to the end of any statutory period in which valid patent protection can be obtained in the U.S. The university must provide the government, through a confirmatory license, a non-exclusive, non-transferable, irrevocable, paid-up right to practice or have practiced the invention on behalf of the U.S. throughout the world. Universities must share with inventor(s) a portion of revenues received from licensing the invention. Any remaining revenue, after expenses, must be used to support scientific research or education.

Agencies may decide, for compelling reasons, that title should be vested in the federal government. Such decisions must be consistent with provisions within the Bayh-Dole Act and made in writing before entering into a funding agreement with a university. Under certain circumstances, the government can require the university to grant a license to a third party or the government may take title and grant licenses itself (these are called "march-in rights"). This might occur if the invention was not brought to practical use within a reasonable time, if health or safety issues arise, if public use of the invention was in jeopardy, or if other legal requirements were not satisfied.

The NPRB also will adhere to individual State laws and regulations on protection of intellectual property rights, and will develop procedures to protect Alaska Native proprietary interests.

Equipment Pools and Sharing

The NPRB is party to various sharing agreements and memoranda of understanding that allow for sharing of equipment. The NPRB has agreed to expedite access to and sharing of its facilities and equipment to reduce costs, increase efficiency and avoid duplication of effort. Its contracts with principal investigators and their institutions may require all equipment and supplies above a certain dollar limit, not consumed in the course of the work and having a useful life of more than one year from the date of purchase with NPRB funds, to remain the property of NPRB and be returned to NPRB within 30 days following termination of the contract. Upon written request, NPRB may determine that some or all of the equipment and supplies need not be returned.

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Appendices

Appendix A
List of Species and Common Names

Common Name	Scientific Name
Alaska Plaice	*Pleuronectes pallasi*
Aleutian Tern	*Sterna aleutica*
Ancient Murrelet	*Synthliboramphus antiquus*
Arctic Cisco	*Salmo autumnalis*
Arctic Cod	*Arctogadus glacialis*
Arctic Flounder	*Liopsetta glacialis*
Arctic Tern	*Sterna paradisaea*
Arrow Worm	*Chaetognatha*
Arrowtooth Flounder	*Reinhardtius stomias*
Atka Mackerel	*Pleurogrammus monopterygius*
Atlantic Salmon	*Salmo salar*
Bearded Seal	*Erignathus barbatus*
Beluga Whale	*Delphinapterus leucas*
Bering Cisco	*Coregonus laurettae*
Bering Sea Snow Crab	*Chionoecetes opilio*
Bering Sea Tanner Crab	*Chionoecetes bairdi*
Black-footed Albatross	*Phoebastria nigripes*
Black-legged Kittiwake	*Rissa tridactyla*
Blue King Crab	*Paralithodes platypus*
Blue Mussel	*Mytilus edulis*
Blue Whale	*Balaenoptera musculus*
Bowhead Whale	*Balaena mysticetus*
Broad Whitefish	*Coregonus nasus*
Brown Bear	*Ursos arctos*
Capelin	*Mallotus villosus*
Cassin's Auklet	*Ptychoramphus aleuticus*
Chinese Mitten Crab	*Eriocheir sinensis*
Chinook Salmon	*Oncorhynchus tshawytscha*
Chum Salmon	*Oncorhynchus keta*
Coho Salmon	*Oncorhynchus kisutch*
Comb Jellies	*Ctenophora*
Common Eider	*Somateria mollissima*
Common Murre	*Uria aalge*
Coyote	*Canis latrans*
Crested Auklet	*Aethia cristatella*
Dall's Porpoise	*Phocoenoides dalli*
Dinoflagellate	*Alexandrium catenella*
Dolly Varden Char	*Salvelinus malma*

