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Gulf of Alaska Ecosystem Monitoring and Research Program (GEM)

The GEM Program Document

July 9, 2002





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ACRONYMS AND TERMS MOST FREQUENTLY USED

ACC Alaska Coastal Current

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- ADEC Alaska Department of Environmental Conservation
- ADF&G Alaska Department of Fish & Game
- Aleutian Low Aleutian Low Pressure System
- ANHSC Alaska Native Harbor Seal Commission
- ARLIS Alaska Resources Library and Information Services

ARMRP Alaska Regional Marine Research Plan

- APEX The Alaska Predator Ecosystem Experiment
- CARTs classification and regression trees

CPR Continuous Plankton Recorder

CPUE catch per unit effort

- CRRC Chugach Regional Resource Commission
- DDT dichlorodiphenyltrichloroethane

ENSO El Niño Southern Oscillation

- EPA US Environmental Protection Agency
- ESA Endangered Species Act
- FGDC Federal Geographic Data Committee
- FOCI Fisheries Oceanography Coordinated Investigations
- ftp file transfer protocol
- GAK1 Gulf of Alaska station 1 located at the mouth of Resurrection Bay (60 N, 149 W)
- GEM Gulf of Alaska Monitoring and Research Program
- GIS Geographic Information System
- GLOBEC Global Ocean Ecosystem Dynamics
- GLOBEC NPZ nutrient-phytoplankton-zooplankton

GOA Gulf of Alaska

IOC Intergovernmental Oceanographic Commission

KBNERR Kachemak Bay National Estuarine Research Reserve LIDAR light detection and ranging MMPA Marine Mammal Protection Act MODIS Moderate Resolution Imaging Spectroradiometer NEP National Estuary Program NMFS National Marine Fisheries Service NMML NMFS National Marine Mammal Laboratory NASA National Aeronautics and Space Administration NOAA National Oceanic and Atmospheric Administration NODC National Ocean Data Center NPAFC North Pacific Anadromous Fish Commission NPI North Pacific Index NRC National Research Council NVP The Nearshore Vertebrate Predator Project OCC Ocean Carrying Capacity PAC Public Advisory Committee PAG Public Advisory Group PCB polychlorinated biphenyls PDO Pacific Decadal Oscillation PWS Prince William Sound PWSAC Prince William Sound Aquaculture Corporation PWS-SEK Prince William Sound-Southeast Kenai QC quality control SCOR Scientific Committee on Oceanic Research SDRs satellite-linked depth recorders SEA The Sound Ecosystem Assessment SeaW1FS Sea-viewing Wide Field-of-view Sensor SOIREE Southern Ocean Iron Release Experiment STAC Scientific and Technical Advisory Committee

TEK Traditional Ecological Knowledge

Trustee Council Exxon Valdez Oil Spill Trustee Council

USFS US Forest Service

USFWS US Fish and Wildlife Service

USGS US Geological Survey

WDFW Washington Department of Fish and Wildlife

WKP Western Kenai Peninsula

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WMS Open GIS Consortium's Web Mapping Server

OVERVIEW OF THE GEM DOCUMENT

The Gulf of Alaska Ecosystem Monitoring and Research (GEM) Program document describes the basic monitoring and research program and the scientific background behind the development of essential program components Chapters 1 through 5 explain the basic motivations for the program, conceptual foundation, tools and strategies for achieving program goals, and program implementation and management Chapters 6 through 9 present the factual basis for the program including detailed descriptions of two important components of the program 1) modeling (Chapter 8) and 2) data management and information transfer (Chapter 9) Table O 1 identifies the question addressed by each chapter and the products provided

	Tıtle	
Chapter	Question Addressed	Products
1	Vision	Mission and goals
	Why do this and what do we hope to achieve?	Geographic scope, funding and governance
2	Conceptual Foundation	Central hypothesis
	How do we think the ecosystem works?	Habitat types and time-space scales
3	Tools and Strategies	Tools Gap Analysis Synthesis, Research
	What information do we need and how do we get it?	Monitoring, Modeling and Data Management
	_	Strategies Community Involvement and Traditional Knowledge, and Resource Management Applicability
4	Program Implementation	Potential questions by habitat type
	Where are we going to start and how will we proceed? (This chapter is expected to change over time)	Program implementation and partnering
5	Program Management	Program administration
	What are the processes and policies for monitoring and research?	Roles and responsibilities of the GEM components
6	Introduction to the Scientific	Leading hypotheses in marine ecosystems
	Background	Principal ecological concepts and theories
	What are the theories and principles on which the conceptual foundation is based?	

Table O 1 Contents of the GEM Program Document

	Title	
Chapter	Question Addressed	Products
7	Scientific Background Physics Biology Human Uses and Economics Comprehensive review of the current state of scientific knowledge of Gulf of Alaska ecosystems	Overview of physical chemical and biological characteristics of the Gulf of
		Alaska
		and prey
		Status of human activities and socio- economics in the GOA
8	Modeling	Modeling definitions and options for program
	What is the role of modeling in GEM?	Implementation
9	Data Management and Information Transfer	Data management and information transfer options for program implementation
	What are the roles of data management and information transfer in GEM implementation?	
A	Acronyms and Web links	
В	Recovery Status of Injured Resources	
С	EVOS Tribal and Community Involvement	
D	GEM Database	
E	Glossary of Existing Agency Programs an	d Projects
F	North Pacific Models of the Alaska Fisheries Science Center and Other Selected Organizations	
G	Fish And Invertebrate Species From 1996 NMFS Trawl Survey Of The Gulf Of	Alaska
Н	Collected Research Questions	

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On March 24, 1989, the *T/V Exxon Valdez* ran aground on Bligh Reef in Prince William Sound, spilling almost eleven million gallons of North Slope crude oil The event was the largest tanker spill in U S history, contaminating approximately 1,500 miles of Alaska's coastline, killing birds, mammals and fish, and disrupting the ecosystem in the path of the spreading oil In 1991, the Exxon Corporation agreed to pay the United States and the State of Alaska \$900 million over ten years to restore, replace, enhance, or acquire the equivalent of natural resources injured by the spill, and the reduced or lost human services they provide (United States of America and State of Alaska 1991) Under the court-approved terms of the settlement, the *Exxon Valdez* Oil Spill Trustee Council (Trustee Council) was formed to administer the restoration funds, and in 1994 the *Exxon Valdez* Oil Spill Restoration Plan was adopted to guide the development and implementation of a comprehensive, interdisciplinary recovery and rehabilitation program

The knowledge and experience gained during years of biological and physical studies in the aftermath of the *Exxon Valdez* oil spill (EVOS) confirmed that understanding the sources of changes in marine resources and ecosystems requires putting those changes into an historical context. Toward this end, in March 1999 the Trustee Council dedicated approximately \$120 million for long-term monitoring and ecosystem-based research within the area affected by the 1989 oil spill, which is generally the northern Gulf of Alaska (GOA), including Prince William Sound, Cook Inlet, Kodiak Island, and the Alaska Peninsula. This new program is called the GEM (the Gulf of Alaska Ecosystem Monitoring and Research) Program, and its mission is to

Sustain a healthy and biologically diverse marine ecosystem in the northern Gulf of Alaska (GOA) and the human use of the marine resources in that ecosystem through greater understanding of how its productivity is influenced by natural changes and human activities

The Trustee Council identified five major goals necessary to accomplish this mission

- Detect• Serve as a sentinel (early warning) system by detecting annual and long-term changes in the marine ecosystem, from coastal watersheds to the central gulf,
- **Understand** Identify causes of change in the marine ecosystem, including natural variation, human influences, and their interaction,
- Inform. Provide integrated and synthesized information to the public, resource managers, industry and policy makers in order for them to respond to changes in natural resources,

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- **Solve** Develop tools, technologies and information that can help resource managers and regulators improve management of marine resources and address problems that may arise from human activities, and
- **Predict** Develop the capacity to predict the status and trends of natural resources for use by resource managers and consumers

Given the size and complexity of the northern GOA ecosystem and the available funding, the GEM Program alone can not meet these goals For that reason, the Trustee Council adopted a set of additional goals for implementing the program These call for the GEM Program to

- Lead the way in integrating, synthesizing, and interpreting monitoring and research results to form and convey a "big picture" of the status of and trends in the GOA ecosystem,
- **Track** work of other entities relevant to understanding biological production in the GOA and **coordinate** GEM with those efforts,
- Leverage funds to augment ongoing monitoring work funded by other entities,
- **Involve** other government agencies, non-governmental organizations, stakeholders, policy makers, and the general public in a collaborative process to achieve the mission and goals of GEM,
- Increase community involvement and local and traditional knowledge in order to enhance long-term stewardship of living marine resources, and
- **Facilitate** application of GEM research and monitoring results to benefit conservation and management of marine resources

To fully achieve its mission, GEM must provide information that enables resource-dependent people, such as subsistence users, recreation users, and commercial fishers, to better cope with changes in marine resources The data and information produced by GEM during its first decade may not totally solve problems for the public, commercial interests, resource managers, and policy makers faced with environmental change Nonetheless, as information accumulates, the ability for GEM to provide problem-solving information and tools can and must increase

The GEM Program is based on the current state of knowledge about the natural factors and ecological impacts of human activities that cause change in the GOA Within the northern GOA, offshore and nearshore marine, estuarine, freshwater and terrestrial environments interact with geologic, climatic, oceanographic, and biologic processes to produce highly valued natural bounty and exceptional beauty. The GOA provides habitat for diverse and abundant populations of fish and shellfish, marine mammals and seabirds. It is a major source of seafood for the entire nation, as well as for Alaska Natives, who rely on it for subsistence and cultural purposes. It is also a source of beauty and inspiration for those who love

nature and part of the "lungs" of the planet for recycling of oxygen and carbon to and from the atmosphere As a result of both human influences and natural processes, these important attributes are continually changing

Populations of important marine resources in the northern GOA have undergone major changes, especially since the late 1970s Salmon catches of all species, and especially of sockeye, have remained near record levels for two decades, with annual catches significantly greater than those in the three decades ending in 1979 Shrimp and red king crab have fallen to extremely low levels in the gulf since 1980, in sharp contrast to the very high levels in the two prior decades Kodiak's red king crab fishery, once among the world's richest, has been completely closed since 1984 As shrimp and crab declined, cod, pollock and flatfish, such as arrowtooth flounder, have rapidly increased Some marine mammals associated with the gulf, such as sea lions, harbor seals and overwintering fur seals, have steadily declined since 1980 Other species, such as sea otters and elephant seals, have been on the rise for more than a decade Colonies of seabirds, such as black-legged kittiwakes, common murres and cormorants have shown declines since about 1980 in some coastal localities, such as Prince William Sound and central Cook Inlet, but not in others Overall, many species and populations associated with nearshore habitats in the GOA have declined since about 1977, whereas species and populations having access to offshore gulf habitats have generally increased

The GOA and its watersheds are part of a larger oceanic ecosystem in which natural physical forces such as currents, upwelling, downwelling, precipitation and runoff, play important roles in determining basic biological productivity Natural physical forces are shaped by the surface topography of the GOA and the submarine topography of the continental shelf and respond primarily to seasonal shifts in the weather, and in particular to long-term changes in the intensity and location of the Aleutian Low Pressure system Increased upwelling offshore appears to increase inputs of nutrients to surface waters, which in turn increases productivity of plankton, the basis of the food chain and the primary food source for all marine life Increased winds appear to increase the transport of zooplankton shoreward toward and past the continental shelf-break. How often and how much offshore zooplankton sources contribute to coastal food webs depends on natural physical and biological forces such as predation, migration, currents, fronts, and eddies, degree and extent of turbulence, and responses of plankton to short and long-term changes in temperature and salinity

The ecological impacts of a wide range of human uses and activities interact with these natural forces to change the productivity and community structure in the GOA More than 70,000 people live within the area directly affected by the oil spill, and two to three times that number use the area seasonally for work and recreation When combined with the population of the nearby centers of Anchorage and Wasilla, plus nearly a million tourists who visit the state each year, it becomes clear that the natural resources of the GOA cannot be immune to the pressures associated with human uses and activities

Human activities have the most direct and obvious impacts at those sites in watersheds and intertidal areas where human populations are high. Crude oil and fuel tanker traffic, increasing tourism and recreational use, expanded road building, and growing commercial and sport fishing pressure could have increasing effects on marine resources and ecosystems. Some human activities affect populations of birds, fish, shellfish, and mammals even far offshore, and also have impacts far from the sites of the actions. Large scale fishing that occurs in international waters impacts Alaska resources. In addition, recent evidence of persistent organic pollutants and heavy metals in fish and wildlife tissues in the gulf indicate that this region is not immune from worldwide concerns about potential effects of contaminants on marine organisms and on human consumers, particularly Alaska Native subsistence users

In short, human activities and natural forces act together over local and global scales to drive and shape marine and terrestrial life in the GOA and its tributary watersheds This conceptual foundation is summarized into a central hypothesis that will guide the GEM Program

Natural forces and human activities working over global to local scales bring about short term and long lasting changes in the biological communities that support birds, fish, shellfish and mammals Natural forces and human activities bring about change by altering relationships among defining characteristics of habitats and ecosystems such as heat and salt distribution, insolation, biological energy flow, freshwater flow, biogeochamical cycles, food web structure, fishery impacts, and pollutant levels

This broad, interdisciplinary hypothesis states what is thought to be known in general, prepares the way for questions that test the validity of this knowledge and serves as a flexible framework for determining the type of monitoring and research activities that will be undertaken in implementing the GEM Program

Since the gulf ecosystem under consideration is extremely complex and consists of thousands of species, it also will not be possible for GEM to answer all, or even most, of the questions that could be posed about the GOA Four habitat types, representative of the GEM region, have been identified as themes around which the interdisciplinary monitoring and research activities that address GEM's central hypothesis will be organized. These habitat types are watersheds, the intertidal and subtidal areas, the Alaska Coastal Current, and the offshore areas (the continental shelf break and the Alaska Gyre). The habitats are composed of identifiable, although not rigid, collections of characteristic microhabitats, resident and migratory species, and physical features. The decision to use habitats as a mechanism for stratifying funds and allocating resources will require the GEM. Program to ensure that such cross-habitat processes and linkages as freshwater flow and cross-shelf nutrient transport are not forgotten or ignored

The GEM central hypothesis can be translated into a hypothesis for each of these habitat types However, before they can be used to guide research, they need to be further refined into questions which can then be used to identify a core set of measurements for long-term monitoring The GEM Program will use the tools of gap analysis, synthesis, and modeling to develop a series of initial research questions and to continually refine and implement GEM's long-term core monitoring program The "flagship" of GEM will be a long-term monitoring program that will be maintained even if funding levels vary The monitoring component will be complemented by strategically chosen research projects These projects will follow up on lingering effects of the *Exxon Valdez* oil spill, explore questions and concerns that arise out of interpretation of the monitoring data, especially in trying to understand the causes of change, and provide key information and tools for management and conservation

To further develop the program, the Trustee Council will use two major strategies incorporating community involvement and traditional knowledge and focusing on resource management applications. Communities and stakeholders must be involved at all levels of the program. The Trustee Council believes that encouraging local awareness and participation in research and monitoring enhances long-term stewardship of living marine resources. In addition, traditional and local ecological knowledge can provide important observations and insights about changes in these resources. In order to enhance the information managers and stakeholders use to cope with these changes, the GEM Program will seek to acquire data with significant potential for use in resource management applications.

The hypotheses, research questions, tools and strategies will all be used to develop a Science Plan for GEM The goal of the Science Plan is to implement a long-term monitoring program to detect and understand change over time within the northern Gulf of Alaska ecosystem The Science Plan will develop over time and include an implementation schedule, partners doing related monitoring or research, models to synthesize results and transfer information to users, core monitoring variables, and core monitoring activities

The GEM Program will be administered by the Trustee Council's core professional staff, based in Anchorage, Alaska Funds will be provided by the Trustee Council's investment fund, managed as an endowment, with the annual program funded by investment earnings after inflation-proofing The Trustee Council's executive director will oversee the financial, program management and administrative, scientific, and public involvement aspects of the program The Trustee Council and staff will actively solicit advice on science and policy matters, including review of monitoring and research activities, from experts, including a Scientific and Technical Advisory Committee (STAC), and from the public, including the Trustee Council's Public Advisory Committee

The STAC will play a key role in guiding the GEM Program and ensuring a high degree of scientific credibility is maintained Subcommittees composed of scientists, resource managers, stakeholders, and other experts and community members will be established to assist the STAC The STAC and subcommittees will work with resource managers, stakeholders, the scientific community and the public to refine a common set of priorities for research and monitoring in the northern gulf

Independent peer review of the GEM Program is essential for a high-caliber scientific program Participation in research and monitoring is expected to be completely open to competition All data must be documented, archived, maintained, and readily accessible to other scientific users and the public In order for GEM to be successful, it will be necessary to integrate, synthesize, and interpret monitoring and research results to form and present a "big picture" of the status of and trends in the northern GOA ecosystem One approach is through the use of periodic "State of the Gulf" and "State of the North Pacific" workshops and reports Another is use of the GEM web site The Trustee Council is committed to public input and outreach as vital components of the long-term GEM Program

Data management and information transfer policies are an integral part of GEM Program management Clear and effective approaches to gathering information and making it widely available in understandable formats are essential to the successful operation of the GEM Program Because the program is a regional program with goals of cooperation, coordination, and integration with existing marine science programs, data policies are to be compatible with, and similar to, existing norms for state, federal, and nongovernmental marine science programs

The GEM Program cannot be the sole solution to problems facing the northern Gulf of Alaska ecosystem However, a permanent fund, dedicated to monitoring the long-term health of a marine ecosystem, is totally unique and provides an unparalleled opportunity to increase our understanding of the functioning of this system The Trustee Council views the GEM Program as a permanent legacy of its efforts to restore the northern Gulf of Alaska from the effects of the 1989 Exaon *Valdez* oil spill And for that reason, the Trustee Council believes that the program must be justified on what it can teach policy makers, resource managers, and the public about options for directing human behavior to achieve the GEM mission "to sustain a healthy and biologically diverse marine ecosystem and the human use of the marine resources in that ecosystem "

1. VISION

In This Chapter

- Origin of the GEM Program
- > Mission and Goals Identified for the Program
- > Geographic Scope, Funding and Governance
- > Building on Lessons of the Past

1.1 Introduction

On March 24, 1989, the *T/V Exaon Valdez* ran aground on Bligh Reef in Prince William Sound, spilling almost eleven million gallons of North

Slope crude oil The event was the largest tanker spill in US history, contaminating approximately 1,500 miles of Alaska's coastline, killing birds, mammals and fish, and disrupting the ecosystem in the path of the spreading oil In 1991, the Exxon Corporation agreed to pay the United States and the State of Alaska \$900 million over ten years to restore, replace, enhance, or acquire the equivalent of natural resources injured by the spill, and the reduced or lost human services they provide (United States of America and State of Alaska 1991) Under the court-approved terms of the settlement, the *Exxon Valdez* Oil Spill Trustee Council (Trustee Council) was formed to administer the restoration funds, and in 1994 the *Exxon Valdez* Oil Spill Restoration Plan was adopted to guide the development and implementation of a comprehensive, interdisciplinary recovery and rehabilitation program

Thurteen years after the spill, total recovery has still not been achieved Appendix B presents the current information regarding the recovery status of resources injured by the spill There are still two main concerns about lingering effects of the spill The first is the potential effect of pockets of residual oil in the environment The second concern is the ability of a population to fully recover by overcoming changes in the population dynamics resulting from the initial oilrelated mortalities and the interaction of these effects with other kinds of changes and disturbances in the marine ecosystem

The knowledge and experience gained during years of biological and physical studies in the aftermath of the *Exxon Valdez* oil spill (EVOS) confirmed that a solid historical context is essential to understand the sources of changes in valued natural resources Toward this end, in March 1999 the Trustee Council dedicated approximately \$120 million for long-term monitoring and ecosystem-based research in the northern Gulf of Alaska (GOA) This new program is called the

CHAPTER 1

GEM (Gulf of Alaska Ecosystem Monitoring and Research) Program Funding for the GEM Program comes from an endowment, with an annual program funded through investment earnings, after allowing for inflation-proofing and modest growth of the corpus

A program rooted in the science of a large-scale ecological disaster is uniquely suited to form the foundation for ecosystem-based management. In making the

Prudent use of the natural resources of the spill area requires increased knowledge of critical ecological information about the northern GOA decision to allocate these funds for a long-term program of monitoring and research, the Trustee Council explicitly recognized that complete recovery from the oil spill may not occur for decades, and that full restoration of these resources will most likely be achieved through long-term observation and, as needed, restoration actions The Trustee Council further recognized that conservation and improved management of these resources and services

would require substantial ongoing investment to improve understanding of the marine and coastal ecosystems that support the resources, as well as the people, of the spill region Improving the quality of information available to resource managers should result in improved resource management. In addition, prudent use of the natural resources of the spill area without compromising their health and recovery requires increased knowledge of critical ecological information about the northern GOA. This knowledge can only be provided through a long-term monitoring and research program that will span decades, if not centuries

1.2 Mission

The original mission of the Trustee Council's Restoration Program, adopted in 1993, was to "efficiently restore the environment injured by the

EVOS to a healthy, productive, world-renowned ecosystem, while taking into account the importance of the quality of life and the need for viable opportunities to establish and sustain a reasonable standard of living "

Consistent with this mission and with the ecosystem approach to restoration adopted by the Trustee Council in the 1994 *Exaon Valdez* Oil Spill Restoration Plan, the mission of the GEM Program is to

Sustain a healthy and biologically diverse marine ecosystem in the northern Gulf of Alaska (GOA) and the human use of the marine resources in that ecosystem through greater understanding of how its productivity is influenced by natural changes and human activities

In pursuit of this mission, the GEM Program will accomplish the following:

- Sustain the necessary institutional infrastructure to provide scientific leadership in identifying research and monitoring gaps and priorities,
- Sponsor monitoring, research, and other projects that respond to these identified needs,

- Encourage efficiency in and integration of GOA monitoring and research activities through leveraging of funds and interagency coordination and partnerships, and
- Promote local stewardship by involving stakeholders and having them help plan, guide, and carry out parts of the GEM Program

In adopting this mission, the Trustee Council acknowledges that, at times, sustaining a healthy ecosystem and ensuring sustainable human uses of the marine resources may be in conflict. In those instances, the goal of achieving a healthy ecosystem will be paramount. The Trustee Council also acknowledges that, at this time, clearly defined measures for assessing "ecosystem health" are lacking (NRC 2000). These measures will be incorporated into the program as they are developed.