Common Name	Scientific Name
Double-crested Cormorant	*Phalacrocorax auritis*
Dover Sole	*Microstomus pacificus*
Dungeness Crab	*Cancer magister*
Emperor Goose	*Chen canagica*
Eulachon	*Thaleichthys pacificus*
European Green Crab	*Carcinus maenas*
Fin Whale	*Balaenoptera physalus*
Flathead Sole	*Hippoglossoides elassodon*
Fork-tailed Storm-Petrel	*Oceanodroma furcata*
Fourhorn Sculpin	*Myoxocephalus quadricornis*
Glaucous Gull	*Larus hyperboreus*
Glaucous-winged Gull	*Larus glaucescens*
Golden King Crab	*Lithodes aequispinus*
Gray Whale	*Eschrichtius robustus*
Greenland Turbot/Halibut	*Reinhardtius hippoglossoides*
Grooved Tanner Crab	*Chionoecetes tanneri*
Harbor Porpoise	*Phocoena phocoena*
Harbor Seal	*Phoca vitulina*
Herring Gull	*Larus argentatus*
Horned Puffin	*Fratercula corniculata*
Humpback Whale	*Megaptera novaeangliae*
Humpback Whitefish	*Coregonus pidschian*
Ivory Gull	*Pagophila eburnea*
Kelp Greenling	*Hexagrammos decagrammus*
Killer Whale	*Orcinus orca*
King/Spectacle Eider	*Somateria spectabilis*
Kittlitz's Murrelet	*Brachyramphus brevirostris*
Korean Hair Crab	*Erimacrus isenbeckii*
Lanternfish	*Myctophidae (family)*
Laysan Albatross	*Phoebastria immutabilis*
Leach's Storm-Petrel	*Oceanodroma leucorrhoa*
Least Auklet	*Aethia pusilla*
Least Cisco	*Coregonus sardinella sardinella*
Lingcod	*Ophiodon elongatus*
Littleneck Clam	*Prothothaca staminea*
Marbled Murrelet	*Brachyramphus marmoratus*
marine cyanobacteria	*Prochlorococcus marinus*
marine cyanobacteria	*Synechococcus*

Common Name	Scientific Name
Mew Gull	*Larus canus*
Minke Whale	*Balaenoptera acutorostrata*
Mudsnail	*Nassarius obsoletus*
North Pacific (Northern) Right Whale	*Eubalaena glacialis*
Northern Fulmar	*Fulmarus glacialis*
Northern Fur Seal	*Callorhinus ursinus*
Northern Pike	*Esox lucius*
Northern Shrimp	*Pandalus borealis*
Pacific Cod	*Gadus macrocephalus*
Pacific Halibut	*Hippoglossus stenolepis*
Pacific Herring	*Clupea pallasi*
Pacific Ocean Perch	*Sebastes alutus*
Pacific Oyster	*Crassostrea gigas*
Pacific Rattail	*Coryphaenoides acrolepis*
Pacific Sandfish	*Trichodon trichodon*
Pacific Sandlance	*Ammodytes hexapterus*
Pacific Saury	*Cololabis saira*
Pacific Sleeper Shark	*Somniosus pacificus*
Pacific Tomcod	*Microgadus proximus*
Pacific Walrus	*Odobenus rosmarus divergens*
Pacific White-sided Dolphins	*Lagenorhynchus obliquidens*
Parakeet Auklet	*Cyclorrhynchus psittacula*
Pelagic Cormorant	*Phalacrocorax pelagicus*
Pigeon Guillemot	*Cepphus columba*
Pink Salmon	*Oncorhynchus gorbuscha*
Polar Bear	*Ursus maritimus*
Rainbow Smelt	*Osmerus mordax*
Red King Crab	*Paralithodes camtschaticus*
Red-faced Cormorant	*Phalacrocorax urile*
Red-legged Kittiwake	*Rissa brevirostris*
Rex Sole	*Glyptocephalus zachirus*
Rhinoceros Auklet	*Cerorhinca monocerata*
Ribbon Seal	*Phoca fasciata*
Ringed Seal	*Phoca hispida*
Rock Scallop	*Crassedoma giganteum*
Rock Sole	*Paraplagusia bilineata*
Rougheye Rockfish	*Sebastes aleutianus*

Common Name	Scientific Name
Sabine's Gull	*Xema sabini*
Sablefish	*Anaplopoma fimbria*
Salmon Shark	*Lamna ditropis*
Scarlet Red King Crab	*Lithodes couesi*
Sea Onion	*Bowiea volubilis*
Sea Otter	*Enhydra lutris*
Sea Peach	*Halocynthia aurantia*
Sea Raspberry	*Gersemia rubiformis and G. fruticosa*
Sei Whale	*Balaenoptera borealis*
Shortraker Rockfish	*Sebastes borealis*
Short-tailed Albatross	*Phoebastria albatrus*
Signal Crayfish	*Astacus astacus*
Smooth Pink Scalop	*Chlamys rubida*
Sockeye Salmon	*Oncorhynchus nerka*
Sooty Albatross	*Phoebetria palpebrata*
Sperm Whale	*Physeter macrocephalus*
Spiny Dogfish	*Squalus acanthias*
Spiny Scallop	*Chlamys hastata*
Spiny Water Flea	*Bythotrephes longimanus*
Spotted Seal	*Phoca largha*
Steller Sea Lion	*Eumetopias jubatus*
Steller's Eider	*Polysticta stelleri*
Surf Clam	*Spisula solidissima*
Thick-billed Murre	*Uria lomvia*
Thornyhead Rockfish	*Sebastolobus alascanus*
Tree Coral	*Oculina robusta*
Triangle Tanner Crab	*Chionoecetes angulatus*
Tufted Puffin	*Fratercula cirrhata*
Walleye Pollock	*Theragra chalcogramma*
Weathervane Scallop	*Patinopecten caurinus*
Whiskered Auklet	*Aethia pygmaea*
White Shark	*Carcharodon carcharias*
Yellowfin Sole	*Limanda aspera*
Zebra Mussel	*Dreissena polymorpha*

Appendix B
Acronym Guide

ACC	Alaska Coastal Current
ACIA	Arctic Climate Impact Assessment
ADEC	Alaska Department of Environmental Conservation
ADFG	Alaska Department of Fish and Game
AFSC	Alaska Fisheries Science Center (NOAA)
AKFIN	Alaska Fisheries Information Network
AMAP	Arctic Monitoring and Assessment Program
ANSC	Alaska Native Science Commission
AO	Arctic Oscillation
AOOS	Alaska Ocean Observing System
APPRISE	Association of Primary Production and Recruitment in a Subarctic Ecosystem
ARC	U.S. Arctic Research Commission
ARCUS	Arctic Research Consortium of the U.S.
ASLC	Alaska SeaLife Center
AYKSSI	Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative
BASIS NPAFC	Bering Sea-Aleutian Salmon International Survey
BERPAC	Third Joint US-USSR Bering and Chukchi Seas Expedition
BEST	Bering Sea Ecosystem Study
BSAI	Bering Sea and Aleutian Islands
BSC	Bering Slope Current
BSCC	Bering Sea Coastal Current
CDQ	Community Development Quota
CMI	Coastal Marine Institute
COML	Census of Marine Life
EFH	Essential Fish Habitat
EFOCI	Eastern Bering Sea Fisheries Oceanography Coordinated Investigations
EIRF	Environmental Improvement and Restoration Fund
ENSO	El Nino / Southern Oscillation
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
EVOSTC	Exxon Valdez Oil Spill Trustees Council
FGDC	Federal Government Data Committee
FOIA	Freedom of Information Act
FOCI	Fisheries Oceanography Coordinated Investigations
FWS	U.S. Fish and Wildlife Service
GAO	General Accounting Office
GEM	Gulf Ecosystem Monitoring
GIS	Geographic Information System
GLOBEC	Global Ocean Ecosystem Dynamics
GOA	Gulf of Alaska
GOOS	Global Ocean Observing System
HAB	Harmful Algal Bloom
HAPC	Habitat Areas of Particular Concern
HCH	Hexachlorocyclohexanes
IARPC	Interagency Arctic Research Policy Committee
IERP	Integrated Ecosystem Research Program
IFQ	Individual Fishing Quota
IOOS	International Ocean Observing System
IPHC	International Pacific Halibut Commission
ISHTAR	Inner Shelf Transfer and Recycling in the Bering and Chukchi Seas
LME	Large Marine Ecosystem
LSI	Land-Shelf Interactions
LTK	Local and Traditional Knowledge
MIZEX	Bering Sea Marginal Ice Zone Experiment
MMPA	Marine Mammal Protection Act
MMS	U.S. Minerals Management Service
MSA	Magnuson-Stevens Fishery Conservation and Management Act
NMFS	National Marine Fisheries Service
NMML	National Marine Mammal Laboratory
NOAA	National Oceanic and Atmospheric Administration
NODC	National Ocean Data Center
NPAFC	North Pacific Anadromous Fish Commission
NPFMC	North Pacific Fishery Management Council
NPMRI	North Pacific Marine Research Institute
NPRB	North Pacific Research Board
NPZ	Nutrient-Phytoplankton-Zooplankton
NRC	National Research Council
NSF	National Science Foundation
OBIS	Ocean Biogeographical Information System
OCSEAP	Outer Continental Shelf Environmental Assessment Program
ONR	Office of Naval Research
PACTS	Pan-Arctic Cycles, Transitions and Sustainability