1.3 Goals

Five major goals have been identified as necessary to accomplish the GEM mission Attaining all five, however, will require several decades Two

of these goals may be attainable within the early decades of operating the GEM Program, given sufficient funding and collaboration with other partners

- 1 Detect Serve as a sentinel (early warning) system by detecting annual and long-term changes in the marine ecosystem, from coastal watersheds to the central gulf, and
- 2 **Understand** Identify causes of change in the marine ecosystem, including natural variation, human influences, and their interaction

Two other goals provide an essential piece of the foundation for a long-term program Although these goals are likely to be fully realized only after the first decade of operating the GEM Program, shorter-term accomplishments should be achieved sooner

- 3 **Inform.** Provide integrated and synthesized information to the public, resource managers, industry and policy makers in order for them to respond to changes in natural resources, and
- 4 **Solve** Develop tools, technologies and information that can help resource managers and regulators improve management of marine resources and address problems that may arise from human activities

The fifth goal is inherently long-term and difficult to achieve, but of considerable potential value to resource users and managers It serves more as a long-range beacon to guide the design of monitoring activities, than as a goal to be attained within the near term

5 **Predict** Develop the capacity to predict the status and trends of natural resources for use by resource managers and consumers

CHAPTER 1

During the process of learning how to detect and understand change in the northern GOA, resource managers and the concerned public should collect incremental dividends on their investment in GEM. Ultimately, however, the benefits will be maximized over the long run. To fully achieve its mission, GEM must provide information that enables resource-dependent people, such as subsistence users, recreationalists, and commercial fishers, to better understand and therefore hopefully cope with changes in marine resources. The data and information produced by GEM during its first decade may not totally solve problems for the public, commercial interests, resource managers, and policy makers faced with environmental change. Nonetheless, as information accumulates, the ability for GEM to provide problem-solving information and tools can and must increase

Given the size and complexity of the northern GOA ecosystem and the available funding, it will not be possible to meet these goals with only the data collected by GEM Addressing the program goals will require achieving the following implementation goals

- Lead the way in integrating, synthesizing, and interpreting monitoring and research results to form and convey a "big picture" of the status of and trends in the GOA ecosystem,
- Track work of other entities relevant to understanding biological production in the GOA and coordinate GEM with those efforts,
- Leverage funds to augment ongoing monitoring work funded by other entities,
- Involve other government agencies, non-governmental organizations, stakeholders, policy makers, and the general public in a collaborative process to achieve the mission and goals of GEM,
- Increase community involvement and local and traditional knowledge in order to enhance long-term stewardship of living marine resources, and
- Facilitate application of GEM research and monitoring results to benefit conservation and management of marine resources

The substantial experience of the EVOS Restoration Program indicates that these six implementation goals are reasonable, necessary, and attainable

1.4 Geographic Scope

Consistent with the Restoration Plan, GEM Program activities will occur within the area affected by the 1989 oil spill, which is generally the northern GOA, including Prince William

Sound (PWS), Cook Inlet, Kodiak Island, and the Alaska Peninsula (Figure 1 1) Recognizing that the marine ecosystems affected by the oil spill do not have discrete boundaries, some monitoring and research activities may extend into adjacent areas of the northern GOA



Figure 1 1 Map of the spill area showing the location of communities

The primary geographic focus of GEM will be the four habitat types that contain the ecosystems of the northern GOA These habitats are the watersheds, intertidal and subtidal, Alaska Coastal Current (ACC), and offshore (the continental shelf break and the Alaska Gyre)

Although GEM has a regional outlook, the waters of the GOA are connected to adjacent waters Waters from the shelf and basin of the GOA eventually enter the Bering Sea and the Arctic Ocean through the Bering Strait Waters from the west coast states (California, Oregon, and Washington), Canada and southern Alaska also feed into the northern GOA Consequently, the program will be of vital importance in understanding the downstream Bering Sea and Arctic Ocean ecosystems, as well as the upstream southern GOA In addition to the linkages

provided by the movements of ocean waters, the GOA is linked to other regions by the many species of birds, fish, and mammals that move through these regions It is also becoming increasingly clear that environmental conditions in the GOA, such as levels of persistent organic pollutants, as well as the temperature of GOA waters, can originate many thousands of miles away

The Trustee Council is aware of the trade-offs between the size of the area to be studied and the frequency and intensity of the monitoring and research that can be conducted there In selecting core variables for long-term research and monitoring, the GEM Program will need to ensure that measurements are conducted at the spatial and temporal scales necessary to achieve the desired goals of the program For this reason, much thought must be given to the selection of the variables and the identification of the subset of the northern GOA that can reasonably be monitored by a program the size of GEM It is anticipated that partnering with other agencies and programs will help extend the GEM research area beyond that which GEM could fund on its own However, because of its critical importance to meeting the program's goals and objectives, core monitoring based on a set of core variables will be fully supported by the GEM Program

1.5 Funding and Governance

The Trustee Council will fund the GEM Program beginning in October 2002 with funds allocated for long-term monitoring and research, estimated to be approximately \$120 million The Trustee

Council will manage these funds as an endowment, with the annual program funded by investment earnings after inflation-proofing, thus providing for a stable program through time The Trustee Council may choose to fund a smaller program in the early years to allow the corpus of the fund to build The Trustee Council's long-term goal is to allow for additional deposits and donations to the fund from other sources to increase the corpus Achieving this goal might require changes in state or federal laws and possibly a change in the court-approved settlement and will be pursued at a later time

Under existing law and court orders, three state and three federal trustees have been designated by the Governor of Alaska and the President of the United States to administer the restoration fund, which includes funding for GEM, and to restore the resources and services injured by the oil spill The State of Alaska trustees are the Commissioner of the Alaska Department of Environmental Conservation, the Commissioner of the Alaska Department of Fish and Game, and the Attorney General The federal trustees are the Secretary of the Interior, the Secretary of Agriculture, and the Administrator of the National Oceanic and Atmospheric Administration, U S Department of Commerce

The trustees established the Trustee Council to administer the restoration fund The state trustees serve directly on the Trustee Council The federal trustees each have appointed a representative in Alaska to serve on the Trustee Council The representatives currently are the Senior Advisor to the Secretary for Alaskan Affairs (Department of the Interior), the Alaska Director of the National Marine Fisheries Service (National Oceanic and Atmospheric Administration), and the Supervisor of the Chugach National Forest (U S Department of Agriculture) All decisions by the Trustee Council are required to be unanimous

It is expected that the current Trustee Council will make policy and funding decisions for the GEM Program It has been suggested that at some time in the future, a new board or oversight structure other than the Trustee Council be established to administer or guide the GEM fund It is also possible that an existing board, either under its current structure or with minor modifications, could take over management of the fund Use of a new governance structure, if justified, would require changes in law and the applicable court decrees Such changes would take considerable time and are not anticipated in the near future

1.6 Building on Lessons of the Past

The GEM Program is not the first attempt to look at large areas of Alaska's marine ecosystems from a broader perspective The *Exxon Valdez* Oil Spill Restoration Program, as well as a number of other programs, provides valuable guidance This

section briefly describes some of these programs and their relevance to the development of GEM

1 6 1 Alaska Regional Marine Research Plan (1993)

The Alaska Regional Marine Research Plan (ARMRP) (1993) is a marine science planning document with a broad geographic scope that was prepared under the U S Regional Marine Research Act of 1991 ARMRP goals express the scientific needs of the Alaska region as of 1992 and are still relevant to the GEM effort

- Distinguish between natural and human-induced changes in marine ecosystems of the Alaska region,
- Distinguish between natural and human-induced changes in water quality of the Alaska region,
- Stimulate the development of a data gathering and sharing system that will serve scientists in the region from government, academia, and the private sector in dealing with water quality and ecosystem health issues, and
- Provide a forum for enhancing and maintaining broad discussion among the marine scientific community on the most direct and effective way to understand and address issues related to maintaining the health of the water quality and ecosystem health in the region

1 6 2 Bering Sea Ecosystem Research Plan (1998)

The Bering Sea has received considerable attention because of concern about long-term declines in populations of high-profile species such as king and tanner crab, Steller sea lions, spectacled eiders, Steller's eiders, common murres, thick-

Goals of other major programs are relevant to the GEM effort billed murres, and red-legged and black-legged kittiwakes (DOI et al 1998b) The GEM mission is consistent with the vision of the federal-state regulatory agencies for the *Bening Sea Ecosystem Research Plan* (DOI et al 1998a), which states "We envision a productive, ecologically diverse Bering Sea ecosystem that will provide long-term, sustained benefits to local communities and the nation" The basic concepts of the GEM Program are also consistent with the overarching hypotheses of the Bering Sea plan

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The Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) established the Global Ocean Ecosystem Dynamics (GLOBEC) program in late 1991 GLOBEC is the core project of the International Geosphere-Biosphere Programme responsible for understanding how global change will affect abundance, diversity, and productivity of marine populations The program focuses on the regulatory control of zooplankton dynamics on the biomass of many fish and shellfish

The GLOBEC Science Plan (U S GLOBEC 1997) describes an approach that uses a combination of field observations and modeling to concentrate on the middle and upper trophic levels of the ecosystem The overarching concept is that marine and terrestrial ecosystems have close connections among energy flow, chemical cycling, and food web structure GEM monitoring activities will be consistent with GLOBEC concepts

1 6 4 Scientific Legacy of the Exxon Valdez Oil Spill (1989 to Present)

Ecological knowledge gained in the years following the 1989 *Exxon Valdez* Oil Spill forms a substantial portion of the foundation of the GEM Program In 1994 the *Exxon Valdez* Oil Spill Restoration Plan was adopted to guide the development and implementation of a comprehensive, interdisciplinary recovery and rehabilitation program The recovery status of each affected resource is based to the extent possible on knowledge of the resource's role in the ecosystem The scientific legacy of the *Exxon Valdez* Oil Spill Trustee Council (Trustee Council) creates the need to understand the causes of population trends in individual species of plants and animals through time and the need to distinguish human impacts from those of climate and interactions with related species

The studies supported by the Trustee Council since 1989 include more than 1,600 damage assessment studies costing more than \$100 million, as well as hundreds of restoration studies costing approximately \$170 million. These studies have resulted in more than 500 peer-reviewed scientific publications, including numerous dissertations and theses. In addition, hundreds of peer-reviewed project reports are available through the Alaska Resources Library and Information. Services (ARLIS) and state and university library systems. Many final reports are available in electronic format through the Trustee Council offices or ARLIS. A current electronic bibliography of scientific publications sponsored by the Trustee.

Council is available on its web site (www oilspill state ak us) or on request to the Trustee Council (EVROTCB 2002) A list of Trustee Council projects, as well as a complete list of final and annual project reports, also is available on the web site or on request (EVROFAB 2002)

In addition to much specific information on the effects of oil on the plant and animal life in the spill area, the studies also provide a wealth of ecological information Most prominent among the Trustee Council's studies are three ecosystem-scale projects, known by their acronyms SEA, NVP, and APEX

The Sound Ecosystem Assessment (SEA) is the largest of the three studies Funded at \$22 million for a seven-year period SEA brought together a team of scientists from many different disciplines to understand the biological and physical factors responsible for producing herring and salmon in PWS The data collected during SEA are expected to form the basis of numerical models capable of simulating the oceanographic processes that influence the survival and productivity of juvenile pink salmon and herring in PWS SEA has already provided new insights into the critical factors that influence fisheries production, including ocean currents, nutrient levels, mixing of water masses, salinity, and temperatures These observations have made it possible to model how physical factors influence production of plant and animal plankton, prey, and predators in the food web

The Nearshore Vertebrate Predator (NVP) project is a six-year, \$6 5 million study of factors limiting recovery of two fish-eating species, river otters and pigeon guillemots, and two invertebrate-eating species that inhabit nearshore areas, harlequin ducks and sea otters The project looked at oil exposure, as well as natural factors such as food availability, as potential factors in the recovery of these indicator species, and has contributed to increased understanding of the linkages between terrestrial and marine ecosystems

The Alaska Predator Ecosystem Experiment (APEX) is an eight-year, \$10 8 million study of ecological relations among seabirds and their prey species The APEX project explored the critical connection between productivities of marine bird populations and forage fish species, in an attempt to understand how wideranging ecological changes might be related to fluctuating seabird populations In addition, analyzing the food of marine birds shows promise in providing abundance estimates for key fish species, such as sand lance and herring

The following topics also have been covered by other Trustee Council-funded studies and the results are available in published scientific literature

- Physical and biological oceanography,
- Marine food web structure and dynamics,
- Predator-prey relationships among birds, fish, and mammals,
- The source and fate of carbon among species,

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- Developmental changes in trophic level within species,
- Marine growth and survival of salmon,
- Intertidal community ecology, and
- Early life history and stock structure in herring

Many studies have focused on key individual species injured by the oil spill, including pink and sockeye salmon, cutthroat trout, Pacific herring, black oystercatchers, river otters, harbor seals, mussels, and kelp

One of the most extensive series of single-species investigations is the \$14 million suite of pink salmon studies These include monitoring the toxic effect of oil, conducting genetic studies related to survival, and supplementing select populations Another extensive series of studies was done on Pacific herring Roughly \$6 million has been spent on the restoration of Pacific herring in addition to the funding for the herring component of SEA Since the crash of 1993, the population has yet to recruit a highly successful post-spill year-class Current investigative strategies are focused on the full range of causes of the crash, such as disease and ecological factors, including the effects of oceanographic processes on year-class strength and adult distribution and understanding stock structure

More than \$6 million has been spent on the restoration of marine mammals, primarily harbor seals, a major source of subsistence food in the diet of Native Alaskans in the northern GOA Harbor seal populations were declining before the spill, took a big hit at the time of the spill event, and have continued to decline ever since, although the rate of decline seems to have slowed Food availability is the major focus of current research, because disease and other factors have been ruled out as causes

1 6 5 Trustee Council Commitment to Traditional Knowledge and Community Involvement

From 1995 –2002, the Trustee Council provided almost \$2 million to the Chugach Regional Resources Commission to facilitate the involvement of local communities in the oil spill restoration program and improve communication between spill area residents, community councils, regional organizations, scientists and the tribal community The facilitators and coordinators have been active participants in all the GEM planning workshops and meetings This project has also funded the development of natural resource management plans in several villages, which tribal representatives believe are a necessary step before incorporating tribal concerns into the GEM Program

This long-term project (1995-2002) was designed to

 Increase meaningful involvement of spill area communities in the Trustee Council restoration efforts/ process,

- Provide information to communities regarding data and scientific research performed by the Trustee Council science program,
- Improve communication of findings and results of restoration efforts to spill area residents, village councils, and the appropriate regional organizations,
- Promote the inclusion of community-based projects, as well as community involvement in science projects throughout the life of the restoration effort,
- Work with the formation of local natural resource management programs that will focus on the stewardship and management of injured resources and lands, and
- Develop a means to compile and utilize western science and traditional wisdom in a cooperative manner to further the restoration process in ways that are sensitive to the needs of the communities

The Chugach Regional Resources Commission coordinated this project by employing community facilitators in ten communities, and a spill area-wide community involvement coordinator who facilitated communication between the communities, the Trustee Council, and scientists

Also since 1995, the Trustee Council has funded Youth Area Watch programs through the Chugach School District and Kodiak Island Borough School District These programs involve youth from local spill area communities in the science behind the restoration effort As of 2002, 168 students have participated in the Prince William Sound and Kodiak programs with students participating in such projects as harbor seal biosampling, seabird momitoring, collection oceanographic data on cruises, and analyzing chemicals found in intertidal mussels

In 1994 the Trustee Council received its first call from a community resident to incorporate Traditional Ecological Knowledge (TEK) of spill area residents into the restoration program Two years later, the Trustee Council's 1996 annual restoration workshop had TEK as its theme, and led to a set of protocols for incorporating TEK into restoration projects developed by a committee of Alaska Natives and others and approved later that year by the Trustee Council The Trustee Council has provided funds each year since 1995 toward the goal of incorporating TEK into the restoration program Efforts have included

- Developing a TEK handbook and reference guide for biologists documenting the sources of TEK in the spill area and incorporating it into a western science approach
- Providing funds for Chugach Regional Resource Commission (CRRC) to contract with TEK expert Henry Huntington for seven years He has worked directly with Alaska Native elders and hunters as well as scientists to bridge the gap between these two different approaches to understanding the natural world A result of this process is that several EVOS projects

incorporate TEK directly into their data sets and results, including projects on community natural resource management, fish and seabird studies, and a series of films about Alutiq culture (see examples below)

 Conducting two workshops to develop tribal management programs and bringing several scientists to spill area communities to share information

Examples of projects incorporating TEK as a result of Trustee Council efforts include

- Scientist Jody Seitz conducted an extensive project involving TEK Researchers interviewed thirty-nine spill area community members to document the historical distribution of forage fish such as juvenile herring, sand lance, capelin, and eulachon This information was mapped and provided to the APEX and SEA researchers The results were extremely valuable because they could not have been obtained from other historical sources or from current data collection efforts
- Scientist Dan Rosenberg solicited local participation from communities and conveyed results of his research on surf scoters, an important subsistence resource The project idea came from local communities Rosenberg worked with community members throughout all stages of the project, from project design to writing the final report
- The Trustee Council provided funding support to the Alaska Native Harbor Seal Commission, which uses Alaska Native hunters to conduct biosampling of harbor seal tissues using lab-approved techniques In 1999, the commission reached an agreement with the National Marine Fisheries Service to co-manage harbor seal populations
- Three videos have been produced with Trustee Council funds to provide the public information about TEK and concerns about subsistence use after the oil spill The first two, *Aluting Pride A Story of Subsistence* and *Changing Tides in Tatitlek* describe subsistence methods, interview Alaska Native people who experienced the spill first hand, show actual subsistence hunts, and illustrate the importance of subsistence in Aluting culture. The third documents the communities of Chenega Bay and Ouzinkie in relation to the effects of the oil spill, residual oil in the spill region, and concerns about paralytic shellfish poisoning toxins, natural toxins found in clams harvested for food. These videos were distributed at no charge to all schools in Alaska via their school districts, all spill area tribal councils, and any other library or school in the U.S. upon request.

The Trustee Council funded Elders/Youth Conferences in 1995 and 1998 that brought together Alaska Native elders, youth, other subsistence users, scientists, and managers to share ideas about subsistence issues and facilitate community involvement. The Trustee Council paid for four people from each of twenty spill area communities to attend each conference. Participants shared stories, voiced frustration, and asked scientists questions about subsistence issues They also developed ideas for youth to get more involved through spirit camps, internships, and educational opportunities These workshops facilitated collaboration between communities of the spill area, while concerns and ideas generated at the conference were reported to the Trustee Council

Additional details on the Trustee Council's tribal and community involvement efforts are included in a report in Appendix C

1.7 References

- ARMRB 1993 Alaska Regional Marine Research Board, Alaska research plan School of Fisheries and Ocean Sciences, University of Alaska Fairbanks
- DOI, NOAA, and ADF&G 1998a Draft Bering Sea ecosystem research plan. Alaska Department of Fish and Game, Commercial Fisheries Division Juneau
- DOI, NOAA, and ADF&G 1998b Bering Sea ecosystem a call to action Alaska Department of Fish and Game, Commercial Fisheries Division Juneau
- EVROFAB 2002 Exxon Valdez Oil Spill Restoration Office bibliography of final and annual reports Anchorage, Alaska, Exxon Valdez Oil Spill Trustee Council
- EVROTCB 2002 Exxon Valdez Oil Spill Restoration Office bibliography of published oil spill investigations Anchorage, Alaska, Exxon Valdez Oil Spill Trustee Council
- NRC 2000 Ecological indicators for the nation National Academy Press Washington, D C
- U S GLOBEC 1997 Global Ocean Ecosystems Dynamics (GLOBEC) science plan IGBP Secretariat, The Royal Swedish Academy of Sciences Stockholm, Sweden.
- United States of America and State of Alaska 1991 Memorandum of agreement and consent decree, A91-081 CIV

2. CONCEPTUAL FOUNDATION AND CENTRAL HYPOTHESIS

In This Chapter

- Conceptual Foundation
- > Central Hypothesis
- > Habitat Types and Time-Space Scales
- > Central Hypothesis by Habitat Type

2.1 Introduction to the GEM Conceptual Foundation

The intellectual framework of the GEM Program is a hierarchy composed of a conceptual foundation, central hypothesis, habitat-specific hypotheses, research questions, and ultimately, testable hypotheses based on the specific questions (Figure 21) Four habitat-specific hypotheses, based on the central hypothesis,

form the core of the GEM monitoring plan The conceptual foundation provides an overarching explanation, or verbal model, of how the Gulf of Alaska (GOA) ecosystems produce biological resources As such, the conceptual foundation is not itself a testable hypothesis on the sources of change in ecosystems, but rather, the origin of hypotheses, both general and testable Habitat-specific hypotheses are based on assumptions about how natural and anthropogenic factors influence ecosystem functioning within each of the habitat types, recognizing that different factors may be important in different habitats. This chapter presents the narrative of the GEM conceptual foundation for the GOA, addresses cross-habitat connections and regional variability, and adapts the narrative of the conceptual foundation to describe the four habitat types used by GEM

2.1.1 The GOA at a Glance

The conceptual foundation for the GOA ecosystem explains how its plant and animal populations are controlled through time A broad, interdisciplinary

conceptual foundation serves as a flexible framework for determining the type of monitoring and research activities that will be undertaken in implementing the GEM Program The conceptual foundation is the product of syntheses of the latest scientific information and an assessment of leading ecological hypotheses It

The conceptual foundation focuses on how the marine ecosystem in the GOA works encapsulates the Trustee Council's understanding of how the GOA operates as an ecological system and how its biological resources, including highly valued populations of animals, are regulated.



Figure 2.1. Overview of the GEM Program structure showing the relation of key concepts to the habitat types, implementation tools, and the schedule of implementation.

Specific citations to the scientific literature are omitted for the sake of brevity, however these may be found in the scientific synthesis of Chapter 7. Taking the watersheds and marine areas of the GOA together at a single glance, the importance of key geological features in shaping the natural physical and biological forces that control productivity is apparent (Figure 2.2). Note that features illustrated in Figure 2.2 are printed in bold in the following text. Natural forces are shaped by the surface topography of the Gulf. Storm tracks moving across the North Pacific from west to east can drive **Aleutian Low Pressure Systems** (**Aleutian Low**) deep into the GOA until the encounter with **boundary mountains** causes the release of **precipitation** and **airborne contaminants**. Freshwater runoff strengthens the **Alaska Coastal Current** (ACC) even as it brings airborne and terrestrial pollutants into the **watersheds** and **food webs**.

Natural forces that control biological productivity are also shaped by the submarine topography (bathymetry) of the **continental shelf**. Deep waters **upwell** across the **continental shelf break**, subsequently being carried across the **photic**



Figure 2.2 The physical and biological elements of the ecosystems of the northern GOA from the mountains surrounding the watersheds to the oceanic waters offshore.

boundary into areas of photosynthetic activity by the motion of surface currents, (Alaska Coastal Current, ACC, Alaska Current, AC), lunar forcing, the motion of the earth, and tidal mixing These deep waters carry old carbon and nutrients up into the food webs of the shelf and onshore areas Where the deep waters encounter islands, seamounts and sills, the resulting currents may deform the boundaries of the frontal zones of the ACC (mid-shelf front) and AC (shelfbreak front), creating eddies that entrain plankton and other plants and animals for long periods of time

Natural physical forces control productivity by limiting the amount of food and availability of habitats During the winter especially, the Aleutian Low produces wind-driven transport of surface marine waters (Ekman transport), bringing water onshore Movement of water onshore creates downwelling that takes plankton and associated nutrients out of the photic zone On the other hand, the wind may act to hold the nutrients dissolved in water and held in detritus in the photic zone in some areas, because wind also produces turbulence that mixes the surface water Turbulent mixing causes nutrients to be retained in surface waters, and retention increases production of phytoplankton, the base of the food web in surface waters Production of zooplankton, secondary productivity, is the trophic connection (linkage) of phytoplankton to production of forage fish, which in turn links primary productivity to seabirds, large fish, marine mammals, and benthic and intertidal communities

The biogeochemical cycle is an important collection of natural biological and physical processes controlling the productivities of both marine and terrestrial environments The mechanisms that move carbon from the surface to the deep waters, are known collectively as the **carbon pump** Atmospheric carbon moves into seawater as carbon dioxide to be incorporated by phytoplankton during photosynthesis Carbon also enters the sea as carbonates leached from the land by freshwater runoff, as plant debris, and as other biological input, such as immigrations of salmon (**salmon fry**) and other anadromous species Carbon moves to benthic communities and to deep water as detritus and emigrant animals (**overwintering copepods** and migrating fish such as myctophids) Emigrant animals (**adult salmon** and other anadromous species) also move marine carbon (and phosphorous and nitrogen) into the watersheds

As illustrated by the interactions of biological and physical components of the biogeochemical cycle, natural biological forces modify the effects of natural physical forces on birds, fish, and mammals Because of biological-physical interactions, natural physical forces that cause changes in **primary productivity** do not necessarily cause proportional changes in populations of birds, fish, mammals, and benthic animals For example, the effects of physical forces on the amount of food available from primary productivity are modified through other natural forces, such as **predation and competition** among individuals, collectively known as the **trophic linkages** Populations that respond strongly to physical forcing of primary productivity on approximately the same time scales are termed "strongly

coupled," and those that exhibit variable responses are termed "weakly coupled" with respect to those physical variables Note that physical forcing changes not only the food available from primary productivity, but also the extent of habitats available for reproduction and feeding

Human actions also serve to change the ways in which populations of plants and animals respond to the natural physical forces that affect the responses of reproduction, growth, and survival through limiting food and habitat Human actions such as water withdrawals, sewage discharge, and development of coastal **communities** change productivity by altering habitat availability and trophic linkages The economy of Alaska depends heavily on extraction of natural resources (primarily oil, fish, and shellfish followed by timber and minerals) Fishing and other extractive uses (subsistence, sport, commercial) affect death rates through removals Other forms of human action are more subtle, but no less effective, controls on productivity In the Northern Gulf of Alaska, recreation and tourism, oil and gas development, logging, road building and urbanization, marine transportation and subsistence harvests are all activities that have the potential to affect fish and wildlife populations and habitat Recreation and tourism may alter growth and reproduction by disturbing rookeries and introducing pollutants Commercial marine transport may alter productivity by introducing pollutants (oil spills) and noxious exotic species as competitors and predators Currently, the human impact on Alaska's marine ecosystems is relatively small compared to impacts in most of the developed world Even here, however, natural resource managers have concerns about localized pollution, the potential impacts of some fisheries, extreme changes in some fish and wildlife populations, and the little known impacts of contaminants and global warming

In summary, Figure 2.2 shows that the GOA and its watersheds are part of a larger oceanic ecosystem in which natural physical forces such as currents, upwelling, downwelling, precipitation and runoff, acting over large and small distances, play important roles in determining basic biological productivity Natural physical forces respond primarily to seasonal shifts in the weather, and in particular to long-term changes in the intensity and location of the Aleutian Low in winter Increased upwelling offshore appears to increase inputs of nutrients to surface waters, which increases productivity of plankton Increased winds appear to increase the transport of zooplankton shoreward toward and past the shelf-break. How often and how much offshore zooplankton sources contribute to coastal food webs depends on natural physical and biological forces such as predation, migration, currents and structure of the fronts, formation and stability of eddies, degree and extent of turbulence, and responses of plankton to short and long-term changes in temperature and salinity

A wide range of human impacts interacts with natural biological and physical forces to change productivity and community structure in the GOA Approximately 71,000 full-time residents live within the area directly affected by the oil spill and two to three times that number use the area seasonally for work

and recreation The spill area population, combined with that of the nearby population centers of Anchorage and Wasilla, totals more than 60percent of the state's 627,000 permanent residents When the resident population is combined with the more than one million tourists who visit the state each year, it becomes clear that the natural resources of the GOA cannot be immune to the pressures associated with human uses and activities Human activities have the most direct and obvious impacts at those sites in watersheds and intertidal areas where human populations are high Nonetheless, some human activities affect populations of birds, fish, shellfish, and mammals far offshore, and also have impacts far from the sites of the actions. In short, human activities and natural forces together act over global to local scales to drive and shape marine and terrestrial life in the GOA and its tributary watersheds.

Because of the tremendous uncertainty about sources of long-term changes, the conceptual foundation does not provide a specific model (testable hypothesis) for ecosystem change Rather, the GEM conceptual foundation is designed to be broad enough to serve as a tool to organize thinking and research over long time periods, to encompass ecosystem interconnections, and to link information from traditional knowledge and scientific disciplines. It takes into account both oceanic and terrestrial ecosystems and addresses the influence of climate and human activity in influencing biological productivity within these interconnected systems. By using this broad, scientifically grounded conceptual foundation, the GEM Program will be able to adapt to changes in understanding ecosystem processes without having to sacrifice long-term research and monitoring goals (NRC 2002)

The GEM Program will, however, need to develop specific testable hypotheses, as derived from a general, or central hypothesis, in order to implement the monitoring and research program As a start on a central hypothesis, consider the one provided by the National Research Council (NRC 2002, p 27), as follows,

The Gulf of Alaska, its surrounding watersheds, and human populations are an interconnected set of ecosystems that must be studied and monitored as an integrated whole Within this interconnected set, at time scales of years to decades, climate and human impacts are the two most important driving forces in determining primary production and its transfer to upper trophic-level organisms of concern to humans

The NRC summary identifies climate and human impacts as the two most important determinants of biological production, among the many forcing factors recognized as significant in the conceptual foundation Nonetheless, the biological communities that support the birds, fish and mammals are subject to a variety of biological and physical agents and factors of change, any one of which can at times play an important, and even dominant, role in controlling populations of birds, fish, shellfish and mammals A formal statement of the central hypothesis that starts with and considers the full suite of forcing factors is needed to allow research and monitoring to identify the most important forcing factors for species and habitats of the GEM region

2.2 The Central Hypothesis and Habitat Types

Identifying the forcing factors, human and natural, that drive biological production requires framing hypotheses and questions that point the way for a scientific monitoring and research program The central hypothesis formally states

widely held beliefs about what drives changes in living marine-related resources in time and space

Natural forces and human activities working over global to local scales bring about short term and long lasting changes in the biological communities that support birds, fish, shellfish and mammals Natural forces and human activities bring about change by altering relationships among defining characteristics of habitats and ecosystems such as heat and salt distribution, insolation, biological energy flow, freshwater flow, biogeochemical cycles, food web structure, fishery impacts, and pollutant levels

Although widely accepted as fact, the specific mechanisms that cause change are largely untested in the GEM region, and the relative importance of the forcing factors is unknown Current speculations, supported by limited observations, are that forcing by winds, precipitation, predation, currents, natural competitors for food and habitat, fisheries, and pollutants change living marine-related resources over different scales of time and space through alteration of critical properties of habitats and ecosystems (Figures 2 3 and 2 4)



Figure 2.3 Possible connections among specific mechanisms and agents of change in living marine-related resources

Although the central hypothesis may appear to be a bland statement of the obvious, it is an essential first step in applying the scientific method to address the many open, and sometimes highly contentious, scientific questions about whether,

and to what extent, human activities are responsible for degradation of habitats and declines in populations of animals The central hypothesis states what is thought to be known in general, preparing the way for questions that test the validity of this knowledge For example it is reasonable to ask of the central hypothesis, "What are the natural forces and are they equally important in all types of habitat?" Critically examining the starting point through posing and answering questions, is intended to point out the need for more specific hypotheses, which in turn lead to more specific questions, and so forth



Figure 2.4 Relations among major parts of the GEM conceptual foundation

The central hypothesis is given more specificity through adaptation to habitat types in the following section Before adding specificity to the central hypothesis, the habitat types need definition, and the context of conducting studies at time-space scales appropriate to the phenomenon needs to be provided

To better organize the GEM Program, four habitat types, representative of the GEM region, have been identified as themes around which the interdisciplinary monitoring and research activities that address GEM's central hypothesis will be organized. These habitat types are watersheds, the intertidal and subtidal areas, the ACC, and the offshore areas (the continental shelf break and the Alaska Gyre). These habitats were selected after evaluating information about how natural forces and human activities control biological productivity in the northern GOA (Chapters 6 and 7). The habitats are composed of identifiable, although not rigid, collections of characteristic microhabitats, resident and migratory species, and physical features.

 Watersheds – freshwater and terrestrial habitats from the mountains to the extent of a river's plume

- Intertidal and subtidal areas brackish and salt-water coastal habitats that extend offshore to the 20-m depth contour.
- ACC a swift coastal current of lower salinities (25 to 31 psu) typically found within 35 km of the shore.
- Offshore the continental shelf break (between the 200-m and 1,000-m depth contours) and the Alaska Gyre in waters outside the 1,000-m depth contour.

The decision to use habitats as a mechanism for stratifying funding and allocating resources will require the GEM Program to ensure that cross-habitat processes and transfers are not forgotten or ignored. Having an appreciation for the scales of time and space over which the processes responsible for biological production occur is essential for designing monitoring and research intended to detect and understand changes in the ecosystem (Figure 2.5). To understand the composition and extent of ecosystems, it is necessary to ask and answer questions about the distances and time associated with the variation in the biological and physical phenomena. As stated eloquently by Ricklefs (1990, p. 169), "Every phenomenon, regardless of its scale in space and time, includes finer scale processes and patterns and is embedded in a matrix of processes and patterns having larger dimensions." Indeed, spatial and temporal scales are part of the definitions of physical and biological processes such as advection and growth.



Figure 2.5 Scales of time and space corresponding to key elements and processes in ecosystems of the GOA. *Illustration provided by John Piatt.*

CHAPTER 2

Taking account of spatial and temporal scales is critical to studying linkages between natural forces and biological responses (Francis et al 1998)

Cross-habitat linkages and processes will be incorporated into the GEM Program in several ways that will be described in more detail in later chapters The primary mechanisms for ensuring they are addressed will be through ongoing synthesis of research results and oversight by the Scientific and Technical Advisory Committee It is also expected that modeling efforts will be regional in focus rather than habitat specific

2 2 1 Central Hypothesis by Habitat Type

The central hypothesis is adapted to each habitat type

<u>Watersheds</u>

Natural forces (such as climate) and human activities (such as habitat degradation and fishing) serve as distant and local factors in causing short-term and long-lasting changes in marine-related biological production in watersheds

Intertidal and Subtidal

Natural forces (such as currents and predation) and human activities (such as increased urbanization and localized pollution) serve as distant and local factors, in causing short-term and longlasting changes in community structure and dynamics of the intertidal and subtidal habitats

Alaska Coastal Current (ACC)

Natural forces (such as variability in the strength, structure and dynamics of the ACC) and human activities (such as fishing and pollution) cause local and distant changes in production of phytoplankton, zooplankton, birds, fish, and mammals

Offshore

Natural forces (such as changes in the strength of the Alaska Current and Alaskan Stream, mixed layer depth of the gyre, wind stress and downwelling) and human activities (such as pollution) play significant roles in determining production of carbon and its shoreward transport

As noted above, these hypotheses can be used as a general guide to monitoring and research, but they need to be further refined into questions which identify a core set of measurements for implementation of long-term monitoring and research In Chapter 4 the habitat-type hypotheses are examined through specific questions that lead to preliminary recommendations on what information needs to be gathered, as a starting point for the GEM Program Basic definitions of the tools for implementing the program, as provided in Chapter 3, are needed before launching into the details of implementation found in Chapter 4

Before moving on to the definition of implementation tools, it should be noted that information for developing these specific questions into a monitoring and research program comes from many sources, including analysis of ongoing and existing research results, evaluation of agency monitoring programs and activities, and input from a variety of interest groups including scientists, resource managers and the communities Over the long-term one of the most valuable resources for identifying research questions may be the legacy of scientific information and results from community involvement projects from the $E_{\lambda\lambda}on$ Valdez Oil Spill Restoration Program The following chapter describes the process by which gap analysis, synthesis, and research are used to implement the GEM Program and guide selection of variables for long-term monitoring Chapter 4 introduces potential research questions that may be used to begin development of the GEM Science Plan

2.3 References

- Francis, R C , S R Hare, A B Hollowed, and W S Wooster 1998 Effects of interdecadal climate variability on the oceanic ecosystems of the northeast Pacific Fisheries Oceanography 7 1-21
- NRC 2002 A century of ecosystem science planning long-term research in the Gulf of Alaska Washington, D C , National Academy Press
- Ricklefs, R E 1990 Scaling patterns and process in marine ecosystems Pages 169-178 in Sherman, K, L M Alexander, and B D Gold, editors Large marine ecosystems patterns, processes and yields American Association for the Advancement of Science, Washington, D C

3. TOOLS AND STRATEGIES

In This Chapter

- Tools Gap Analysis, Synthesis, Research, Monitoring, Modeling and Data Management
- Strategies Community Involvement and Traditional Knowledge, and Resource Management Applicability

3.1 Introduction

The hypotheses presented in Chapter 2 are refined into a series of initial research questions through the use of gap analysis, synthesis and research, as

supported by modeling and data management These tools also will be used to continually refine and implement GEM's long-term core monitoring program To further develop the program, the Trustee Council will use two major strategies incorporation of community involvement and traditional knowledge, and potential for resource management applicability (Figure 3 1)



Figure 3 1 GEM Structure

This chapter defines and discusses these tools and strategies and explains how each will be used to implement the GEM Program

3.2 Program Tools

Research questions emerge from a consideration of the central hypothesis and the hypotheses for each habitat presented in the previous chapter

Potential research questions and the information necessary to answer them are presented in Chapter 4 The recommendations on the information needed were developed through a process of "gap analysis," as defined in the following section and as supported by information in Appendix D From the starting point of preliminary questions and the information needed to answer them (Chapter 4), the GEM Program is intended to follow a path of synthesis, research, and monitoring to detect, understand, and, eventually, predict changes in living marine-related resources of the northern Gulf of Alaska (GOA) Modeling and data management are critical elements in evaluating and managing the GEM long-term research program, and will closely support synthesis and research activities

3 2 1 Gap Analysis

In the process of starting the GEM Program, key hypotheses about how the GOA ecosystem functions were evaluated and refined into a set of potential questions for each of the primary habitat types in the GOA (Chapter 4) The major information gathering programs in the North Pacific (Appendix D) were reviewed to identify where they are collecting data that could be used to answer the questions, and where there were gaps in the information that would need to be filled by future research. This ongoing identification of information needs, or gap analysis, is an important part of the process of identifying the starting points for monitoring and research, for avoiding duplicating the efforts of others, and for continuing to refine the program as it progresses. This analysis will continue during implementation of the GEM Program, with initial general questions being replaced by increasingly specific questions as knowledge about the ecosystem increases.

It is important to have a clear understanding of how the nature of the question determines the nature and outcome of the gap analysis The gap analysis has four essential parts a question, identification of information necessary to answer the question, a survey of relevant available information, and identification of gaps in the available information

The first part, the question, is fundamental to the gap analysis and defines the survey of all relevant information needed to answer it A general question calls for a general gap analysis, and a more detailed question calls for a more detailed gap analysis. The gap analysis seeks to identify what information is currently being collected that could help answer the question and what information, for which no data are being collected currently, is needed to answer the question. The data gaps become the priorities for focusing research and monitoring activities

A continuing gap analysis, supported by a regularly updated database of current and historical information-gathering projects in the GOA and adjacent areas, is essential to implementing the GEM Program This analysis will be performed by the staff and researchers and will be key to finding new partners for monitoring activities, identifying new opportunities for research and synthesis, and providing increased opportunities for collaboration, without risking duplication of effort or the possibility of failing to obtain needed data. In the short term, this database will provide information needed to select core monitoring variables and locations. In the longer term, the supporting database will become a valuable tool for resource managers, policy makers, other scientists, stakeholders, and the general public. As the GEM Program moves from the general hypotheses about what controls and connects biological production within and between habitats, and toward specific questions and testable hypotheses, the gap analysis will become highly specific

322 Synthesis

A second starting point for developing the GEM Program is synthesis, because all good science ultimately involves synthesis In the words of biologist E O Wilson (1998)

We are drowning in information while starving for wisdom The world henceforth will be run by synthesizers, people able to put together the right information, think critically about it, and make important choices wisely

Synthesis builds on and updates the current understanding of the northern GOA It brings together existing data from any number of disciplines, times, and regions to evaluate different aspects of the GEM Program's conceptual foundation, central hypotheses, and related ideas Synthesis has three broad uses First, it is used to provide direction for developing hypotheses to be tested and, combined with research and monitoring, to update and refine the program structure and implementation plan In this respect, synthesis is an ongoing evaluative process throughout the life of the GEM Program that will help to ensure that the program is meeting its goals and objectives Second, synthesis is used as a tool to inform stakeholders and the public about the developing understanding of the factors responsible for change in the marine environment Some of the most important synthesizers of GEM monitoring and research will be the public Synthesis will be useful in workshops, meetings, publications, and other methods for communicating information to the public And third, synthesis is used to help solve resource management problems, by identifying new applications of existing information or by identifying opportunities to solve existing problems by collecting new information Synthesis is a logical place to begin the cycle of monitoring and research, but once used to initiate a project or component, it becomes a companion to monitoring and research and an ongoing part of the overall program

For the purposes of the GEM Program, synthesis is distinguished from research and from retrospective analysis, a form of research Unlike research, synthesis does not necessarily start from a specific hypothesis or question Instead, synthesis takes an interdisciplinary approach to evaluating existing information or data to identify potential new applications and uses As such, synthesis is a critical component in ensuring that cross-disciplinary and cross-habitat linkages and processes are adequately considered during research and monitoring Synthesis may be supported by various forms of retrospective analysis (discussed below)

3 2 3 Research

Research is defined under GEM as collecting relatively short time series of new observations to evaluate a testable hypothesis relating to the conceptual foundation or a specific aspect of the monitoring program. In the early stages of GEM Program implementation, research will be critical in helping to identify the core variables around which the long-term monitoring activities will be developed. For example, when synthesis, modeling, or other analysis indicates the need for measuring a core variable, research may be necessary to understand how to gather the data in a specific locality and/or to determine and evaluate the appropriate measurement technology. Research may build on or use existing data and may also build models. Testing current understandings through research provides the basis for making changes to the monitoring program.

Reti ospective analysis is treated in the GEM Program as a specialized form of research, sometimes used as an integral component of synthesis, that employs existing time series data to evaluate a testable hypothesis or other questions of similar specificity relating to monitoring, often supported by statistical modeling Retrospective analysis contributes to building numerical models and to synthesis

Research, in the form of *process studies*, plays a vital role in moving beyond the correlative relationships that arise from the monitoring efforts to understand the underlying mechanisms controlling biological production both within and across habitat types Process studies develop information on the mechanisms through which energy and matter are transferred across varying scales of time and space This critical deeper understanding is essential to provide a framework and substance for the numerical modeling and synthesis Large-scale process studies may encompass ecosystem-level processes occurring across multiple trophic levels, water masses, and habitat types, whereas small-scale studies may deal with mechanisms as specific as the digestion rates of individual animals Processes such as predation, nutrient transport, and heat transfer are critical to understanding changes in living marine-related resources Process studies support model building by defining relationships among individuals and species and between phenomena such as primary production and physical forcing Process studies also contribute to other forms of research, such as retrospective analysis, and to synthesis

The short-term end point for GEM Program synthesis and research is implementation of core monitoring activities that are refined as suggested by new information The continuing roles for synthesis and research, as supported by modeling, are to advance understanding of the relationships among and within the habitat types of the ecosystems, plant and animal species, physical and chemical oceanographic processes, and climate in the northern GOA in accordance with the conceptual foundation Continual refinement and testing of hypotheses, synthesis across geographic areas and species, and modeling of biological and physical processes are expected As seen in Figure 31, synthesis is expected to play a dominant role in defining the monitoring program during the early years of the program, with the relative amount of revenues devoted to synthesis declining as long-term monitoring sites are selected and implemented Synthesis will nonetheless continue to be important indefinitely, as a means for understanding and improving the flow information produced by the monitoring programs

324 Monitoring

As defined for the purposes of the GEM Program, monitoring is the action of repeatedly collecting long-time series observations. At the level of data acquisition, monitoring differs from research primarily in the length of time over which the measurements are taken, and the nature of methods and devices employed. Monitoring differs from research by employing methods and devices that are "tried and true," whereas research may use experimental devices or novel methods to acquire data. For example, observations now considered monitoring, such as satellite observations of sea surface height, were once seen as novel research. Such satellite observations remain in the research domain to some extent, as efforts to refine the spatial resolution of the available data continue.

The decision on what and where to monitor is based on the results of research and synthesis to identify core variables. The development of long time series of data is essential to detecting and understanding change in the ecosystem. When combined with research and modeling, monitoring can demonstrate how ecosystems change over time and in response to various inputs. As such, it provides a sound scientific basis for making a variety of management decisions potentially affecting ecosystem resources. Appropriate temporal and spatial scales for the hypotheses being analyzed are important aspects of detecting change, and, are therefore, key considerations in the design of monitoring.