PAH	Polycyclic Aromatic Hydrocarbons
PBDE	Polybrominated Diphenyl Ethers
PCB	Polychlorinated Biphenols
PCCRC	Pollock Conservation Cooperative Research Center
PCN	Polychlorinated naphthalines
PDO	Pacific Decadal Oscillation
PI	Principal Investigator
PICES	North Pacific Marine Science Organization
POP	Persistent Organic Pollutants
PROBES	Processes and Resources of the Bering Sea
PSP	Paralytic Shellfish Poisoning
PWSSC	Prince William Sound Science Center
QA/QC	Quality Assurance/Quality Control
RFP	Request for Proposals
RUSALCA	Russian-American Long-Term Census of the Arctic
SAFE	Stock Assessment and Fishery Evaluation Document
SALMON	Sea-Air-Land Modeling and Observation Network
SBI	Shelf-Basin Interactions
SCC	Siberian Coastal Current
SEA	Sound Ecosystem Assessment
SEARCH	Study of Environmental Arctic Change
SEBSCC	Southeast Bering Sea Carrying Capacity
SEIS	Supplemental Environmental Impact Statement
SNACS	Study of the Northern Alaska Coastal System
SSB/R	Spawning Stock Biomass per Recruit
TBT	Tributyltin
UAF	University of Alaska Fairbanks
USCOP	U.S. Commission on Ocean Policy
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WWF	World Wildlife Fund

Appendix C
National Research Council Study Committee Membership, Support Staff, and Findings

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NRC Study Committee Recommendations on NPRB Science Plan

NRC Findings Regarding Criteria for Successful NPRB Science Plan

Finding 1: The overriding conceptual foundation is critical to the success of a long-term science program since it will provide a framework for more specific recommendations and will guide the program in the long term as well as the short.

> Recommendation 1-1: In developing a science plan, the NPRB must include policies and procedures that provide for the development and articulation of the overriding goal or conceptual foundation.

> Recommendation 1-2: Since emerging issues cannot be predicted, the NPRB needs to include mechanisms that will allow the conceptual foundation to evolve over time through periodic review.

Finding 2: The geographic area as stated in the mandate is vaguely defined and might be larger than the NPRB budget could support.

> Recommendation 2-1: The NPRB science plan should limit studies in the North Pacific and Arctic Ocean to geographically prescribed areas where comprehensive studies can be undertaken. For example, the Arctic could be limited to the East Siberian, Chukchi and Beaufort Seas, and the North Pacific to its subarctic gyre, except for studies that naturally extend outside these boundaries. These regions, together with the Bering Sea, comprise an interacting series of ecosystems that may be studied comprehensively through research funded by the NPRB.

Finding 3: Although the NPRB funds are a large new contribution to the total research budget of the area, they are not limitless and they do fluctuate over time due to fluctuating interest rates.