Monitoring in the GEM Program will be organized into core monitoring and partnership monitoring Because of its critical importance to meeting the program's goals and objectives, *core monitoring* based on a set of core variables will be fully supported by the GEM Program *Partnership monitoring* is envisioned to extend the GEM core monitoring program by teaming with partners involved in research that is also relevant to the hypotheses that GEM will be testing Partnership monitoring will be partially supported by leveraging GEM resources with the resources of the partner organization

The end point for monitoring is a geographically distributed network gathering data on the state of the marine ecosystem in the GEM region, using spatially structured survey methods This implies a broad spatial scale for monitoring, as a combination of GEM with that of other entities These data are transformed into information for user groups by using synthesis, research, modeling, data management, and information transfer

3.2.5 Modeling

Modeling is used to make the relationships between the parts and processes of the ecosystem clear, and as such, serve as a critical element in making connections between habitats and across disciplines. Models are tools for organizing data and telling a story and can be written in a variety of media as verbal, visual, statistical, or numerical models. In the GEM Program, the specific purposes of modeling are to help accomplish the following:

- Inform, communicate, and provide common problem definition;
- Identify core variables and relationships;
- Set priorities;
- Improve and develop experimental designs to attain monitoring objectives;
- Evaluate cross-habitat linkages and transfers; and
- Improve decision-making and risk assessment.

Modeling, monitoring, and data management strategies need to work in concert for each to be fully effective (Figure 3.2). Modeling is a pivotal link between monitoring and data management and information transfer on the one hand, and synthesis and research on the other. Modeling feeds back information to the monitoring program in the form of recommendations on how the monitoring system can be made more effective. Modeling also helps interpret data for the use of synthesis and research activities.

There are numerous synonyms for the types of models defined for the purposes of the GEM Program. Verbal models are also known as "qualitative" and



End-to-End Observing System

Figure 3.2 The End-to-End Observing System in which the monitoring observations are linked by data management and information transfer to end users, including modeling, synthesis, research, and management applications. (Adapted from Tom Malone [U.S. GOOS Steering Committee 2000])

"conceptual", statistical models are also known as "correlative" and "stochastic", and numerical models are also known as "deterministic" and "mechanistic" Note that "prediction," "simulation," and "analysis" are not types of models, but uses of models For example, the use of any kind of statistical or numerical model to reproduce the behavior of a process, such as population growth, is known as a simulation All four types of models will be used in the GEM Program In the near-term, however, models of biological phenomena are expected to be mostly verbal, visual, and statistical, whereas models of physical and chemical phenomena are likely to be primarily numerical, in addition to being verbal and statistical

The long-term modeling end points for monitoring, synthesis, and research in GEM are working biophysical models that make managers, policy makers, and resource users aware of changes in natural resources, help them understand the human and natural origins of these changes, and give them some idea of what to expect in the future A detailed discussion of the definitions and strategies for modeling in the GEM Program is provided in Chapter 8

3 2 6 Data Management and Information Transfer

Data management and information transfer are the processes of acquiring in the field, receiving in the office, formatting, and storing data, providing quality control and assurance, developing and managing databases, and making the data understandable and available to users (See also Chapter 9) It includes the development of information products based on interpreted data and the delivery of these products, including user interfaces The immediate objective of data management and information transfer is to ensure that the data collected by projects under GEM are well documented, safely stored, and accessible to the public within a reasonable period of time after collection. An ongoing objective of data management and information transfer in the GEM Program is to achieve to the greatest extent possible the documentation, storage and public access for past data acquired with E_{xxon} Valdez Oil Spill (EVOS) funds under the Natural Resource Damage Assessment and Restoration programs of the Trustee Council

The long-term end point for GEM data management and information transfer is a system that manages the rapid and efficient flow of data and information based on core monitoring projects to end users, and that facilitates the flow of data and information between and among GEM partners and the user community

GEM data management is a program support function intended to accomplish the following-

- Support cross-disciplinary integration of physical and biological information, and traditional knowledge within a structured, decisionmaking framework,
- Support synthesis, research, and modeling that evaluate testable hypotheses on the roles of natural forces and human activities in controlling biological production, and

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 Lay the groundwork for future use of distributed, Web-based analysis and management tools as the monitoring program becomes fully operational

By necessity, the data incorporated into the GEM Program will be derived from a variety of sources and formats, which will include retrospective data sets and traditional knowledge and may contain spatial and temporal components Synthesis and research will need to incorporate data not directly collected by the GEM Program, such as satellite remote-sensing information and fishery catch data Incorporation of these data into regional models and decision-making systems will require tools for data ingestion and query, especially to facilitate modeling Because the output from the GEM Program will be used by people from a wide variety of disciplines and backgrounds, the user interfaces must be easy to understand and accessible through a distributed network, such as the Internet

Data management and acquisition policies are essential to ensure the rapid transfer of information to end users Although the data must flow through the system as quickly as possible, quality control and assurance procedures and the prerogatives of scientists to publish interpretations of the data need to be respected One approach that may prove useful is the establishment of "peer reviewed" data sets that allow the scientists involved to receive credit for their efforts in the publications of other scientists who may use the data

Information transfer products will depend on the nature of the monitoring and research activities that are yet to be chosen Possibilities for these products, based on the experience of other monitoring and research programs, are discussed in Chapter 9 and could include models and measures relevant to determining the productivity of key species such as salmon

3.3 GEM Program Strategies

The previous section discussed the standard tools that will be used to develop and evaluate data and manage information in the GEM Program This section presents two strategies that also will be

important in guiding the GEM Program incorporating traditional knowledge and community involvement, and potential for resource management applicability These strategies will be applied to the GEM Program as a whole and will influence the way that the tools presented in the previous section are used

3 3 1 Incorporating Community Involvement and Traditional Knowledge

Community involvement and the incorporation of traditional knowledge in the GEM Program are critical to the program's long-term success The significance of traditional knowledge is becoming increasingly recognized (IUCN 1986, Martinez 1994, Kimmer 2000) and can play a role in providing early warning signs of ecosystem change (Ford 2001) Local residents are expected to provide ecological knowledge that can be incorporated into established scientific models They also can be a source of research questions which help ensure research that is relevant to

both ecological and community needs Community-based monitoring efforts can efficiently collect essential data and build local stewardship as well as long-term support for the GEM Program

The EVOS settlement requires meaningful public involvement in all Trustee Council programs, as well as a Public Advisory Committee Residents of coastal communities have a direct interest in scientific and management decisions and activities concerning the fish and wildlife resources and environments on which they depend for their livelihoods and sustenance (Huntington 1992) The Trustee Council believes that encouraging local awareness and participation in research and monitoring enhances long-term stewardship of living marine resources

Community involvement can occur in many ways Several approaches have been tried in the EVOS restoration program and elsewhere in Alaska and other northern regions, and GEM will draw on these experiences to design specific processes for involving communities and their expertise(Huntington 2000, Brown-Schwalenberg et al 1998, Fehr and Hurst 1996, Hansen 1994, Brooke 1993) One avenue is through active membership on the 20-member Public Advisory Committee, made up of representatives of tribal and incorporated communities, stakeholders, scientists and members of the general public Another is through active participation of public members on various scientific subcommittees and work groups and during targeted workshops to help plan and guide the GEM Program as it develops Other ways include having citizens, students and communities implement local monitoring activities

Traditional and local ecological knowledge can provide important observations and insights about changes in the status and health of marine resources (Huntington 1998) With Trustee Council funding, Alaska Native tribes in the GEM research area are currently developing natural resource plans that will help identify important resources and potential threats and be useful in designing local monitoring schemes that help answer key questions for the GEM Program

The Trustee Council has always listened closely to the views and interests of the people living in the spill-affected region, and responded to their concerns consistent with the legal restrictions of the EVOS settlement funds Under the terms of the settlement, restoration funds can only be used to respond to injuries to the public's natural resources – not injury to individuals or to communities However, the communities have the well being of these resources at heart, and any program to provide for the long-term health of the resources, has the benefit of providing for the long-term health of the local communities

3 3 2 Potential for Resource Management Applicability

The GEM Program is intended to increase and enhance the information managers and stakeholders use to cope with changes in natural resources To accomplish this, GEM will seek to acquire data with significant potential for use in resource management applications, ensure that data is converted into useful information in a timely manner, and invite research and synthesis projects that both involve and benefit natural resource management agencies

Salmon fishery management illustrates management concerns that are common to most natural resources The typical salmon fishery operates on a resource that

GEM questions are directed at understanding not only specific mechanisms of production in representative habitat types, but also the connections among habitat types depends on a variety of habitat types (freshwater, nearshore, and offshore) during the course of its life cycle (Figure 3 3) Management of the salmon fishery requires detecting and understanding the consequences for production of habitat management decisions (Box 1 9, Figure 3 3) throughout the salmon's life cycle GEM seeks to provide data relevant to answering specific questions about how a range of habitat types function to produce salmon and other species The cyclic nature of the salmon

fishery in time and space makes it clear that biological production in one habitat type cannot be understood in isolation from production in the other habitat types in which the salmon completes its life cycle GEM questions are directed at understanding not only specific mechanisms of production in representative habitat types, but also the connections among habitat types

The management applications actually achieved will depend on a variety of factors, including the degree to which resource managers participate in the review, development, and implementation of the GEM Program

3.4 Conclusion

The tools and strategies described above are used together to make the GEM Program scientifically sound, compatible with other programs, relevant

to communities and resource managers, and open to the information local residents may provide Using the tools and strategies to implement the GEM Program is addressed in following chapter



Figure 3.3 Diagram of the salmon fishery with life cycle stages, harvest, and habitat management decisions in geographic and temporal contexts (*Mundy 1998*).

3.5 References

- Brooke, L F 1993 The participation of indigenous peoples and the application of their environmental and ecological knowledge in the Arctic environmental protection strategy Inuit Circumpolar Conference Ottawa
- Brown-Schwalenberg, P, HP Huntington, and H Short 1998 Traditional knowledge and environmental recovery experiences from the Exxon Valdez oil spill Bridging traditional ecological knowledge and ecosystem science, August 1998, Flagstaff, AZ
- Fehr, A and W Hurst 1996 A seminar on two ways of knowing indigenous and scientific knowledge Inuvik, NWT, Aurora Research Institute
- Ford, J 2001 The relevance of indigenous knowledge to contemporary sustainability Northwest Science Forum 75 183-188
- Hansen, B 1994 Report on the seminar of integration of indigenous peoples and their knowledge Reykjavik, Iceland, Copenhagen Ministry for the Environment (Iceland), Ministry of the Environment (Denmark), and the Home Rule of Greenland (Denmark Office)
- Huntington, H P 1992 Wildlife management and subsistence hunting in Alaska Belhaven Press London.
- Huntington, H P 1998 Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge Arctic 51 237-242
- Huntington, H P 2000 Using traditional ecological knowledge in science methods and applications Ecological Applications 10 1270-1274
- IUCN 1986 (International Union for Conservation of Nature) Tradition, conservation and development Occasional newsletter of the Commission on Ecology's Working Group on Traditional Knowledge No 4 International Union for Conservation of Nature UK
- Kimmer, R W 2000 Native knowledge for Native ecosystems Journal of Forestry 98 4-9
- Martinez, D 1994 Traditional environmental knowledge connects land and culture Winds of Change 89-94
- Mundy, P R 1998 Principles and criteria for sustainable salmon management Alaska Department of Fish and Game http //www cf adfg state ak us/geninfo/pubs/ pubshome htm
- Myers, KW, RV Walker, HR Carlson, and JH Helle 2000 Synthesis and review of US research on the physical and biological factors affecting ocean

production of salmon Pages 1-9 in Helle, J H, Y Ishida, D Noakes, and V Radchenko, editors Recent changes in ocean production of Pacific salmon North Pacific Anadromous Fish Commission Bulletin, Vancouver

- NRC 2002 A century of ecosystem science planning long-term research in the Gulf of Alaska Washington, D C , National Academy Press
- Ricklefs, R E 1990 Scaling patterns and process in marine ecosystems Pages 169-178 in Sherman, K , L M Alexander, and B D Gold, editors Large marine ecosystems patterns, processes and yields American Association for the Advancement of Science, Washington, D C
- U S GOOS Steering Committee 2000 Third meeting of the U S GOOS steering committee June 29-30, 2000 Huntington Beach, California U S GOOS
- Wilson, E O 1998 Consilience the unity of knowledge Vintage Books, A Division of Random House, Inc. New York

CHAPTER 3

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4. PROGRAM IMPLEMENTATION

In This Chapter

- Introduction to the GEM Science Plan
- Conceptual Foundation by Habitat
- Key Questions by Habitat
- GEM Program Implementation

This chapter describes the starting point for developing the GEM Science Plan. As such, it should be considered a work in constant progress. Once completed the GEM Science Plan will be periodically updated in response to direction from the Scientific and Technical Advisory Committee, its subcommittees, and using input from communities and the general public (see Chapter 5). Changes to potential research questions during the early years of the program could be substantial.

4.1 Introduction

Before the general hypotheses developed and presented in Chapters 2 and 3 can be used to guide the GEM research and monitoring program, they

need to be refined into a set of specific research questions, and the research questions need to be evaluated to determine what data need to be collected and analyzed to answer them. The process and timelines for defining, asking, and getting the data to answer the questions, also known as research and monitoring, is described by the GEM Science Plan, which does not now exist.

The goal served by the Science Plan is to implement a long-term monitoring program, which can only be done after the requisite synthesis and research have been completed.

This chapter is the first step in developing the Science Plan. It extends the GEM conceptual foundation (through the primary physical and biological processes, and human activities believed to be most important in affecting change in the Gulf of Alaska [GOA]) to each general habitat type. From this information, and building on the habitat hypotheses, a series of potential questions have been developed that can be used as a starting point for identifying initial research activities. The potential research questions presented in these sections are meant to capture some of the main uncertainties in how fluctuations in the northern GOA ecosystem influence the distribution and abundance of valued organisms. They do not attempt to capture the entire scope of potential research questions. Instead,

they address discrete aspects of the conceptual foundation and are starting points for identifying research activities As knowledge of the ecosystem increases, the research questions are expected to gain greater specificity and refinement through ongoing hypothesis testing, gap analysis, and identification of specific information needs It is expected that the potential research questions will change as a result of the Scientific and Technical Advisory Committee (STAC) process described in Chapter 5

Following the habitat-specific research questions is an initial implementation plan for the GEM Program during a 5-year period, from FY 03 to FY 07 This plan incorporates the following elements

- A *proposed schedule for implementation*, FY 03 to FY 07, for core and partnership activities, models, and data management
- Lists of probable or *prospective partners* that are actively doing related monitoring or research in the habitat type
- Development of *models* as a way to synthesize monitoring and research results and transfer information to end users
- Candidate (possible) core monitoring activities recommended based on the conjunction of partnership opportunities and opportunities for measuring biological and physical quantities related to the key question and information gaps
- *Candidate (possible) core variables* recommended based on approaches suggested by the literature reviewed in the scientific background (Chapter 7)

The proposed schedule for implementing GEM monitoring activities in the watershed, intertidal/subtidal, and Alaska Coastal Current (ACC) habitat areas is similar, but modeling and data management needs differ in each habitat. For offshore research, GEM will primarily be involved in partnering activities, since research offshore is already being undertaken by a number of other large-scale programs. As a result, the schedule for implementation largely is dependent on the implementation schedules for partner programs.

4.2 Watersheds

421 Conceptual Foundation for Watersheds

Watersheds are linked by biogeochemical cycles and common climatic forcing to the marine ecosystem Input of terrestrial carbon contributes to the carbon budget of the oceans Likewise, marine contributions of nutrients appear to be important to growth of aquatic and terrestrial plants and animals in watersheds Primary natural forces are precipitation and insolation. Watersheds depend on import of marine nutrients by anadromous fish and other animals. Therefore, maintenance of healthy salmon runs and populations of terrestrial animals that feed in the nearshore marine environment is key to healthy watershed ecosystems. Woody debris and vegetation from land are also exported to the marine environment, providing a carbon source and habitat for some species. The common effects of climate also link these two systems. Fresh water from coastal watersheds contributes huge amounts of fresh water to the GOA and makes possible the Alaska Coastal Current-the single most dominant and integrating feature of the physical environment on the continental shelf.

Human activities in the watersheds that remove natural vegetation can result in soil erosion and its attendant effects on stream and coastal marine life. Fresh water can carry contaminants to the marine environment. Sources of these contaminants can be of local origin–sewage and septic wastes, industrial and military wastes, motor vehicles, and oil from spills–or imported from distant sources and carried across the Pacific Ocean by atmospheric processes.

Key Hypothesis: Natural forces (such as climate) and human activities (such as habitat degradation and fishing) serve as distant and local factors in causing short-term and long-lasting changes in marine-related biological production in watersheds.

4.2.2 Potential Watershed Questions:

a. What are levels of marine-related nutrients in watersheds and how do the annual inputs of marine nutrients vary?

Specific Information Needs: Levels of nitrogen-stable isotopes in freshwater plants and animals, and feasibility of studying sources of precursors of reduced iron in watersheds with marine access.

b. What is the annual variability in precipitation and runoff in Alaska watersheds bordering the northern GOA? (Same question applies to intertidal-subtidal and ACC habitats.)

Specific Information Needs: Annual precipitation and runoff for all watersheds flowing into the northern GOA. In some cases, where data gaps exist, it may be possible to use marine salinity data to supplement precipitation and stream flow measures in estimating total freshwater run off from land to the GOA. Input of the amount of fresh water entering the GOA from northern British Columbia and Southeast Alaska would also be needed to use marine salinity as a proxy for freshwater runoff.

c. What are the levels of contaminants entering and leaving watersheds along marine-related pathways?

Specific Information Needs Levels of contaminants such as persistent organic pollutants in anadromous species as adult immigrants and as juvenile emigrants of the watersheds

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Development of watershed monitoring activities will be led by a core synthesis effort in FY 03, building on preparatory core research in FY 02 to establish an approach to measuring levels of marine influence in animals and plants of the watersheds. Core synthesis will assist in developing hypotheses by about FY 04 that can be tested and refined by core research in FY 05 and FY 06. At least one core monitoring station will be initiated by FY 06, but may not be fully operational until FY 07.

Table 41 presents the proposed schedule for implementation

	Monitoring Activity			Data
Fiscal Year	Core	Partners	Model	Management
2003	Synthesis	Monitor	Verbal(c)	Prototype
	Research			
2004	Synthesis	Monitor	Statistical(c)	Coordination (c)
	Research	Research		Archiving(c)
2005	Research	Monitor	Statistical(c)	Coordination (c)
		Research	Numerical prototype (p)	Archiving (c)
				Distribution (p)
2006	Research	Monitor	Statistical(c)	Coordination (c)
	Monitor	Research	Numerical (p)	Archiving (c)
				Distribution (p)
2007	Monitor	Monitor		Archiving (c)
	Research		Numerical (p)	Distribution (p)

Table 4 1 Proposed Implementation Schedule for Watershed Habitat

Notes

c = core (GEM Program supported) activity

p = partnership (jointly supported) activity

Prospective partners ADF&G, USFWS (Kenai Natural Wildlife Refuge [KNWR]), USGS, EPA, ADEC, USFS, Cook Inlet Keeper (CIK), Alaska Department of Natural Resources (ADNR), and Washington Department of Fish and Wildlife (WDFW)

Candidate core monitoring activities Kenai River watershed, Karluk River watershed

Candidate core variables isotopes of nitrogen in aquatic and riparian plants and animals, precursors of reduced iron in water, and anadromous fish

424 Prospective Partners and Partner Activities

Partner activities in FY 03 are expected to be the supporting monitoring programs already in place, such as enumeration of animals and plants, water

quality monitoring, existing hydrology models, including annual and seasonal runoff, and permitting of human activities such as resource harvests and land development Starting in FY 04, partners will be encouraged to assist in funding research to further site selection. This research process will extend through FY 06, terminating after the monitoring stations are fully operational. Because an analogous research program is underway at the Washington Department of Fish and Wildlife (WDFW), that agency may be willing to share information and the costs of process studies of mutual interest.

425 Models

Models of the relationship between marine productivity and watershed productivity (Finney et al 2000) will likely be verbal as of FY 03 Statistical modeling to describe the strength of relations among variables and power analysis to guide sampling should start in FY 04, continuing through the evaluation of the initial monitoring stations in FY 06 The end point of modeling will be a numerical model of the geochemistry of the core variable(s) in the watershed to the boundary of the intertidal and subtidal areas This model will be initiated in about FY 05 and operational (in some sense) by FY 07 It is recognized that a number of partner monitoring activities in addition to the core activity will be needed to create parameters for a numerical model. If numerical modeling proves intractable, statistical modeling would be extended in the interim

4 2 6 Candidate Core Monitoring Activities

Candidate core monitoring activities will be chosen to build on existing long time series of data collected by prospective partners. The Kenai and Karluk rivers are two likely candidates. For the Kenai River watershed, three decades of data on adult salmon returns to the spawning grounds of the watershed can be used as estimates of marine influence. In addition, salmon catch data span more than five decades. The proximity to Anchorage places the Kenai River watershed under heavy pressure from human activities and their associated impacts, many of which are documented by government regulators. Multiple prospective partners have extensive programs in place to monitor vegetation, terrestrial animals, limnology, and other variables of potential relevance to the key question. The Karluk River watershed is unique in having a published record of more than 300 years of changes in marine influence in general, and marine nitrogen in particular (Finney et al. 2000). In addition, the prospective partners have collected more than eight decades of counts of salmon returns for the watershed.

4 2 7 Candidate Core Variables

Isotopes of nitrogen in plants and animals and sources of reduced iron are candidates for core variables, based on work described in the scientific background under marine-terrestrial connections and chemical oceanography (Chapter 7) In watersheds of the GEM region, where nitrogen limits productivity, marine nitrogen in anadromous fish species, principally salmon, could be an important
driver of watershed productivity Phosphorus and iron from salmon may also be important to watershed productivity, but direct measures of the origin of these elements are not available Indirect measures might be, for example, phosphorus or iron concentration per gram of fish times average fish weight times return number A decade of work on the role of iron in primary productivity in marine areas suggests that geophysical and biological processes in watersheds may contribute to marine productivity Processes in the watersheds may limit marine productivity by controlling the availability of precursors of reduced iron

4 3 Intertidal and Subtidal

The intertidal and subtidal-or nearshore-area is technically a part of the ACC regime in most places (the next habitat to be considered), except arguably in some embayments, such as the fjord

systems in northern Prince William Sound (PWS) But, because of the importance and vulnerability of the intertidal and shallow subtidal areas and the dependence of so many valued species on nearshore habitat, it is treated here separately from the ACC

4 3 1 Conceptual Foundation for Intertidal and Subtidal

The productivity of intertidal and subtidal marine communities depends on both fixed algae and some other vascular plants in shallow water, as well as freefloating phytoplankton Nutrient supply to fixed plants is not well characterized, but presumably is controlled by oceanographic processes and seasonal cycles of water turnover on the inner shelf as well as some contributions from stream runoff This process of nutrient supply is essentially the same as for nearshore phytoplankton Ultimately, as mentioned in Chapter 7, Section 5 3, the runup of deepwater from the central GOA onto the shelf and some poorly characterized processes for cross-shelf transport of the nutrients are critical to growth of both fixed and floating nearshore algae The nearshore waters can be depleted of nutrients during the growing season if the warm surface layers where primary productivity is drawing down nutrients is not mixed with deeper waters by wind and tidal action Within-season variability in primary production, therefore, appears to depend on the previous late summer run up of deepwater onto the shelf, some poorly described cross-shelf transport processes, and within-growing season wind and tidal mixing

Cloud cover also is likely to be very important in regulating the amount of solar energy reaching the ocean surface Nearshore turbulence, which is the result of the prevailing climate and tidal action, promotes the growth of algae and phytoplankton. These plants are the food supplies for filter-feeding mollusks, such as clams and mussels, which are important sources of food for a variety of nearshore animals, such as sea otters and sea ducks. Climate also directly affects intertidal and subtidal animals through changes of temperature, water salinity, and ice formation. Ice formation is an important source of mortality and reduced growth of intertidal algae and some animal populations in some situations. It is

suspected that bottom-up forcing through variability of primary production is an important influence on intertidal invertebrate communities on the scale of decades, but there are no long-term data sets to examine this supposition. If wave action is too intense, it can limit population growth; for example, waves during storms often throw large amounts of herring eggs (embryos) onto the beach where they die.

A large number of intertidal and subtidal animal populations respond to both bottom-up and top-down natural forcing as well as to human activities. Bottomup forcing appears to have more documented effects on such populations as herring, pollock, shrimp, crab, salmon, and seabirds than have been documented for infaunal and attached intertidal animals. There are good examples of population controls by removals (top-down influences) and many of these relationships, such as that between sea urchins and sea otters, are cited in Chapter 7.12.2.5. Disease possibly influences some populations, such as *Viral Hemorrhagic Septicemia* virus effects on Pacific herring in PWS.

The intertidal and subtidal benthos is particularly vulnerable to human use through harvesting of various invertebrates, trampling, discharge of contaminants, road and home construction, and soil erosion. At the present time, impacts of such activities appear to be localized because of the dispersed nature of human activities along the vast coastline of the northern GOA. The nearshore sentinel populations may need to be monitored more closely, however, as Alaska's population and use of the nearshore zone expands in the future.

Key Hypothesis: Natural forces (such as currents and predation) and human activities (such as increased urbanization and localized pollution) serve as distant and local factors, in causing short-term and long-lasting changes in community structure and dynamics of the intertidal and subtidal habitats.

4.3.2 Potential Intertidal and Subtidal Question:

a. What is the variability of selected plant and animal populations in the intertidal and subtidal zones?

Specific Information Needs:

- Variability in numbers and diversity of fixed algae and invertebrates in several regions, such as PWS, Kachemak Bay, and Kodiak Island.
- Relative availability of larval dispersal stages.
- Measures of the cycling of carbon, nutrients, and contaminants in key species such as *Fucus*.
- A detailed map of intertidal plant biomass during the growing season on a wide spatial scale.

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- Monitoring of clam populations
- Measurements of population processes of sea otters
- Identification and measurement of human impacts of concern

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Development of the intertidal and subtidal monitoring activities is expected to begin with a planning workshop in FY 02 and an intense core synthesis effort in FY 03 that involves extensive preparatory core research. The inherently high variability of the community structure of the intertidal and subtidal habitat-and its vulnerability to the effects of predation and human degradation-may make it difficult to develop a design that can separate human activities from natural forces, forestalling implementation of initial monitoring until FY 06. Core synthesis is planned to provide hypotheses by about FY 05 that can be tested and refined by core research in FY 06 and FY 07. The initial schedule calls for at least one core monitoring station to be initiated by FY 06, but it may not be fully operational until FY 07.

Table 4 2 presents the proposed schedule for implementation

434 Prospective Partner Activities

Partner activities in FY 03 will be the supporting monitoring programs already in place, such as monitoring of individual species for basic biology and contaminant loads, surveys of species composition and distribution, surveys of substrates, and measurements of physical oceanography Starting in FY 04, partners will be encouraged to assist in funding research to further site selection. These research activities will extend through FY 06, terminating after the monitoring station is fully operational in FY 07 (Table 4 2)

435 Models

Models of changes in community structure of the intertidal-subtidal areas in response to human activities and natural forcing are expected to be primarily verbal from FY 03 to FY 05 Statistical modeling, particularly power analysis to guide sampling, is expected to be operable as soon as FY 03, because of experience gained in the *Exxon Valdez* Oil Spill coastal habitat program and related damage assessment and restoration work Statistical modeling will continue through the evaluation of the initial monitoring station in FY 06 The end point of a numerical model to combine physical forcing and human activities for describing community structure is a very ambitious undertaking for a core activity within a 5-year time frame and may not be feasible at all without substantial partner support

	Monitori	ng Activity		Data
Fiscal Year	Core	Partners	 Model	Management
2003	Synthesis	Monitor	Verbal(c)	Prototype
	Research		Statistical(c)	Coordination (c)
2004	Synthesis	Monitor	Verbal(c)	Coordination (c)
	Research	Research	Statistical(c)	Archiving(c)
2005	Research	Monitor	Verbal(c)	Coordination (c)
		Research	Statistical(c)	Archiving (c)
				Distribution (p)
2006	Research	Monitor	Statistical(c)	Coordination (c)
	Monitor	Research		Archiving (c)
				Distribution (p)
2007	Monitor	Monitor	Statistical(c)	Archiving (c)
	Research		Numerical prototype (p)	Distribution (p)

Table 4 2 Proposed Implementation Schedule for Intertidal and SubtidalHabitat

Notes

c = core (GEM Program supported) activity

p = partnership (jointly supported) activity

Prospective partners ADF&G (Kachemak Bay National Estuarine Research Reserve [KBNERR]), NOAA (National Ocean Service) UAF, Cook Inlet Regional Citizens Advisory Council (CIRCAC), Prince William Sound Regional Citizens Advisory Council (PWSRCAC), USFS, EPA-ADEC (EMAP), Alyeska Pipeline Service Company

Candidate core monitoring activities Kachemak Bay (lower Cook Inlet), Green Island (PWS)

Candidate core variables substrate type and distribution, species composition and distribution, recruitment

4 3 6 Candidate Core Monitoring Activities

Candidates for core monitoring activities will be selected based on substantial partnering opportunities, chances for assessing human activities and impacts, and logistics Likely candidates are Kachemak Bay in Lower Cook Inlet and Green Island in PWS Kachemak Bay is close to the city of Homer and becoming a developed recreational destination In addition, the bay has the presence of coastal habitat assessment programs already in place within the Kachemak Bay National Estuarine Research Reserve (KBNERR), as well as nearby moorings taking oceanographic measurements The U S Forest Service (USFS) has a long-term ecological monitoring site at Green Island, which is still seeing effects from the 1989 oil spill A new weather station is being installed nearby at Applegate Rocks, and additional oceanographic moorings in nearby Montague Strait are likely

4 3 7 Candidate Core Variables

Community structure in the intertidal and subtidal areas is determined by substrate type and amount, as well as by physical oceanographic features, such as wave action Species composition and distribution are fundamental to

determining community structure, as is the recruitment rate of key species such as barnacles, mussels, and clams, depending on substrate

4.4 Alaska Coastal Current

As noted above, the domain of the ACC in many cases starts at the shoreline and extends out to a frontal area several tens of kilometers onto the continental shelf The inshore boundary of this

current system is not precisely defined in this subsection because the nearshore aspects of the ecosystem have been covered above

441 Conceptual Foundation for ACC

Because the ACC is a buoyant, low-salinity, eastern, boundary current fed essentially by a line-source of fresh water along the length of the Alaska coastline, it offers a unique opportunity to study basin-scale physical forcing of biological production Although one characteristic of the ACC is the draw-down of nutrients during the growing season to levels that are undetectable, the in-season variability is clearly driven by patterns in wind mixing, and is very significant A promising model developed by Eslinger et al (2001) is capable of tracking the in-season variability of plankton production based on the physical characteristics of the water column and the wind field The extent to which patterns of seasonal wind mixing are the major contributors to longer-term variability in primary productivity is not clear Tidal mixing likely contributes to variability, as do other potential mechanisms that transport deep-water nutrients into shallow waters, for example, late-summer relaxation of onshore Ekman transport and up-canyon currents

Annual variability of nutrient supply likely has a great influence on long-term variability in primary production For example, this influence would be consistent with the relationship between the Bakun upwelling index and pink salmon marine survival rates up to 1990 (see Chapter 7) and the differences observed between the volumes of settled plankton in the 1980s and in the 1990s (Brown unpublished)

Another physical phenomenon that apparently affects biological production in the water column is eddies Eddies have been documented in Shelikof Strait, for example, and greatly influence retention of larval pollock in a favorable environment (Bogard et al 1994, Bailey et al 1997) Beyond their study in the Fisheries Oceanography Coordinated Investigations (FOCI) program, not much is known generally about eddies in the ACC and their biological influences. There are also eddies in Kachemak Bay, some of which are stratified at the surface by freshwater inputs that may similarly benefit pelagic species there and off Kayak Island, southeast of PWS. The southerly and easterly winds that predominate during most of the year drive offshore water inshore (via Ekman transport), carrying offshore planktonic organisms close to shore and providing potential sources of food for nearshore organisms, such as juvenile pink salmon Finally, the outer edge of the ACC often forms a front with the water masses seaward of it. This front is characterized by strong convergence of offshore and inshore water masses and significant downward water velocities. It appears at times to concentrate plankton, nekton, fish, and birds, and is probably an important site for trophic interactions.

Many of the types of natural and human activities that affect the nearshore species apply also to the ACC. This similarity is due in part to the fact that many species cross between the nearshore environment and deeper waters. Bottom-up forcing appears to be of great importance, because areas of the ACC with high levels of *chlorophyll a* during the growing season and vigorous vertical mixing, such as Lower Cook Inlet, also support large populations of fish, seabirds and marine mammals. The ACC is the main domain of the GOA for the productive fisheries for both pelagic and benthic species. Consequently, human activities are potentially a quite large aspect of removals. Other possible human impacts include contaminants and long-term global warming.

Key Uypothesis: Natural forces (such as variability in the strength, structure and dynamics of the ACC) and human activities (such as fishing and pollution) cause local and distant changes in production of phytoplankton, zooplankton, birds, fish, and mammals.

4.4.2 Potential Alaska Coastal Current Questions:

a. What is the annual variability of strength, location and dynamics of the ACC?

Specific Information Needs: Measurements of variability in temperature and salinity with depth, on time scales from days to multiple decades at locations sufficient to understand seasonal-scale variability and at localities sufficiently widely dispersed to understand large-scale structure, including intrusion into bays.

b. What is the variability in the supply of deepwater nutrients to the photic zone of the ACC and their concentrations in that zone on time and space scales appropriate to understanding annual primary production?

Specific Information Needs: Measurements of, or proportional to, macronutrients and micronutrients at appropriate spatial scales.

c. What is the variability in *chlorophyll a* concentrations and phytoplankton species composition in the photic zone of the ACC on time and space scales appropriate to understanding annual primary production?

Specific Information Needs

- Chlor ophyll a measurements
- Information on phytoplankton species composition
- d What is the variability of zooplankton biomass and species composition in the ACC on time and space scales appropriate to understanding annual primary and secondary production?

Specific Information Needs Information about zooplankton biomass and species composition

e What is the variability in the availability of forage fish to higher trophic levels (birds, fish, mammals) in the ACC?

Specific Information Needs

- Analyses of the diets of selected higher-trophic-level organisms (birds, mammals, large predatory fish)
- Analyses of selected higher-trophic-level organisms (birds, mammals, large predatory fish) for fatty acid composition in relation to diet
- f What are the major factors affecting long-term changes in sea bird populations?

Specific Information Needs Annual colony and chick productivity counts of appropriate species in selected GOA colonies

g What are the major factors affecting long-term changes in harbor seal populations?

Specific Information Needs

- Annual surveys of molting population in selected GOA haul-outs
- Fatty acid profiles of individual animals and scat analysis surveys in selected GOA haul-outs

443 Program Implementation

Development of ACC monitoring will require a period of synthesis and research that involves collaboration between physical and biological scientists to decide on how to best detect changes in annual and seasonal production and transfer of energy to higher trophic levels. The determination of what physicalchemical processes are most important to measure for primary and secondary production will require a synthesis that combines existing physical and biological information and hypotheses. Specific seasonal questions such as what controls the timing, duration, and magnitude of the spring bloom on the inner continental shelf need to be carefully cast as testable hypotheses before committing to long-term monitoring Having the Sound Ecosystem Assessment (SEA), Alaska Predator Ecosystem Experiment (APEX), Global Ocean Ecosystem Dynamics (GLOBEC) Northeast Pacific National Estuary Program (NEP), FOCI, Ocean Carrying Capacity (OCC), and National Pacific Anadromous Fish Commission (NPAFC) programs precede and parallel the GEM Program is extremely fortuitous for development of this component. The experience and lessons from these programs will be extremely beneficial in helping GEM build its core monitoring components For these reasons, development of ACC monitoring activity will begin with a core synthesis effort that is closely coordinated with the ongoing research and monitoring efforts mentioned above

Understanding how best to measure biological productivity and trophic transfer in the ACC will take longer to develop than the approach to physical measurements, which could be developed in a relatively short period of time['] The long-term observation program being carried out in PWS and across the shelf in the northern GOA under GLOBEC started in 1997 and will extend through 2004 Intense process studies are scheduled for 2001 and 2003 It will take some time to distill the large amount of information available from such studies and other programs to the point of recommending a full suite of core biological measurements for core GEM Program monitoring in the ACC

Table 4 3 presents the proposed schedule for implementation

444 Prospective Partner Activities

National Oceanic and Atmospheric Administration's (NOAA) interest in the ACC continues to be high, as demonstrated through its participation in the GLOBEC and OCC programs and some continuing work in the FOCI program in Shelikof Strait It is almost certain that the GAK1 station and line, maintained and monitored by the University of Alaska and in place now for decades, will play a central role in future monitoring of the physical structure of the ACC based on temperature and salinity measures Recently added biological measures, including *chloi ophyll a*, will likely be maintained and supplemented Other opportunities for partnerships include more recently established GLOBEC stations from PWS across the continental shelf and one of the lines used in the FOCI program in the Shelikof Strait The US Geological Survey (USGS) Biological Resources Division, which has an established set of seabird monitoring colonies spaced at about 500-km intervals around the GOA and into the Bering Sea, is another strong candidate for a partner Close coordination with methods of the colonial seabird program of the USFWS Alaska Maritime Refuge is envisioned to make seabird data consistent around the coast of Alaska For measuring forage species variability, population abundance data from the Alaska Department of Fish and Game (ADF&G) on Pacific herring in PWS and also for populations at Kodiak Island and in Kamishak Bay, although not complete, may be useful Starting in FY 04 and extending through FY 06, partners will be encouraged to assist in funding research to further site selection for monitoring the ACC

	Monitori	ng Activity		Data	
Fiscal Year	Core	Partners	 Model	Management	
2003	Synthesis	Monitor	Statistical(c)	Coordination (c)	
	Research		Numerical (p)		
2004	Synthesis	Monitor	Statistical(c)	Coordination (c)	
	Research	Research	Numerical (p)	Archiving(c)	
2005	Research	Monitor	Statistical(c)	Coordination (c)	
		Research	Numerical prototype (p)	Archiving (c)	
				Distribution (p)	
2006	Research	Monitor	Statistical(c)	Coordination (c)	
	Monitor	Research	Numerical (p)	Archiving (c)	
				Distribution (p)	
2007	Monitor	Monitor		Archiving (c)	
	Research		Numerical (p)	Distribution (p)	

 Table 4 3 Proposed Implementation Schedule for Alaska Coastal Current

 Habitat

Notes

c = core (GEM Program supported) activity

p = partnership (jointly supported) activity

Prospective partners UAF (IMS, School of Fisheries and Ocean Sciences [SFOS]), U S Department of Interior (DOI) (National Park Service [NPS], USFWS, USGS), North Pacific Research Board (NPRB), NOAA (NMFS/National Ocean Service [NOS]), EPA-ADEC EMAP Candidate core monitoring activities GAK1, Hinchinbrook Entrance, Montague Strait Candidate core variables temperature, salinity, fluorescence, plankton, forage species

Plankton measurements (settled volume) are taken now by potential partners at six hatcheries in PWS On the basis of past correlations of plankton-settled volume with annual pink salmon returns and decadal-scale herring abundance, these data could provide information about productivity of the ACC system of relevance to multiple species under certain conditions Extension of the "plankton watch" to hatcheries in other areas and local communities throughout the northern GOA may be a worthwhile and potentially economical way to maintain long-term data sets and archives of plankton Other opportunities to collect samples and analyze plankton communities may include cruises with net and hydroacoustic sampling, as well as satellite images Also of possible merit are the use of ships that offer opportunities, for example, the continuous plankton recorder is recommended to be deployed on oil tankers traveling from Valdez to Long Beach under EVOS sponsorship in FY 02 Certainly any satellite images of the sea surface that measure *chloi ophyll a* concentrations provide very useful synoptic pictures, even taking into account the limitations that cloud cover and lack of subsurface data present Decisions will be made with the guiding philosophy of collecting data of relatively low frequency in space and time so that decadal scale change can be resolved

Perhaps the largest challenge for the ACC habitat will be developing monitoring activities to measure variability in forage fish populations and associated predator populations Some options for exploration of partnerships for assessing forage fish abundance and associated phenomena include the following:

- Larval surveys building on the databases and archived specimens from the FOCI program
- Use of forage fish occurrence in the stomachs of large fish collected in the sport fishery-or in some of the large fishery assessment programs conducted by NOAA and ADF&G-as an index of relative abundance (The Trustee Council sponsored a successful study of these occurrences of forage fish in the sport fishery for halibut out of Homer)
- Small mesh trawl surveys conducted by ADF&G around Kodiak Island and lower Cook Inlet to assess shrimp abundance (A large database from this program extends for some locations back to the 1960s for a large variety of species on the inner shelf)
- Aerial surveys with the use of conventional photography or other sorts of imaging (such as LIDAR) of shallow water aggregations of juveniles or adults
- Hydroacoustic sensors mounted on various ships of opportunity and fixed moorings
- Analysis of food items brought back to the nests of colonial seabirds (such as puffins) as an indication of the relative abundance of various forage fish species in particular areas
- Other net sampling programs that may be under way or contemplated

445 Models

Several hydrographic and circulation models have been or are being developed for the ACC (see also Chapter 8, and Appendix F) Models of the relationship of marine planktonic production to water column structure were developed in the EVOS SEA program (Eslinger et al 2001) and are expected eventually to be developed further under the GEM Program

The GLOBEC nutrient-phytoplankton-zooplankton (NPZ) 1-D and 3-D models are a suite of coupled biological-physical models concerned with the coastal region of the GOA They address effects of concern to the GEM Program in the ACC and offshore cross-shelf transport, upstream effects, local production, and conditions conducive to suitable juvenile salmon rearing habitat

Models of particular interest from the FOCI program are the 1-D and 3-D versions of the Shelikof NPZ models, and the GOA Walleye Pollock Stochastic Switch Model (SSM) (see Chapter 8, and Appendix F) The Shelikof NPZ models

are a set of coupled (biological and physical) models designed to examine hypotheses about pollock recruitment in the Shelikof Strait region The Pollock SSM is a numerical simulation of the process of pollock recruitment Of particular interest to the GEM Program is the identification by the SSM of three specific agents of mortality wind mixing, ocean eddies, and random effects Ecopath models developed by Okey, Pauly, and others at the University of British Columbia are also of interest, especially for PWS, but also for the GOA continental shelf and slope (excluding fjord, estuarine, and intertidal areas) (see Appendix F)

4 4 6 Candidate Core Monitoring Activities

It appears that the physical oceanographers have developed a level of understanding about inner-shelf dynamics that will allow the GEM Program to identify a core set of measurements, locations, and frequencies that address questions relevant to the GEM Program A core monitoring activity based on the partnership at the GAK1 station is likely Others may be added in FY 04 to FY 07 as identified by synthesis and the results of other programs (GLOBEC and FOCI stations and moorings) and as funding allows Full core monitoring in the ACC may not be fully operational until FY 07

4 4 7 Candidate Core Variables

The key variables in measuring the productivity of the ACC are temperature, insolation, salinity, fluorescence, and abundance of key forage species, including fish and zooplankton

4.5 Offshore: Alaska Current and the Subarctic Gyre

451 Conceptual Foundation for Offshore

In the offshore areas of the Alaska Current and the subarctic gyre, forcing by winds associated with the Aleutian Low Pressure System (Aleutian Low) has a profound effect on production and shoreward transport of plankton Production and shoreward transport of plankton are determined by the following

- Upwelling at the center of the subarctic gyre,
- Depth of the mixed layer (freshwater and solar energy input set up the mixed surface layer where primary production takes place),
- Possible upwelling of nutrients along the continental slope and at the shelf break where the shelf break front may direct upwelled water toward the surface, and

 Formation of eddies along the shelf break that may incubate plankton in a favorable environment for production and be mechanisms of exchange between offshore and shelf water masses Individual eddies may persist for months and are therefore potentially important in any one growing season

The contrasts in biological production and shoreward transport of plankton between intense and relaxed Aleutian Low conditions in the Alaska Current and the subarctic gyre are profound In periods with more negative atmospheric pressure that is keyed by the northeastern movement of the Aleutian Low into the GOA in winter, the following interrelated physical changes are observed

- Acceleration of the cyclonic motion of the Alaska Current and subarctic gyre,
- Increased upwelling in the middle of the subarctic gyre (and possibly along the continental shelf),
- Entrainment of more of the west wind drift (southerly portion of the subarctic gyre) northward into the GOA, rather than into the California Current system,
- Warmer surface-water temperatures and increased precipitation and fresh water runoff from land,
- Freshening of the surface layer,
- Increased winds and Ekman transport, and
- Increased onshore downwelling

These phenomena are thought to cause the following biological changes

- The result of the shallower mixed surface layer is that the spring plankton production is likely higher (remember that nutrients may not be limiting in the subarctic gyre),
- Greater standing crops of zooplankton and nekton that have been observed are probably made possible by the higher productivity of the phytoplankton,
- More food is available for the fish that feed on plankton and nekton, such as salmon, and
- Salmon populations track mean atmospheric pressure for the wintertime sea surface on scales of decades

In addition to the multi-decadal oscillations of atmospheric pressure, climate changes manifested in the northern GOA also include periodic El Niño's and the long-term warming of the oceans El Niño's have been associated with successful recruitment of a series of groundfish species, such as pollock, as well as some die-

off of seabirds. Because the El Niño phenomenon appears to be manifested solely in warming of the upper 200 m of the ocean, its biological effects are probably mediated through water stratification and its relationship to primary production and growth of larval fish.