> Recommendation 3-1: During periods of funding constraints, all long-term monitoring should be protected and short-term process studies should focus on core scientific questions. If financially necessary, it would be better to support research in a limited geographic area than to scatter research over a larger area.

Research Themes and Approaches

Ecosystem States and Variability

Finding 4: Ecosystems vary on multiple time and space scales. Some processes are predictable and others are aperiodic. To meet their legislative mandate, the NPRB will need to focus on integrated, interdisciplinary studies of entire ecosystems. Such studies will lead to applications necessary for the management of aquatic resources.

Recommendation 4-1: The NPRB should support fundamental science to study the structure and function of ecosystems, in order to understand the populations they support.

Recommendation 4-2: The NPRB should encourage formation of interdisciplinary research teams by priority funding of well-integrated research groups.

Recommendation 4-3: NPRB Funding should support a well-integrated mix of long-term, process, and modeling studies, accompanied by development of appropriate technology if that technology is necessary to answer an important scientific question.

Recommendation 4-4: The NPRB should fund a balanced mixture of regional and largescale investigations. Those regional and large-scale studies should be well integrated.

Recommendation 4-5: The NPRB should encourage proposals that include data on the roles and trends of important non-commercial species, such as potential prey species, indicator species, keystone species, and others. Although there are data for commercial species, information regarding non-commercial species is particularly lacking.

Finding 5: Knowledge of past and current states of physics and biology is necessary in order to predict ecosystem change. The unique funding structure of the NPRB provides a rare opportunity for establishment of long-term monitoring sites at well thought-out locations. The value of longterm data is in their continuity, and once interrupted they lose their value.

Recommendation 5-1: Long term monitoring sites should be established and observations should be continued uninterrupted. Once a long-term monitoring plan is established, it should be changed only for compelling reasons, and only in such a way that continuity of the long-term record is preserved.

Finding 6: The collection and incorporation of traditional knowledge are challenging and generally have not been done well.

Recommendation 6-1: The NPRB should facilitate communication between scientists and stakeholders in the NPRB study area. Several groups, such as the Alaska Native Science Commission, have expertise in this process and the NPRB should work with appropriate stakeholder representatives to develop strategies for accomplishing scientist/stakeholder interaction.

Recommendation 6-2: The NPRB should consider funding the collection of traditional knowledge relevant to the NPRB goals and encourage the incorporation of traditional knowledge into research planning and hypothesis development.

Human-Induced Effects

Finding 7: Human activities have direct and indirect effects on ecosystems.

Recommendation 7-1: The NPRB should fund studies that have a high potential to determine whether specific human activities have an effect on marine ecosystems, what the scales of such impacts are likely to be, and what kinds of mitigation are possible. Such studies could include impacts from proposed or actual industrial or municipal development, fishing and hunting, shipping, and contamination.

Economic, Social, and Management Research

Finding 8: New management methods such as individual fish quotas and fishing cooperatives have lead to structural changes in the industry.

Recommendation 8-1: Economic and social data should be gathered on an ongoing basis to evaluate the changes that new management regimes have brought or are likely to bring.

Finding 9: The subsistence economy appears to be under increasing pressure from a dwindling resource base and increased demand.

Recommendation 9-1: Economic and social research is needed to ascertain the long-term viability of the subsistence economy and the social changes spurred by decreasing resources and increasing populations. Researchers should be encouraged to work with rural communities and Tribes and with Tribal and Native organizations on these types of research projects.

Forecasting and Responding to Change

Finding 10: A lack of data and understanding of underlying processes inhibits the development of models, both statistical and numerical models, for forecasting purposes.

Recommendation 10-1: The NPRB should fund research that leads to the improvement of predictive models. This research includes the acquisition of long-term data records and the undertaking of short-term process studies that reveal underlying processes.

Management Issues

NPRB Members, Staff, and Panels

Finding 11: The NPRB mandate is large and complex, and currently the only staff is its executive director.

Recommendation 11-1: The NPRB should provide adequate administrative staff to support the executive director, although care must be taken to minimize the level of funding going to administration.