The Alaska Current is centered over the shelf break, an area of high biological activity. The high concentrations of plankton observed at the shelf break, whether they result from accumulation of plankton originating further offshore, in situ production, or both, provide a rich resource for a variety of organisms and their predators. It is not clear that juvenile salmon feed in this regime, but adults of all salmon species certainly do. Other prominent organisms include sablefish, myctophids (lantern fish), sea lions, some seabirds, and whales. Well-developed benthic communities exist on the outer shelf, shelf break, and continental slope, including commercially exploited populations of shrimp, crab, cod, halibut, and pollock. Some fishing activities, such as bottom trawling, have the potential to do habitat damage and possibly limit populations of animals associated with the sea bottom. Issues associated with the balance between production and removals of commercially important species are of the utmost societal importance in Alaska and further ecological information, modeling, and synthesis centered on the Alaska Current regime is necessary.

Key Hypothesis: Natural forces (such as changes in the strength of the Alaska Current and Alaskan Stream, mixed layer depth of the gyre, wind stress and downwelling) and human activities (such as pollution) play significant roles in determining production of carbon and its shoreward transport.

4.5.2 Potential Offshore Questions:

a. What is the annual variability in the production of zooplankton in the offshore areas?

Specific Information Needs: Abundance of zooplankton on time and space scales appropriate to understanding annual production.

b. How are the supplies of inorganic nitrogen, phosphorus, silicon, and other nutrients essential for plant growth in the euphotic zone annually influenced by climate-driven physical mechanisms in the GOA?

Specific Information Needs: Measurements of inorganic nitrogen, phosphorus, silicon, and other nutrients on time and space scales appropriate to understanding annual variability.

c. What is the role of the Pacific High Pressure System in determining the timing and duration of the movement of dense slope water onto and across the shelf to renew nutrients in the coastal bottom waters?

Specific Information Needs: Synoptic information on sea level pressure and horizontal and vertical structure of density and nutrients on the

outer continental shelf and Alaska Gyre in relation to the ACC on appropriate time and space scales

d Is freshwater runoff a source of 1ron and silicon that 1s important to marine productivity in the offshore and adjacent marine waters?

Specific Information Needs Levels of biologically available silicon and iron from offshore water in relation to the ACC on appropriate time and space scales

e Does iron limitation control the species and size distribution of the phytoplankton communities in the offshore areas?

Specific Information Needs Levels of biologically available iron and species composition and size distribution of the phytoplankton communities from offshore water on appropriate time and space scales

453 Program Implementation

As with the ACC portion of the program, results of GLOBEC research need to be carefully considered before implementation of long-term monitoring in this broad habitat type This deliberate approach is reflected in the emphasis on synthesis for this habitat type in the early years of the proposed schedule for implementation (Table 4 4)

454 Prospective Partner Activities

Support of partners in existing monitoring projects may be necessary to obtain sufficient information for design of a monitoring program Because of the expense of initiating most offshore sampling programs, careful selection of partners and the use of long-term, low-frequency data gathering will be key strategies for understanding decadal-scale changes in this environment. Current efforts to apply the continuous plankton recorder technology on ships of opportunity in the GOA offer partnership opportunities. Extension of existing ships of opportunity programs to include measurement of variables of interest to the GEM Program is also a possibility

455 Models

The GLOBEC NPZ 1-D and 3-D models are discussed above in Section 4.4.5 A broader model addressing NPZ for the entire North Pacific is the North Pacific Ecosystem Model for Understanding Regional Oceanography, in which fluxes of nitrogen, silicon, and carbon will be tracked (see Appendix F)

	Monitori	ng Activity	Data	
Fiscal Year	Core	Partners	 Model	Management
2003	Synthesis	Monitor	Statistical(c)	Coordination (p)
		Research		
2004	Synthesis	Monitor	Statistical(c)	Coordination (p)
		Research		Archiving(p)
2005	Synthesis	Monitor	Statistical(c)	Coordination (p)
		Research	Numerical prototype (p)	Archiving (p)
				Distribution (p)
2006	Synthesis	Monitor?	Statistical(c)	Coordination (p)
			Numerical (p)	Archiving (p)
				Distribution (p)
2007	Synthesis	Monitor?		Archiving (p)
			Numerical (p)	Distribution (p)

Table 4 4 Proposed Implementation Schedule for Offsho

Notes

c = core (GEM Program supported) activity

p = partnership (jointly supported) activity

Prospective partners NPRB, NOAA (NMFS/NOS), Canadian Department of Fisheries and Oceans (CDFO), Japan Fishery Agency

Candidate core monitoring activities GLOBEC stations, Valdez-Long Beach Line, and other ships of opportunity

Candidate core variables nutrients detritus and plankton, temperature and salinity

4 5 6 Candidate Core Monitoring Activities

A reasonable oceanographic program in the ACC can probably be extended across the shelf break with the use of existing GLOBEC, FOCI, and OCC sampling stations, moorings, and transects The use of the Valdez-Long Beach line with oil tanker-mounted fluorescence and zooplankton sampling gear appears to be an attractive methodology for long-term, low frequency sampling over large spatial scales

4 5 7 Candidate Core Variables

Particularly crucial aspects of the offshore environment are physical processes and attendant biological responses at the shelf break and front (for example, extent of deep-water intrusion onto the shelf in the late summer and fall), the mixed layer depth in the Alaska Gyre in the spring-summer, and Ekman transport of offshore production onshore Measurements of basic variables are essential to understanding the role of these offshore aspects in affecting productivity of other habitats These variables include temperature, salinity, nutrients, detritus, and plankton

4 6 Conclusions. Moving the GEM Program Forward

To maintain the value of the long-term monitoring program, data collection and sampling protocols will necessarily be conservative, changing only with demonstration of substantial need, and then only after careful

deliberation Therefore, it is critical that GEM choose its monitoring projects with caution and deliberation The process envisioned will select research projects in the early years of the program that show promise of leading eventually to inclusion in the long-term monitoring program Research will be focused around initial research questions developed through the STAC and subcommittee processes (see Chapter 5), using the questions provided in this chapter as a starting point for deliberation In the initial years of the program, research projects will be selected through a solicitation process The Trustee Council will issue the request for proposals with recommendations from the STAC, the Public Advisory Commuttee and community involvement (see Chapter 5) As the GEM Program matures, requests for proposals may become increasingly targeted toward requests for specific research and monitoring projects and capabilities However, a portion of the available funds will continue to be allocated to the innovative synthesis and research proposals necessary to maintain high standards of scientific rigor and cost effectiveness Workshops and subcommittees will be important mechanisms to involve the public, including resource managers, communities and other stakeholders, in selecting research and monitoring activities

4.7 References

- Bailey, K M, P J Stabeno, and D A Powers 1997 The role of larval retention and transport features in mortality and potential gene flow of walleye pollock Journal of Fish Biology 51 135-154
- Bogard, SJ, PJ Stabeno, and JD Schumacher 1994 A census of mesoscale eddies in Shelikof Strait, Alaska during 1989 Journal of Geophysical Research 99 18243-18254
- Brown, E unpublished Institute of Marine Sciences, School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, Alaska
- Eslinger, D, RT Cooney, CP McRoy, A Ward, T Kline, EP Simpson, J Wang, and JP Allen 2001 Plankton dynamics observed and modeled responses to physical factors in Prince William Sound, Alaska Fisheries Oceanography 10 (Suppl 1) 81-96
- Finney, B P, I Gregory-Eaves, J Sweetman, M S V Douglas, and J P Smol 2000 Impacts of climatic change and fishing on Pacific salmon abundance over the past 300 years Science 290 795-799

c

5. PROGRAM MANAGEMENT: ADMINISTRATION, PUBLIC AND COMMUNITY ADVICE AND INVOLVEMENT, SCIENTIFIC GUIDANCE, AND DATA POLICIES

In This Chapter

- > Program Administration
- > Providing for Public and Community Advice and Involvement
- > Process for Providing Scientific Advice, Review and Management
- > Establishing Data Management Office and Policies

5.1 Administration The administration and management of the GEM Program must be cost-efficient, have a high degree of scientific credibility, and provide for public access and accountability

The GEM Program will be administered by a core professional staff that is not directly affiliated with any particular agency, institution, or program This is currently the case with the management of the *Exxon Valdez* Oil Spill Trustee Council Office (Figure 5 1) An executive director will oversee the financial, program management and administrative, scientific, and public involvement aspects of the program The executive director and staff, while housed for administrative purposes in a single government agency, will work under a cooperative agreement for all six trustees The Trustee Council and staff will actively solicit advice on science and policy matters, including review of monitoring and research activities, from experts, including the Scientific and Technical Advisory Committee (STAC), and from the public, including the Public Advisory Committee (PAC)

511 The Work Plan

A Work Plan will document the current activities that implement the program As projects for monitoring and research are approved by the Trustee Council, they will become part of the Work Plan The Trustee Council may be asked to adopt a new Work Plan each year, or they may be asked to adopt new groups of projects into the Work Plan on a periodic basis

GEM PROGRAM IMPLEMENTATION

External Review Committee (every 5-10 years)

EVOS Trustee Council

Director & Staff

PAC • 5°-cheholders • Communitie • Scienti ts

Scientific & Technical Advisory Committee Public Review & Comment

Ad hac Habitat Data working Subcommittee Managument srouts Subcommittee

Oil Effects Subcommittee

Figure 5.1 The organizational elements involved in GEM implementation Modified in response to comments from the Nation Research Council

512 Proposal Development and Evaluation Process

The proposal development and evaluation process will have the following elements or steps, which are also shown in Figure 5.2 As implementation of the GEM Program begins, however, these steps may be modified as efficiencies and improvements are found

- A "State of the Gulf" workshop will be held periodically, at which the current status of the health of the Gulf of Alaska (GOA) ecosystem will be assessed Project investigators, peer reviewers, resource managers, stakeholders, and the public will be invited to this meeting, at which research and monitoring results will be presented and discussed In some years, this workshop will be replaced by or augmented with a process of consultations and workshops with various committees and work groups of science and public advisors to evaluate and affirm or revise priorities
- An *Invitation to Submit Proposals*, which will specify the types of proposals that are priorities for consideration to implement the mission and goals of the GEM Program, will be issued periodically Research proposals are envisioned to be of finite duration and have short-term goals (for example, 2 to 5 years) Monitoring projects will be evaluated and renewed on longer time scales (such as once every 5 years) The *Invitation(s)* will be the vehicle

for notifying the scientific community, the public and others that proposals will be considered during a certain period of time

- Proposals received in response to the *Invitation* will be circulated for technical peer review (see below) In addition, proposals will be reviewed by the STAC and appropriate subcommittees for their ability to contribute to the information-gathering needs of the central hypothesis and questions, and also for how they contribute to meeting the programmatic goals and strategies of the Trustee Council (see Chapters 1 and 3), such as promoting community involvement, developing resource management applications, and leveraging funds from other sources Past performance of principal investigators will be assessed Staff will also review all budgets
- Comments from the PAC and the general public will be solicited A reasonable period of time for public comment will be built into the review process
- The executive director will present to the Trustee Council the recommendations of the STAC and PAC, a summary of any additional public comment, and additional recommendations if appropriate

The Trustee Council, after receiving advice from its public and scientific advisors and staff, will vote on which proposals to fund

GEM Proposal Evaluation Process

STATE OF THE GULF WORKSHOPS AND REPORTS

WORK PLAN

PROPOSAL

INVITATION

TRUSTEE COUNCIL ADOPTION

PUBLIC REVIEW
 Public Advisory
 Committee
 General Public

TECHNICAL REVIEW • Paer Review • Committees

* Staff

STAFF RECOMMENDATION

Figure 5.2 GEM Proposal Evaluation Process

CHAPTER 5

513 Reports and Publications

Annual and final reports will be required for all projects, following established procedures To ensure that investigators are making satisfactory progress toward project objectives, staff will review annual reports In addition, annual reports may possibly be sent out for independent peer review Final reports will be subject to independent peer review, and comments from the independent peer reviewers must be addressed in the final versions of final reports All final reports will be archived at the Alaska Resources Library and Information Service (ARLIS) and available on the Trustee Council's web page

Publications in the peer-reviewed literature will be expected of program participants

514 Peer Review

Each project, as well as some annual and all final reports, will be peer-reviewed by appropriate experts identified by staff who, as a rule, are not also conducting projects funded by the Trustee Council The peer review may be either paid or volunteer, whichever is most expeditious and appropriate The external peer review process will provide a rigorous critique of the scientific merits of all monitoring and research proposals and selected reports Review functions may be carried out in writing, by telephone and occasionally on site or in person

Special review panels may be convened from time to time to evaluate and make recommendations about aspects of the GEM Program At other times, special panels may meet with project investigators and others to fully explore particular topics, problems, or projects

515 External Program Review

The Trustee Council is committed to review of the program by an outside entity, such as the National Research Council, at periodic intervals This review will look at the program's structure and implementation to ensure that the GEM mission and goals are being achieved

5 2 Public and Community Advice and Involvement The importance of public participation in the Trustee Council process, as well as establishment of a public advisory group to advise the trustees, was specifically recognized in the *Exxon Valdez* settlement and is an integral part of the agreement between the state and federal governments

The Trustee Council is committed to public input and public outreach as vital components of the long-term GEM Program Figure 5.1 illustrates the role of public participation in the GEM Program

5 2 1 Public Advisory Committee

The Public Advisory Group (PAG) in effect from 1991 – 2002 has 17 members representing 12 interest groups and the public at large, as well as two ex-officio members from the Alaska Legislature The charter for a new Public Advisory Committee (PAC) will be certified in September 2002 The PAC will consist of 20 members, representing 14 distinct public interests The PAC will meet at least twice a year to provide broad program and policy guidance to the Trustee Council and staff on the overall development and progress of the GEM Program The group will take an active role in setting priorities and ensuring that the overall program is responsive to public interests and needs

5 2 2 Public Advice

The Public Advisory Committee is not the only source of public advice for the Trustee Council Opportunities for public advice and comment are incorporated throughout the process The Trustee Council is a public entity subject to the State of Alaska Open Meetings Act and corresponding federal laws All meetings are public, noticed to the public, and include a formal public comment period Newsletters, annual reports, public meetings in communities in the spill-affection region, and the Trustee Council's Web site (www oilspill state ak us) are all tools to promote and encourage public input and participation

5 2 3 Public and Community Involvement

The Trustee Council is committed to incorporating public and community involvement in the GEM Program at all levels This means not just providing advice on proposals and policies, but involving communities early on in developing research hypotheses and questions and helping decide what variables to monitor and in what locations

Developing a program that includes extensive community involvement will be a challenge, and will necessarily evolve over time The Trustee Council is funding several planning projects in FY 02-FY 03 to further develop ways to better incorporate local and community involvement in the GEM Program

Ongoing efforts include, but are not limited to, these elements

- Community meetings where community members are asked to identify and provide information on issues and questions that are most important to them
- Public, stakeholder and community membership on the Public Advisory Committee Expansion of the committee size to allow greater participation by communities and stakeholders
- Community representation on all subcommittees and work groups used in developing and implementing the GEM Program Making funding available to encourage participation in subcommittees and work groups

- Joint meetings between the Scientific and Technical Advisory Committee and the Public Advisory Committee to foster communication between scientific interests and community interests
- Membership of at least one STAC member on the PAC
- A proposal solicitation and review process that encourages communitybased proposals
- The inclusion of community-based monitoring programs and traditional knowledge in the GEM Program, especially in the watershed and intertidal/subtidal habitats

5 3 Scientific Advice, Review and Management

In addition to peer review of individual proposals and public review and advice, a committee and work group approach will be used to guide GEM Program development and implementation

5 3 1 GEM Science Director

The GEM Program Science Director will work closely with other scientific advisory bodies, and will be the staff member tasked with overseeing implementation of the science program and informing interested communities of the program's results The Science Director will work with other Trustee Council staff in overseeing implementation of research and monitoring activities, ensuring timely delivery and dissemination of research results, and maintaining the GEM database The Science Director makes recommendations to the Executive Director and the Trustee Council on program implementation and development

5 3 2 Scientific and Technical Advisory Committee (STAC)

The STAC is a standing committee that is expected to provide the primary scientific advice to the Executive Director on how well the collection of proposed monitoring and research projects (the work plan) and the GEM Program meet the mission and goals of the program and test the conceptual foundation

The STAC has three primary functions

- 1 Provide leadership in identifying and developing testable hypotheses relevant to the conceptual foundation of the GEM plan, consistent with the mission, goals and policies of the Trustee Council.
- 2 Make recommendations to the Executive Director and GEM Science Director on preparation of the science program and implementation plans, proposal solicitation and peer review, and selection of research, monitoring, synthesis, modeling and other studies best suited to meeting the goals of the GEM Program

3 Provide support and oversight to subcommittees and ad hoc work groups as needed (see below)

The STAC is composed of emeritus and senior scientists and others selected primarily for their broad expertise and leadership who serve for four-year, staggered renewable terms At least one of the scientists serving on the STAC also serves on the PAC The STAC members are not principal investigators for GEM projects Institutional and professional affiliations are of interest in selecting members, because connections to other marine science programs are valuable for ensuring collaboration and coordination on GEM Program implementation The GEM Science Director is a co-chair and non-voting member of the STAC

533 Subcommittees

Subcommittees are standing committees organized to address specific aspects of the GEM Program, to facilitate coordination among scientists, resource managers, and the public and communities, and to help the STAC provide leadership and oversight for the program

The functions of the subcommittee(s) are to

- Recommend to the STAC testable hypotheses, items for invitation and peer reviewers,
- Identify and help guide implementation of core monitoring stations and variables that are relevant to the key questions and testable hypotheses,
- Advise on, or possibly convene special review panels or work groups about, aspects of the GEM Program

The subcommittees are composed of scientists, resource managers, educators, and community members selected for knowledge, expertise or familiarity with the issue around which the subcommittee is created For example, subcommittees could be developed around each of the broad habitat types (watersheds, intertidal and subtidal, Alaska Coastal Current (ACC), and offshore) or just one overall habitat, lingering oil effects, data management systems and information technology, modeling, monitoring or other GEM Program areas Subcommittee members can be principal investigators on current GEM funded projects Institutional, professional, and other affiliations will also be of interest in selecting members to promote collaboration and cooperation

534 Work Groups

The STAC and subcommittees may periodically form ad hoc work groups to develop specific products as requested Work groups could also be charged with solving a particular problem in a finite amount of time, such as the proper location of an oceanographic mooring

535 Workshops

The STAC or subcommittees may recommend organizing workshops to provide input on core variables for monitoring, research activities, community involvement strategies, and other program elements The GEM Program anticipates that workshops will play an important role in implementing the science program and disseminating the results of GEM research to resource managers and communities

5.4 Data Management and Information Transfer

The Data Management Office will be an essential component of the GEM Program The office will be headed by a Data Systems Manager who will evaluate continuously the evolving information management needs of the GEM Program, and identify and recommend cost-effective solutions to

the Executive and Science directors Over time the mix of in-house supporting staff and out-sourced tasking may vary, but there will be a long-term commitment to providing consistent and high quality data management support (data quality, archive, and analysis) to the GEM Program Staff in the Data Management Office will coordinate with other agencies in regard to data management and information transfer, manage computing resources, develop software programs, and maintain web sites in support of the GEM Program In addition, staff in the Data Management Office will be responsible for developing and ensuring compliance with data policies and procedures

Data management and information transfer policies are an integral part of GEM Program management Clear and effective approaches for information gathering, archiving and dissemination are essential to the successful operation of a long-term ecosystem science project such as the GEM Program Because the GEM Program is regional in geographic scope, with goals of cooperation, coordination, and integration with existing marine science programs, data management and information transfer policies are to be compatible with, and similar to, existing norms for state, federal, and nongovernmental marine science programs Whenever possible, existing norms will be adapted or adopted for use by the Trustee Council Standards adopted by the Federal Geographic Data Committee, GLOBEC, and the U S Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP), and other organizations will be considered for developing GEM data management and information transfer policies (Options and procedures for data management and information transfer are considered in more detail in Chapter 9)

The GEM data management and information transfer policies will incorporate the following broad elements

 A commitment to making data and models available in a well documented and understood form

- Full and open sharing of data and models at low cost, after verification and validation
- Timely availability of data and models
- Acceptance of and adherence to the data policies as a condition for participation in the GEM Program and receipt of funding
- Adherence to data collection and storage standards
- Availability of data and models on the GEM public web site, or through a national public archive
- Long-term archiving of all data and models in a designated storage facility
- Proper metadata, including identification of the origin of all data and models with a citation

6. INTRODUCTION TO THE SCIENTIFIC FOUNDATION

In This Chapter

- > Leading Hypotheses in Marine Ecosystems
- Principal Ecological Concepts

6.1 Introduction

GEM's mission, as defined in Chapter 1, is to

Sustain a healthy and biologically diverse marine ecosystem in the northern Gulf of Alaska (GOA) and the human use of the marine resources in that ecosystem through greater understanding of how its productivity is influenced by natural changes and human activities

As developed in response to this mission, a comprehensive, general conceptual foundation is the basis for the GEM Program (Chapter 2) The validity of the conceptual foundation is essential to the success of the GEM Program by virtue of its use to generate the hypotheses and questions that drive monitoring and research Chapter 6 begins the process of establishing the scientific credentials of the conceptual foundation by presenting the leading hypotheses on structure and function of marine ecosystems and the principal ecological concepts on which it is based Chapter 7 continues and concludes that process with a presentation and synthesis of relevant scientific literature

6.2 Some Leading Hypotheses This section reviews leading hypotheses that explain changes in biological production as a result of natural and human activities

6 2 1 Match-Mismatch Hypothesis

The essence of the match-mismatch hypothesis is

- Populations of organisms are adapted to certain environmental conditions
- When those conditions change rapidly, predator and prey populations may not track in the same way

• As a result, transfer of energy into the higher levels of the food web is compromised

This hypothesis has been proposed by Mackas to explain changes in production with the slow shift to earlier emergence of *Neocalanus* copepods at Ocean Station P in the last several decades (Mackas et al 1998) The match-mismatch hypothesis was also invoked by Anderson and Piatt to explain ecological changes observed in a long time series of small-mesh trawl sampling around Kodiak Island and the Alaska Peninsula (Anderson and Piatt 1999)

6 2 2 Pelagic-Benthic Split

Eslinger et al (2001) suggested that strong inshore blooms of spring phytoplankton that occur in conditions of strong stratification put more biological production into the benthic ecosystem, in contrast to weaker, but more prolonged blooms, that occur in cool and windy growing seasons. Under the latter conditions, it has been proposed that biological production is more efficiently used by the pelagic ecosystem and that relatively less of the production reaches the benthos. It is conceivable that during a series of years in which one condition is much more prevalent than the other, food might be reallocated between pelagic-feeding and benthic-feeding species and be reflected in changes in these populations. Strong year classes of particular long-lived species also might result from conditions of strong stratification causing more biological production or weaker blooms, leading to dominance of the system by certain suites of species

6 2 3 Optimum Stability Window Hypothesis

Gargett (1997) proposed that there is a point in the range of water stability below which water is too easily mixed downward, resulting in less than maximum productivity, and above which the water is stratified to the extent that it resists wind mixing Gargett proposed that the fluctuating differences in salmon production between the California Current and subarctic gyre domains are ultimately the result of these two systems being on different parts of this response curve at different times

6 2 4 Physiological Performance and Limits Hypothesis

A number of explanations for long-term change more simply propose that the abundance of certain species, mainly fish, is a direct response to their physiological performance at different temperatures. Under this hypothesis, the changes in dominance of cod-like fishes and crustaceans that were seen in eastern Canada around 1990 and in the northern GOA around 1978 were initially a response to warm (ascendancy of gadids) or cold (ascendancy of crustaceans) water temperatures. In other words, the main agents of change are the direct effects of water temperatures acting on physiological functions of individuals, in addition to the combined effects of freshwater input, winds, and temperature on ecological processes.

6 2 5 Food Quality Hypothesis

The food quality hypothesis is also referred to as the junk food hypothesis It attributes declines of many higher trophic-level organisms observed in the last several decades (harbor seals, sea lions, and many seabirds) to the predominance of suites of forage species that have low energy content (less lipid) than previous food sources (for example, gadids and flatfishes) Consistent with this hypothesis is evidence from the Trustee Council's Alaska Predator Ecosystem Experiment program, which showed that it takes about twice as much pollock as herring to raise a kittiwake chick to fledging during the nesting season (Piatt and Van Pelt 1998, Piatt 2000, Romano et al 2000) With the relative rarity of capelin and sand lance in the diets of seabirds in Prince William Sound (PWS) during the last several decades, it seems that many of the population declines might be at least partially attributable to the role of these fatty fish in seabird diets The change in food sources has been advanced for marine mammal populations that have been in decline

6 2 6 Fluctuating Inshore and Offshore Production Regimes Hypothesis

Although the fluctuating inshore and offshore production regimes model is closely related to the Gargett hypothesis of an optimum stability window, it proposes that under the same set of atmospheric forcing conditions opposite production effects are seen inshore and offshore Figures 6 1a-d illustrate some features of this model

The model was developed from observations during the last several decades that populations of many seabirds, harbor seals, and sea lions, which forage mainly in inshore waters, have been declining while marine survival of salmon and high levels of offshore plankton and nekton suggested that offshore productivity was very high It is proposed that the various manifestations of climate forcing have combined since about 1978 (positive Pacific Decadal Oscillation [PDO]) to make the ocean more productive offshore Characteristics of the offshore ocean include more upwelling of deep nutrients and a mixed surface layer that is shallower and more productive These same climatic conditions are proposed to have made the inshore areas of the GOA less productive During the positive PDO, greater freshwater supply (precipitation on the ocean and terrestrial runoff) results in greater-thanoptimal nearshore stratification Also, during the positive PDO, greater winds cannot overcome the stratification during the growing season, but do inhibit the relaxation of downwelling Therefore, fewer nutrients are supplied to the inshore regime from the annual run up of deep water onto the shelf During a negative PDO, the opposite pattern in biological response results from a colder, less windy, and drier maritime climate



Figure 6.1a Schematic of proposed fluctuating inshore and offshore production regimes in the GOA showing relative changes in the physical processes during a positive PDO (strong wintertime low **pressure**).



Figure 6.1b Schematic of proposed fluctuating inshore and offshore production regimes in the GOA showing relative changes in the biological consequences of conditions during a positive PDO (strong wintertime low pressure).

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Figure 6.1c Schematic of proposed fluctuating inshore and offshore production regimes in the GOA showing relative changes in the physical changes during a negative PDO (weak wintertime low pressure).



Figure 6.1d Schematic of proposed fluctuating inshore and offshore production regimes in the GOA showing relative changes in the biological consequences of conditions during a negative PDO (weak wintertime low pressure).

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CHAPTER 6

627 627 Human Impacts Hypotheses

Hypotheses on human impacts explain alterations of ecosystems as the result of human activities Changes in species composition, alteration of the relative abundances of species and their food species, and changes in production and productivities of populations of plants and animals are widely accepted as being consequences, to some degree, of human activities (Jackson et al 2001) An important, constant dilemma in the history of natural resource management is distinguishing between human and non-human causes of fluctuations in production of biological resources through time (Mangel et al 1996, NRC 1999) Indeed, this classic dilemma is the origin of the central hypothesis for GEM A large body of existing hypotheses, summarized below, view specific human activities, such as harvesting and pollution, as causes of changes in biological production that are direct or indirect sources of mortality for plant and animal populations, including those of humans

6.2.7.1 Theory of Sustainable Fishing

According to the theory of sustainable fishing, it is possible to strike a balance between the losses caused by human and natural forces, and the gains due to reproduction and growth, such that the abundance of a species in an area remains constant through time Also known as the *deterministic theory of fishing* (Quinn and Deriso 1999), this theory has intellectual origins in the equation of logistic population growth first introduced in this context in 1837 (Quinn and Deriso 1999), and in even older concepts of population regulation that can be traced to the late eighteenth century (1798) It is well known that the ideal of a constant population size regularly producing predictable amounts of biomass for human consumption in perpetuity is rare in the case of wild populations (1973) (Ricker 1975, Quinn and Deriso 1999) Nonetheless, this ideal is the basis for the legal, scientific and popular concepts of sustainable uses of all types of renewable natural resources, and it motivates the need for GEM to distinguish between, and to help quantify, natural and human caused sources of mortality

The original basic theory of sustainable fishing has been expanded to include the concept that the process of fishing sustainably for one species may not constitute fishing sustainably for other species (Quinn and Deriso 1999) For example, one of the operating hypotheses for investigations of causes for decline of the Steller sea lion in the Gulf of Alaska by the National Marine Fisheries Service (NMFS 2002) is that the declines are due to commercial fisheries out-competing the sea lion for food Starvation and associated nutritional stress are hypothesized to be direct agents of mortality and causes of lowered reproductive rates

Fisheries are also hypothesized to compete with terrestrial species by lowering the overall productivity of watersheds in the GEM region and adjacent areas, thereby also reducing the production of salmon that originate in those watersheds (Finney 1998, Finney et al 2000, Gresh et al 2000, Finney et al 2002) Transport of nutrients from the marine environment to the watersheds by anadromous species, principally Pacific salmon, is thought to be important for sustaining the overall productivity of some types of watersheds, including the salmon species themselves (Mathisen 1972, Kline et al 1990, Kline et al 1993, Bilby et al 1996, Mathisen et al 2000) Note that application of the deterministic theory of fishing without inclusion of nutrient-effects could lead to a downward spiral in the annual production of the salmon species being managed, instead of the constant population predicted by the theory (Finney et al 2000) As the salmon fishery removes nutrients from the watershed, the carrying capacity of the watershed for salmon is lowered, thereby causing the deterministic theory of fishing to prescribe to managers a lower "sustainable" level of spawners. The lower level of spawners means even less nutrients and a lower level of productivity for the watershed. Lower productivity means an even lower estimate of "sustainable" spawners from the theory, leading to less nutrients for the watershed, and a downward spiral in salmon production

6.2.7.2 Ubiquitous Distribution and Northern Concentration of Anthropogenic Contaminants Hypothesis

Transport of contaminants from sites of release in lower latitudes by atmospheric and oceanic processes and through biologic pathways concentrates anthropogenic contaminants in northern ecosystems in even the most remote, uninhabited regions of the northern hemisphere, including the GEM region (Crane and Galasso 1999) Contaminants produced by human activities in humanpopulated areas, principally radionuclides, organochlorines, and heavy metals, alter ecosystems in all parts of the world by changing rates of biological production (productivities), as agents of direct and indirect mortality For example, one of the operating hypotheses for investigations of causes for decline of the Steller sea lion in the Gulf of Alaska by the National Marine Fisheries Service (NMFS 2002) is that the declines are due to reproductive impairment and mortality resulting from contaminants from distant and local sources Also in the GEM region, two organochlorines, polychlorinated biphenyls (PCB) and the pesticide dichlorodiphenyltrichloroethane (DDT), were found to be transported to remote localities in the Copper River drainage (circa 63º N 145º W) by migratory fish species and by wind (Ewald et al 1998) Both DDT and PCB concentrations per individual increase as they move through the food chain, with both at times being found in very high concentrations near the top of the food chain in birds and mammals, including humans DDT is well known to cause reproductive impairment, especially in birds Metabolites of DDT (p,p'-DDE) were found in blubber taken by biopsy of killer whales in Prince William Sound in concentrations high enough (21 – 210 ppm) to suggest reproductive impairment and infant mortality, and relatively high concentrations of other organochlorines were also found (Ylitalo et al 2001) PCB is known to cause pathological changes in reproductive and immune systems For example, relatively high concentrations of PCB in the milk fat of Inuit women are consistent with the high incidence of infectious disease among Inuit infants in Arctic Quebec, Canada (Dewailly et al 1993)
6.2.7.3 Anthropogenic Distribution of Exotic Species Hypothesis

According to this hypothesis, human transport of vertebrate and invertebrate species causes changes in ecosystems by radically changing species composition and relative abundances of species through alterations of food web (trophic) pathways and interactions The food webs of the GEM region appear to be susceptible to alteration by certain freshwater and anadromous fish species that are known to be able to complete their life cycles at these latitudes Atlantic salmon, northern pike, and yellow perch (ADF&G 2002) Anthropogenic introductions of both northern pike and yellow perch have been documented, and Atlantic salmon have become established to the south in British Columbia as a result of failed pen rearing operations In addition, a number of other vertebrate and invertebrate animal species and a number of freshwater and salt marsh plants may be able to establish themselves in the GEM region if introduced (ADF&G 2002)

6.2.7.4 Cumulative Human Effects Hypothesis

Individual instances of fishing, introduction of contaminants, transport of exotic species, and other human impacts that are not alone sufficient to cause discernible changes in the ecosystem are inexorably accumulated through time to levels that can and do profoundly alter the habitats and trophic pathways of the ecosystem, thereby reducing production of many animal and plant species As a corollary, cumulative effects are directly proportional to human population density and they can reach levels that prohibit any sustainable human use of certain species (Mangel et al 1996) For example, many salmon populations near and adjacent to human centers in the Pacific Northwest (California, Oregon, Washington, Idaho) are now categorized by the federal government as threatened or endangered, and can no longer provide a harvestable surplus with respect to humans, (Stouder et al 1997), whereas salmon populations in areas of low human densities are producing historical record-high levels of harvest (Mundy 1996) Further it is self-evident that environments around urbanized areas (such as Los Angeles, Puget Sound, Boston Harbor, San Francisco Bay, and New York Bight) and watershed systems (Columbia River Basin and San Joaquin River) have highly altered ecosystems that contain invasive exotic species, individuals impaired by contamination, and fish populations that have been highly altered by the combined effects of various human impacts It appears that this degradation occurred over a long period of time and as a result of the combined impacts of many different human activities

6.3 Principal Ecological Concepts

Production at the base of the food web, primary productivity, is strongly influenced by physical forces, and ultimately determines ecosystem productivity However, the abundance of any particular population within the food web

depends on three things immediate food supply (prey), removals (mortality), and habitat

All animals and plants in the oceans ultimately rely on energy from the sun or, in some special cases, on chemical energy from within the earth The amount of solar energy converted to living material determines the level of ecosystem production (total amount of living material and at what rate it is produced) As a rule of thumb, populations of individual species (such as salmon, herring and harbor seals) cannot exceed about 10 percent of the biomass of their prey populations (about the average conversion of prey to predator biomass) Therefore, the amount of energy that gets incorporated into living material and the processes that deliver this material as food and energy to each species are key factors influencing reproduction, growth and death in species of concern Increases in prey, with other factors such as habitat being equal, generally allow populations to increase through growth and reproduction of individual members At the same time, there are factors that lead to decreases in populations, loss of suitable habitat, decreases in growth, reproduction and immigration, and increases in the rate of removal (death and emigration) of individuals from the population As a result, the combined effects of natural forces and human activities that determine food supply (bottom-up forces), habitat (bottom-up and top-down forces), and removals (top-down forces) determine the size of animal populations by controlling reproduction, growth, and death

6 3 1 Physical Forcing and Primary Production

The vast majority of the energy that supports ecosystems in the GOA comes from capture, or fixation, of solar energy in the surface waters How much of this energy is captured by plants in the ocean's surface layer and watersheds and passed on ultimately determines how much biomass and production occur at all levels in the ecosystem Capture of solar energy by plants in the oceans and watersheds and the conversion of solar energy to living tissue (primary production) depends on several interacting forces and conditions that vary widely from place to place, season to season, and year to year as well as between decades Needless to say, without a clear understanding of how these changes occur, it will not be possible to understand the most important aspects of ecological change in the GOA. The process of capturing solar energy is explained below

First, in the ocean, primary production occurs only in the relatively shallow lit photic zone (a few hundred feet) In watersheds, cloud cover and shading play a larger role in variability of productivity Second, plants that fix this energy, by using it to make simple sugars out of carbon dioxide and water, depend on nutrients which are absorbed by the plants as they grow and reproduce Solar energy that is not captured by plants in the ocean warms the surface waters, making it less dense than the water beneath the photic zone, which causes layering of the water masses A continuous supply of nutrients to the surface waters is necessary to maintain plant production Likewise, terrestrial plants depend on nutrients carried from the ocean by anadromous fish Because the deep water of the GOA is the main reservoir of nutrients for shallow waters, and apparently also an important source for watersheds, the processes that bring nutrients to the surface and into the watersheds are key to understanding primary, and, therefore, ecosystem productivity Changes in nutrient supply on time scales of days to decades and spatial scales from kilometers to hundreds of kilometers have important impacts on primary production, generating perhaps as much as a thousand-fold difference in the amount of solar energy that is captured by the living ecosystem Nutrient supply from the deep water is influenced by the properties of the shallower water above (mainly because of the decreasing density of the water toward the surface) Nutrient supply is also influenced by physical forces that can overcome the density differences between deep and shallow waternamely, wind acting on the water surface and tidal mixing For watersheds, nutrient supply apparently depends strongly on biological transport of marine nitrogen by salmon, which die and release their nutrients in fieshwater, as well as other sources (such as nitrogen fixers)

As demonstrated in the scientific background in Chapter 7, the knowledge of nutrient supply in the GOA, both how it occurs and how it may be changed on multi-year and multi-decadal scales, is very rudimentary As the energy of the wind and tides mixes surface and deeper water, it not only brings nutrients to the surface layers, but also mixes algae that fix the solar energy down and out of the photic zone, which tends to decrease primary production. Therefore, other factors being equal, continuous high primary production in the spring-summer growing season is a balance between enough wind and tidal mixing to bring new nutrients to the surface, but not so much wind or tidal mixing that would send algal populations to deep water. The seasonal changes in downwelling, solar energy, and water stratification that set up the annual plankton bloom are described in Section 7.1.4, of the scientific background. As noted in that section, however, it is not well understood how differences in physical forces from year to year and decade to decade change primary production many-fold in any particular place.

6 3 2 Food, Habitat, and Removals

Increases in immediate food supply (prey) will translate to population increase, all other factors being equal The allocation of energy in each individual is key to growth of the population it belongs to Food supply is converted into population biomass through growth and reproduction of individuals in specific favorable habitats Therefore, factors in the habitat such as water temperature, distribution of prey, and contaminants that can influence the allocation of food energy to the following activities will influence the population size chasing and capturing prey, maintaining body temperature (for homeotherms and other physiological processes), growth, and reproduction

Removals are all the processes that result in loss of individuals from the population, or mortality These processes include death from contamination, human harvest, predation, disease, and competition For example, harvest of a large proportion of the largest and most fecund fish in a population will soon decrease the population, as will a virulent virus or the appearance of a voracious predator in large numbers

Also included under the category of removals is any factor that negatively affects growth or reproductive rate of individuals, because such factors can decrease population size Contaminants are considered potential removals because of the following possible effects

- Causing damage that makes energy utilization less efficient and requires energy for repairs,
- Interfering with molecular receptors that are part of the regulatory machinery for energy allocation,
- Damaging immune systems that make disease more likely, and
- Outright killing of organisms at high concentrations

Habitats in marine and freshwater environments are ultimately controlled by temperature and salinity, as modified by many other biological, physical and chemical factors Basic physiological functions such as respiration and assimilation of nutrients from food occur only within certain boundaries of temperature and salinity As stated in Section 6.2, a number of hypotheses on the origins of longterm change relate the abundance of certain aquatic species to their physiological performance in different temperatures. For example, changes in dominance of codlike fishes and crustaceans in eastern Canada around 1990 and in the northern GOA around 1978 were explained as positive responses of gadids to increasingly warm temperatures. Using the same reasoning, the ascendancy of crustaceans such as shrimp in the GOA in the 1950s and 1960s, and in eastern Canada during the 1990s, have been attributed to cooling water temperatures.

On the basis of the first principles of physics, chemistry, and biology, temperature and salinity must be agents of change in biological resources through effects relating to physiological functions in individual plants and animals Effects on individuals add to the combined effects of freshwater input, winds, and temperature on ecological processes The preceding ecological concepts have been applied directly to the GOA ecosystems to show how the system and its plant and animal populations are controlled in the conceptual foundation, Chapter 2

633 Trophic Structure

The principal trophic groups of the northern GOA are represented by the analysis of Okey and Pauly for PWS (Okey and Pauly 1999) The upper trophic levels (3 5+) are dominated by large vertebrates, including toothed whales, harbor seals and sea lions, seabirds, sharks, and fish species that are large as adults (Table 6 1) Primary consumers on trophic levels between 1 (primary producers) and 3 (tertiary) include jellyfish, zooplankters (including larvae of crustaceans and fish), infauna, and meiofauna The primary sources of food in the northern GOA are phytoplankton, macroalgae and eelgrass, and detritus The species of the dominant biomass are macroalgae and eelgrass, followed closely by shallow and deep infauna, deep epibenthos, and herbivorous zooplankton. In terms of

production per biomass (P/B), the dominant species groups are clearly the phytoplankton, followed by the herbivorous zooplankton. In terms of food consumption per biomass (Q/B), invertebrate-eating birds top the list, followed by small cetaceans and pinnipeds, and herbivorous zooplankton. Using this concept of the trophic structure of the northern GOA, data on the lower trophic levels (<3 5) are extremely important to detecting and understanding change in valued marine-related resources.