Finding 12: Although input from the user community is often sought, science plans are generally written by scientists familiar with the regional scientific issues.

Recommendation 12-1: The NPRB Science Panel or other scientists with appropriate expertise in regional scientific issues, who can place the regional science within the larger framework, should write the NPRB Science Plan.

The Proposal Process

Finding 13: The current management structure can lead to real or perceived conflicts of interest in reviewing and awarding research grants.

> Recommendation 13-1: Final approval of funding decisions should be made directly by the U.S. Secretary of Commerce or by a representative who is remote from the consequences of funding decisions. The Secretary of Congress representative on the Board should not be the same individual who approves funding recommendations on behalf of the Secretary.

Finding 14: The NPRB has not yet developed clear criteria for proposal review and distribution of funds that avoid real and perceived conflicts of interest. The Board's long-term legacy will depend on its funding decisions.

> Recommendation 14-1: The NPRB members should recuse themselves, in accordance with standard practice, when proposals from their agency or university are considered for funding.

> Recommendation 14-2: The NPRB should establish and publish fair procedures for awarding grants and then follow those procedures without exception. The criteria established by the NSF are especially respected within the scientific community and might serve as a model.

> Recommendation 14-3: The Science Panel should appoint a Proposal Selection Committee to rank research proposals and advise the Executive Director of their decisions.

> Recommendation 14-4: The Advisory Panel and Science Panel should not be involved in proposal funding decisions because of potential conflicts of interest.

> Recommendation 14-5: Since the Proposal Selection Committee will be a panel of experts, the NPRB and the Secretary of Commerce (or his/her representative) should respect their proposal rankings. The NPRB funding decisions should be documented in writing including an explanation of any deviations from the ranking of the Proposal Selection Committee.

External Review

Finding 15: All long-lived science programs benefit from periodic external reviews.

> Recommendation 15-1: The NPRB should conduct periodic internal and external reviews of the science plan, policies, and long-term programs at five-year intervals. The caution, however, is that the long-term monitoring components of the NPRB programs should be protected to the extent financially possible.

Education and Outreach

Finding 16: Incorporating public input and informing the public of program findings are important NPRB duties.

Recommendation 16-1: The NPRB should encourage outreach and education activity components either by Principal Investigators as part of proposals or as independently funded activities. These components should address all levels of education, making sure to include remote communities.

Recommendation 16-2: The NPRB should facilitate communication between scientists and stakeholders in the NPRB study area. They should consider continuing site visits throughout the northwest U.S. and Alaska region to foster understanding of the efforts of the NPRB and to receive public input on future research directions.

Data Policy and Management

Finding 17: An effective data management and dissemination strategy is vital to ensuring the success of NPRB-funded projects.

Recommendation 17-1: The NPRB Science Plan should instruct Principal Investigators to place all data in the public domain after no more than two years. Within interdisciplinary programs, data should be shared as soon as possible. This will serve to maximize dissemination of knowledge even prior to archival publication.

Recommendation 17-2: The NPRB should establish an administrative staff position responsible for data management and dissemination. This person should create and maintain a web-based archive of data that is easily navigated. Recent successful examples for the NPRB to follow include the Long Term Ecological Research, the Ridge Inter-Disciplinary Global Experiment, and the Joint Global Ocean Flux Study.

Finding 18: Archiving tissue samples and organisms provides a basis for documenting and understanding biodiversity.

Recommendation 18-1: The NPRB should join a sample archiving program that provides safe storage and allows for easy retrieval.

Coordination with Other Projects and Programs

Finding 19: The NPRB has finite resources and its mission overlaps with those of other agencies and programs.

Recommendation 19-1: The NPRB should appoint one or more individuals to act as liaisons with other state and federal agencies, universities, environmental groups, industry and Tribes and Tribal/Native organizations whose missions relate to those of the NPRB. Wherever possible, partnerships should be formed with these groups to leverage maximum benefit from available funds.

Recommendation 19-2: The NPRB should conduct an annual Principal Investigator workshop in conjunction with the annual Joint Science Symposium to foster project collaborations and share data.

Appendix D
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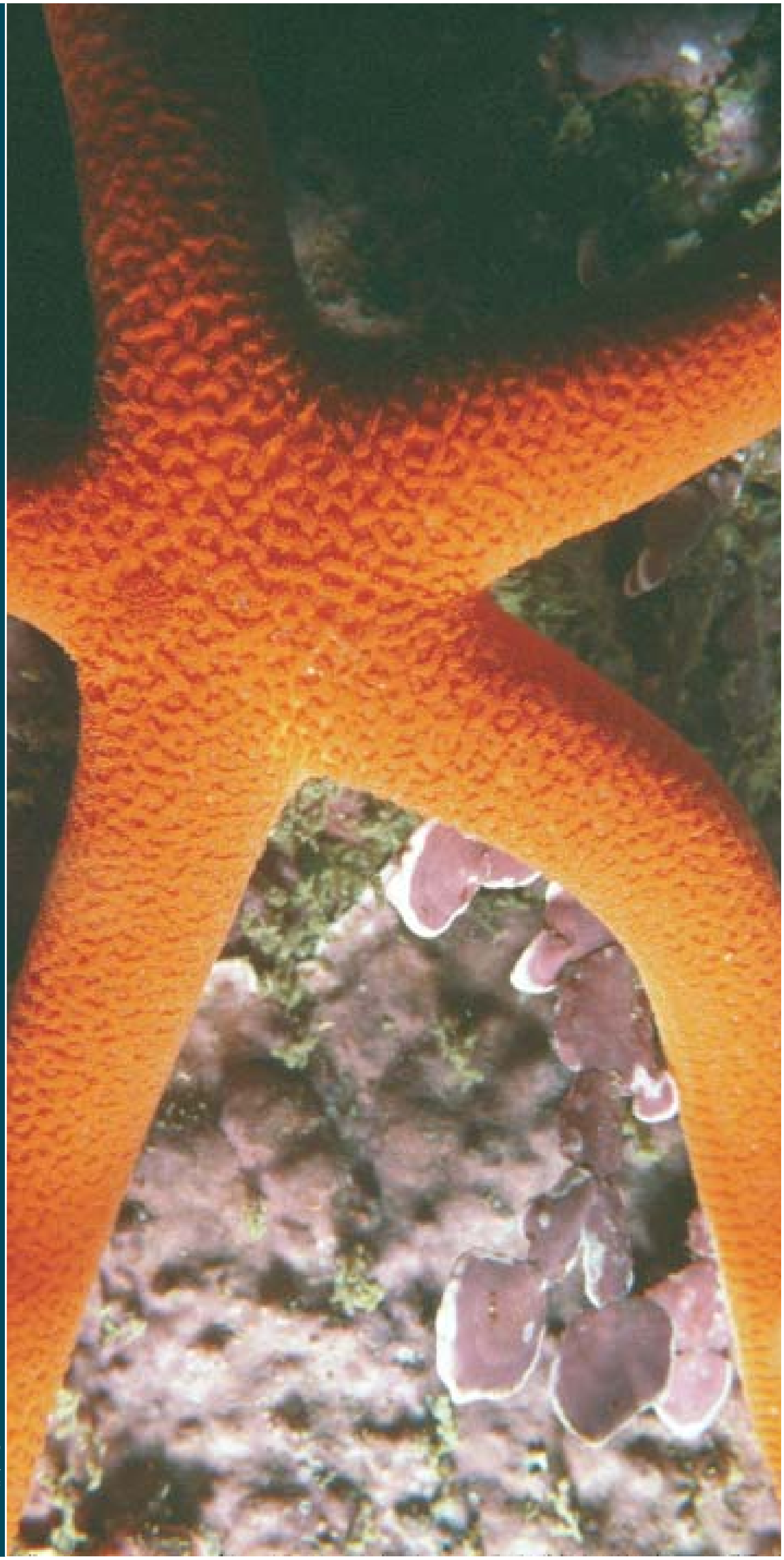

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