Group name	Trophic Level	Biomass (t km ² year ¹)	P/B (yr ¹)	Q/B (yr ¹)
Orcas	4 98	0 003	0 050	8 285
Sharks	4 81	0 700	0 100	2 100
Pacific halibut	4 59	0 677	0 320	1 730
Small cetaceans (porpoises)	4 52	0 015	0 150	29 200
Pinnipeds (harbor seal & sea lion)	4 45	0 066	0 060	25 550
Lingcod	4 33	0 077	0 580	3 300
Sablefish	4 29	0 293	0 566	6 420
Arrowtooth flounder adult	4 25	4 000	0 220	3 030
Adult salmon	4 17	1 034	6 476	13 000
Pacific cod	4 14	0 300	1 200	4 000
Arrowtooth flounder juvenile	4 01	0 855	0 220	3 030
Avian predators	3 89	0 002	5 000	36 500
Seabırds	3 78	0 011	7 800	150 60
Deep demersal fish (skates and flatfishes)	3 78	0 960	0 930	3 210
Pollock age 1+	3 76	7 480	0 707	2 559
Rockfish	3 74	1 016	0 170	3 440
Baleen whales	3 65	0 149	0 050	10 900
Salmon fry 0-12 cm	3 51	0 072	7 154	62 800
Nearshore demersal fish (greenling and sculpin)	3 35	4 200	1 000	4 240
Squid	3 26	3 000	3 000	15 000
Eulachon	3 25	0 371	2 000	18 000
Sea otters	3 23	0 045	0 130	117 000
Deep epibenthos	3 16	30 000	3 000	10 000
Capelin	3 11	0 367	3 500	18 000
Adult herring	3 10	2 810	0 540	18 000
Pollock age 0	3 07	0 110	2 340	16 180
Shallow large epibenthos	3 07	3 100	2 100	10 000
Invertebrate eating bird	3 07	0 005	0 200	450 500
Sandlance	3 06	0 595	2 000	18 000

 Table 6 1 Representative Trophic Groups of the Northern Gulf of Alaska

 Arranged in Descending Order by Trophic Level

Group name	Trophic Level	Biomass (t km ² year ¹)	P/B (yr ¹)	Q/B (yr ¹)
Juvenile herring	3 03	13 406	0 729	18 000
Jellies	2 96	6 390	8 820	29 410
Deep small infauna	2 25	49 400	3 000	23 000
Near omni-zooplankton	2 25	0 103	7 900	26 333
Omni-zooplankton	2 25	24 635	11 060	22 130
Shallow small infauna	2 18	51 500	3 800	23 000
Meiofauna	2 11	4 475	4 500	22 500
Deep large infauna	2 10	28 350	0 600	23 000
Shallow small epibenthos	2 05	26 100	2 300	10 000
Shallow large infauna (clams etc)	2 00	12 500	0 600	23 000
Near herbi-zooplankton	2 00	0 136	27 000	90 000
Herbi-zooplankton	2 00	30 000	24 000	50 000
Near phytoplankton	1 00	5 326	190 000	0 000
Offshore phytoplankton	1 00	10 672	190 000	0 000
Macroalgae/eelgras	1 00	125 250	5 000	0 000
Inshore detritus	1 00	3 000	-	-
Offshore detritus	1 00	4 500	-	-

Table 6 1 Representative Trophic Groups of the Northern Gulf of Alaska Arranged in Descending Order by Trophic Level

Notes Bold values were calculated by the Ecopath software

P/B is production per biomass Q/B is food consumption per biomass

Source Table 74 (Okey and Pauly 1999)

The GOA and its watersheds are part of a larger oceanic ecosystem in which natural physical forces such as currents, upwelling, downwelling, precipitation and runoff, acting over large and small distances, play important roles in determining basic biological productivity Natural physical forces respond primarily to seasonal shifts in the weather, and in particular to long-term changes in the intensity and location of the Aleutian Low system in winter Increased upwelling offshore appears to increase inputs of nutrients to surface waters, which increases productivity of plankton Increased winds appear to increase the transport of zooplankton shoreward toward and past the shelf-break How often and how much offshore zooplankton sources contribute to coastal food webs depends on natural physical and biological forces such as predation, migration, currents and structure of the fronts, formation and stability of eddies, degree and extent of turbulence, and responses of plankton to short and long-term changes in temperature and salmity

A wide range of human impacts interacts with natural biological and physical forces to change productivity and community structure in the GOA Human activities have the most direct and obvious impacts at those sites in watersheds and

intertidal areas where human populations are high Nonetheless, some human activities affect populations of birds, fish, shellfish, and mammals far offshore, and also have impacts far from the sites of the actions In short, human activities and natural forces together act over global to local scales to drive and shape marine and terrestrial life in the GOA and its tributary watersheds Natural forces and human impacts, as exemplified by heat and salt distribution, insolation, biological energy flow, biogeochemical cycling and food web structure, fishery removals, pollutant inputs, and the relationships among them over time define the state of the marine ecosystem Natural forces and human impacts bring about changes in populations of birds, fish, shellfish, and mammals by altering the relationships among these state variables that define the marine ecosystem. This understanding of the mechanisms affecting change in the GOA provides the basis for developing a key hypothesis about the GOA ecosystem that will form the conceptual foundation around which the GEM Program is focused

6.4 References

- ADF&G 2002 Draft Aquatic Nuisance Species Management Plan Ginny Fay
- Anderson, P J and J F Piatt 1999 Community reorganization in the Gulf of Alaska following ocean climate regime shift Marine Ecology Progress Series 189 117-123
- Bilby, R E , B R Fransen, and P A Bisson 1996 Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams evidence from stable isotopes Canadian Journal of Fisheries and Aquatic Sciences 164-173
- Crane, K and J L Galasso 1999 Arctic environmental atlas Washington, D C U S Naval Research Laboratory, Office of Naval Research
- Dewailly, E, P Ayotte, S Bruneau, C Laliberte, DCG Muir, and RJ Nortstrom 1993 Inuit exposure to organochlorines through the aquatic food chain in Arctic Quebec Environmental Health Perspectives 101 618-620
- Ewald, G, P Larsson, H Linge, L Okla, and N Szarzi 1998 Biotransport of organic pollutants to an inland Alaska lake by migrating sockeye salmon (Oncorhynchus nerka) Arctic 51 40-47
- Finney, B P 1998 Long-term variability of Alaska sockeye salmon abundance determined by analysis of sediment cores North Pacific Anadromous Fish Commission Bulletin 388-395
- Finney, B P, I Gregory-Eaves, J Sweetman, M S V Douglas, and J P Smol 2000 Impacts of climatic change and fishing on Pacific salmon abundance over the past 300 years Science 290 795-799

- Finney, B P, Gregory-Eaves, I, Douglas, M S V, and Smol, J P 2002 Fisheries productivity in the northeastern Pacific Ocean over the past 2,200 years Nature 416 729-733
- Gargett, A 1997 Optimal stability window A mechanism underlying decadal fluctuations in north Pacific salmon stocks Fisheries Oceanography 109-117
- Gresh, T, J Lichatowich, and P Schoonmaker 2000 An estimation of historic and current levels of Salmon production in the northeast Pacific ecosystem evidence of a nutrient deficit in the freshwater systems of the Pacific northwest Fisheries 25 15-21
- Jackson, J B , M X Kırby, W H Berger, K A Bjorndal, L W Botsford, B J Bourque, R H Bradbury, R Cooke, J Erlandson, J A Estes, T P Hughes, S Kıdwell, C B Lange, H S Lenihan, J M Pandolfi, C H Peterson, R S Steneck, M J Tegner, and R R Warner 2001 Historical overfishing and the recent collapse of coastal ecosystems Science 293 629-638
- Kline, TC, JJ Goering, OA Mathisen, PH Poe, and PL Parker 1990 Recycling of elements transported upstream by runs of Pacific salmon I $\Box^{15}N$ and $\Box^{13}C$ evidience in Sashin Creek, Southeastern, Alaska Canadian Journal of Fisheries and Aquatic Sciences 47 136-144
- Kline, TC, JJ Goering, OA Mathisen, PH Poe, PL Parker, and RS Scalan 1993
 Recycling of elements transported upstream by runs of Pacific salmon II
 □¹⁵N and □¹³C evidence in the Kvichak River watershed, Bristol Bay,
 Southwestern, Alaska Canadian Journal of Fisheries and Aquatic Sciences 50 2350-2365
- Mackas, D L, R Goldblatt, and A G Lewis 1998 Interdecadal variation in developmental timing of *Neocalanus plumchrus* populations at Ocean Station P in the subarctic North Pacific Canadian Journal of Fisheries and Aquatic Sciences 55 1878-1893
- Malthus, T 1798 An Essay on the Principle of Population, editor J Johnson, in St Paul's Church-Yard London
- Mangel, J, L M Talbot, G K Meffe, M T Agardy, D L Alverson, J Barlow, D B Botkin, G Budowski, T Clark, J Cooke, R H Crozier, P K Dayton, D L Elder, C W Fowler, S Funtwicz, J Giske, R J Hofman, S J Holt, S R Kellert, L A Kimbal, D Ludwig, K Magnusson, Malayang III, C, C Mann, E A Norse, S P Nothridge, W F Perrin, C Perrings, R Peterman, G B Rabb, H A Regier, J E Reynolds, K Sherman, M P Sissenwine, T D Smith, A Starfield, R J Taylor, M F Tillman, C Toft, J Twiss, R John, J Wilen, and T P Young 1996 Principles for the conservation of wild living resources Ecological Applications 6 338-362

- Mathisen, O A 1972 Biogenic enrichment of sockeye salmon lakes and stock productivity Verhandlungen der Internationalen Vereinigung für Theoretische and Angewandte Limnologie 18 1089-1095
- Mathisen, O A , J J Goering, and E V Farley 2000 Nitrogen and carbon isotope ratios in sockeye salmon smolts Verrh Internat Verein Liminol 27 3121-3124
- May, R M 1973 Stability and complexity in model ecosystems, editor Princeton University Press Princeton, N J
- Mundy, P R 1996 The Role of Harvest Management in the Future of Pacific Salmon Populations Shaping Human Behavior to Enable the Persistence of Salmon Pages 315-330 Naiman, R J and D Stouder, editors Chapman Hall, New York, USA
- NMFS 2002 Principle Hypotheses Surrounding the Steller Sea Lion Decline (SSLI)
- NRC 1999 Sustaining Marine Fisheries National Academy Press Washington, D C
- Okey, T A and D Pauly 1999 Trophic mass balance model of Alaska's Prince William Sound ecosystem, for the post-spill period 1994-1996 EVOS restoration project 98330-1 annual report The Fisheries Centre, University of British Columbia Vancouver
- Piatt, J F 2000 Survival of adult murres and kittiwakes in relation to forage fish abundance, *Exxon Valdez* oil spill restoration project annual report (Restoration Project 99338) U S Geological Survey, Alaska Biological Science Center Anchorage, Alaska
- Piatt, J F and T I Van Pelt 1998 Survival of adult murres and kittiwakes in relation to forage fish abundance, *Exaon Valdez* oil spill restoration project annual report (Restoration Project 98338) U S Geological Survey Anchorage, Alaska
- Quinn, T J and Richard B Deriso 1999 Quantitative Fish Dynamics Oxford University Press
- Ricker, W E 1975 Computation and interpretation of biologocal statistics of fish populations Bulletin of the Fisheries Research Board of Canada 191 1-382
- Romano, M D, D D Roby, J F Piatt, and A Kitaysky 2000 Effects of diet on growth and body composition of nestling seabirds, *Exxon Valdez* oil spill restoration project final report (Restoration Project 98163N) U S Geological Survey, Oregon Cooperative Fish and Wildlife Research Unit, and Oregon State University Corvallis, Oregon
- Stouder, D J, P A Bisson, and Robert J Naiman (editors) 1997 Pacific salmon and their ecosystems status and future options Chapman and Hall New York

Ylitalo, G M, C O Matkin, J Buzitis, M M Krahn, L L Jones, T Rowles, and J E Stein 2001 Influence of life-history parameters on organochlorine concentrations in free-ranging killer whales (*O1 cinils oi ca*) from Prince William Sound, Alaska The Science of the Total Environment 281

7. SCIENTIFIC BACKGROUND: PHYSICS, BIOLOGY, HUMAN USES AND ECONOMICS

In This Chapter

- Overview of Physical, Chemical, and Biological Characteristics of the Gulf of Alaska
- Discussion of Climate, and Physical, Geological, Chemical and Biological Oceanography
- > Discussion of Status of Non-human Populations, Predators, and Prey
- Discussion of Status of Human Activities and Socioeconomics in the Gulf of Alaska

7.1 Introduction

The scientific background is a comprehensive review of the current state of scientific knowledge of the Gulf of Alaska (GOA) ecosystem upon

which the Gulf Ecosystem Monitoring (GEM) Program is based. Its body of scientific knowledge includes the socioeconomic, physical, chemical, and biological characteristics of the GOA, the status of major animal species, and the state of human impacts in the GOA. It provides the underpinning for the GEM conceptual foundation and central hypothesis, and it will provide reference material for initiating the research and monitoring programs. The scientific background also includes the scientific information that led to current hypotheses introduced in Chapter 6

The information in Sections 7.2 through 7.5 Marine Mammals is current as of August 2001 Sections 7.14 and 7.15 are current as of July 2002

7.2 Summary of the Physical and Biological Background for the Northern Gulf of Alaska

721 Introduction

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The cold and turbulent GOA is one of the world's most productive ocean regions It sustains immense populations of seabirds, marine mammals, and fishes, and provides a way of life for tens of thousands of Alaskans Indeed, the gulf is

still wild, full of life, and deserves protection and wise management as one of the bio-gems of the planet

Just why the GOA is so unusually productive remains unclear The fish, birds, and mammals at the top of the food chain are supported by a diverse marine food web (Table 7 1), dependent on the physical characteristics of an ever-changing ocean—one that experiences seasonal, annual, and longer-period extremes in weather and climate The plant nutrients come from deep water, fueling production at the base of the marine food web This production is eventually expressed in the stock size and production of higher-level consumers Somehow, physical conditions in this region promote sufficient exchange between deep and shallow waters to bring these fertilizing elements to the surface, where they stimulate plant growth each year To understand the gulf's complex ecosystem, and the productivity of its species big and small, will require more precise knowledge about the interactions between many biological and physical factors

Group name	Trophic Level	Biomass (t km ² year ¹)	P/B (yr ¹)	Q/B (yr ¹)
Orcas	4 98	0 003	0 050	8 285
Sharks	4 81	0 700	0 100	2 100
Pacific halibut	4 59	0 677	0 320	1 730
Small cetaceans (porpoises)	4 52	0 015	0 150	29 200
Pinnipeds (harbor seal & sea lion)	4 45	0 066	0 060	25 550
Lingcod	4 33	0 077	0 580	3 300
Sablefish	4 29	0 293	0 566	6 420
Arrowtooth flounder adult	4 25	4 000	0 220	3 030
Adult salmon	4 17	1 034	6 476	13 000
Pacific cod	4 14	0 300	1 200	4 000
Arrowtooth flounder juvenile	4 01	0 855	0 220	3 030
Avian predators	3 89	0 002	5 000	36 500
Seabirds	3 78	0 011	7 800	150 60
Deep demersal fish (skates and flatfishes)	3 78	0 960	0 930	3 210
Pollock age 1+	3 76	7 480	0 707	2 559
Rockfish	3 74	1 016	0 170	3 440
Baleen whales	3 65	0 149	0 050	10 900
Salmon fry 0-12 cm	3 51	0 072	7 154	62 800
Nearshore demersal fish (greenling and sculpin)	3 35	4 200	1 000	4 240
Squid	3 26	3 000	3 000	15 000
Eulachon	3 25	0 371	2 000	18 000
Sea otters	3 23	0 045	0 130	117 000

 Table 7 1 Representative Trophic Groups of the Northern Gulf of Alaska

 Arranged in Descending Order by Trophic Level

Group name	Trophic Level	Bıomass (t km ² year ¹)	P/B (yr ¹)	Q/B (yr ¹)
Deep epibenthos	3 16	30 000	3 000	10 000
Capelin	3 11	0 367	3 500	18 000
Adult herring	3 10	2 810	0 540	18 000
Pollock age 0	3 07	0 110	2 340	16 180
Shallow large epibenthos	3 07	3 100	2 100	10 000
Invertebrate eating bird	3 07	0 005	0 200	450 500
Sandlance	3 06	0 595	2 000	18 000
Juvenile herring	3 03	13 406	0 729	18 000
Jellies	2 96	6 390	8 820	29 410
Deep small infauna	2 25	49 400	3 000	23 000
Near omni-zooplankton	2 25	0 103	7 900	26 333
Omni-zooplankton	2 25	24 635	11 060	22 130
Shallow small infauna	2 18	51 500	3 800	23 000
Meiofauna	2 11	4 475	4 500	22 500
Deep large infauna	2 10	28 350	0 600	23 000
Shallow small epibenthos	2 05	26 100	2 300	10 000
Shallow large infauna (clams, etc)	2 00	12 500	0 600	23 000
Near herbi-zooplankton	2 00	0 136	27 000	90 000
Herbi-zooplankton	2 00	30 000	24 000	50 000
Near phytoplankton	1 00	5 326	190 000	0 000
Offshore phytoplankton	1 00	10 672	190 000	0 000
Macroalgae/eelgras	1 00	125 250	5 000	0 000
Inshore detritus	1 00	3 000	-	-
Offshore detritus	1 00	4 500	-	-

Table 7 1 Representative Trophic Groups of the Northern Gulf of Alaska Arranged in Descending Order by Trophic Level

Notes Bold values were calculated by the Ecopath software

 $\ensuremath{\textit{P/B}}$ is production per biomass $\ensuremath{\,{\rm Q/B}}$ is food consumption per biomass

Source Table 74 (Okey and Pauly 1998a)

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Fortunately, recent studies provide a scientific framework for the region and suggest a direction for future long-term research and monitoring In aggregate, this new knowledge on how selected species interact with prey, predators and competitors — and most importantly, how these associations are influenced by shifts in ocean climate and human activities — provides exciting new possibilities for understanding this great ecosystem. This knowledge will help resource managers sustain populations of these species despite growing human influence in the region (possible climate change and elevated pollution levels) and the pressure of increased human use (harvests, recreational impacts, and population).

This summary describes the northern GOA ecosystem as it is now understood, and reveals gaps in current knowledge about the dynamics of higher-level productivity (Greater detail is provided following this summary in the full Scientific Background)

7 2 2 The Principal Habitats and Living Resources

The extent of damage resulting from the massive oiling of Prince William Sound and the coastal waters to the west in the spring of 1989 will never be fully known In the short term, GEM studies will focus on the spill-affected resources that remain at risk But the *Exron* Valdez Oil Spill Trustee Council (Trustee Council) has decided to commit its long-term support to a program of broader ecological research and environmental monitoring The effort will center on the major physical and biological phenomena that influence marine productivity in the principal habitats of the northern GOA For purposes of the GEM Program, these habitats have been identified as

- The coastal watersheds,
- The intertidal and shallow subtidal zones to a depth of 20 meters,
- The Alaska Coastal Current (ACC), and
- The offshore areas embracing the continental shelf break and beyond to the continental slope and deep ocean basin

In these interacting environments, scientists will seek to understand how the dominant fishes, seabirds, and marine mammals use their critical habitats to sustain their populations in the face of cyclic ocean climate, extensive commercial and subsistence harvests, and threats from pollution and diseases

7.2.2.1 The Watersheds

The extensive coastal watersheds that drain into the northern GOA represent spawning and rearing habitat for anadromous species like Pacific salmon and eulachon, and nesting habitat for some seabirds like marbled murrelets The carcasses of spawned-out salmon supply substantial amounts of marine-derived nutrients to the poorly nourished streams, lakes, and rivers used for their reproduction In addition, dying salmon provide a food supply for many birds and mammals throughout the coastal range Bears, eagles and many gulls benefit locally from this extensive forage resource Analyses have also shown that marinederived nitrogen from anadromous fishes leaves a detectable signal in many coastal plant communities

The human harvest of anadromous species may affect not only those species, but also all of the plants and animals touched by marine nutrients Therefore, understanding the distribution of marine nutrients by anadromous fish species puts a new dimension on fisheries management So, it is reasonable to ask to what extent human consumption of salmon effects the production of other plants and animals in the coastal watersheds Moving beyond single-species management toward ecosystem-based management in coastal watersheds will require long-term monitoring of the flux of marine nutrients

These same watersheds experience extensive human activity in addition to fishing Large-scale logging and commercialization, including coastal settlements and towns, can alter or destroy some habitats Expanding recreational activities in the coastal zone between Prince William Sound and Kodiak Island will also include additional land uses Compared with other regions in North America, however, most watersheds in the periphery of the GOA are remote and relatively undisturbed

7.2.2.2 The Intertidal and Subtidal

The intertidal and shallow subtidal habitats are represented by a variety of near-shore estuarine, ford, and exposed coastal settings These habitats range from precipitous and rocky, to gently sloping with muddy or sandy bottoms The intertidal and shallow subtidal zones are among the most productive of marine habitats in the GOA Here the annual growth of microalgae, seaweeds, and seagrasses supports many invertebrates that, in turn, are food for fishes, marine birds, and mammals Guillemots and sea otters, for example, depend on the crabs, clams, and mussels, along with small benthic fishes, found in the intertidal and subtidal habitats This specialized edge-zone habitat is also a nursery for juvenile pink and chum salmon, and juvenile Pacific herring for several months each year Huge schools of spawning herring and capelin deposit their eggs in the shallows each spring These mass spawnings induce a feeding frenzy that may last for a week or more Gulls, kittiwakes, seals, sea lions, fishes, and a variety of large invertebrates gather to feed on the egg masses The fish eggs are often eaten in huge numbers by shorebirds and other species that stop over in the region during the spring migration

The intertidal and shallow subtidal zones may be at greatest risk to human activities There is increasing use of vehicles, boats, and aircraft by recreationalists and sport fishermen to exploit these areas In addition, floating pollutants and refuse, particularly plastic materials from the fishing industry, make landfall in the intertidal zone Unlike the coastal watersheds that remain relatively unaltered at many locations, it is rare to walk the intertidal zone anywhere in the GOA and not see evidence of human activity The degree to which these "footprints" result in environmental degradation is clear in the case of oil and toxic spills, but largely unknown for other pollution

7.2.2.3 The Alaska Coastal Current

Hugging the inner third of the continental shelf, the ACC provides a sizeable and ecologically important transition zone between the shallow, nearshore communities and the huge outer-shelf and oceanic pelagic ecosystems Fed by runoff from glaciers, snowmelt, and rainfall, the well-defined coastal current is a near-shore "river in the sea" with a freshwater output about one and a half times that of the Mississippi River It flows consistently to the north and west around the northern GOA from British Columbia to Unimak Pass on the Aleutian Chain The ACC, urged along by coastal winds, distributes subarctic plankton communities around the region and into protected inside waters such as Prince William Sound and lower Cook Inlet During the summer months, the ACC has local reversals and small eddies, which can concentrate plankton and small fishes in convergence zones, for foraging fish, birds, and marine mammals

The ACC is an important feeding habitat for many fish, birds, and mammals Most seabirds nest in coastal colonies of on islands where protection from predators is afforded by the isolation of rocky cliffs Because of this nesting behavior, the distribution and abundance of seabirds during their reproductive season is governed primarily by the availability of suitable, safe nesting sites and access to adequate prey Seabirds in the GOA are often grouped on the basis of their foraging behavior Surface feeders like kittiwakes obtain prey mostly in the upper 1 meter (m), coastal divers such as guillemots and murrelets exploit the shallow water column and nearshore seabed, while murres are deep divers capable of feeding in the water or on the bottom to depths of 200 m Seabirds feed close to colonies when opportunities arise, but most are also capable of flying a long distance to feed. It is not unusual for coastal seabirds to fly to the outer shelf and shelf-break regions to feed themselves and their offspring

Marine mammals residing in the ACC are primarily fish eaters, although a few feed on bottom-dwelling invertebrates and some hunt other marine mammals or even seabirds Killer whales are either resident (fish eaters primarily) or transient (feeding mostly on other marine mammals) Seals, sea lions, and sea otters bear and protect their offspring in coastal rookeries sprinkled around the edge of the GOA and influenced by the ACC Fur seals and sea lions exploit a broad array of nearshore and oceanic habitats, although the juveniles appear to be more confined to the waters near rookeries By comparison, sea otters and harbor seals are almost sedentary in habit, usually ranging only short distances for food Juvenile and adult harbor seals hunt and consume a variety of fishes, squids, and octopus in mostly coastal habitats. While sea otters can retrieve food from depths to 100 m, they rarely leave the shallow coastal areas where they live as generalist predators on a broad array of sessile or slow-moving macro-invertebrates, including clams, mussels, crabs, sea urchins, and starfishes

Many fishes and shellfishes also live, feed, and reproduce in the ACC Coastal rockfishes, Pacific herring, juvenile and adult walleye pollock, juvenile and adult salmon, adult cod, and many species of shrimps and crabs occur in protected fjords, inlets, bays, and sounds where they forage and/or reproduce, and where their early life stages feed and grow Halibut and lingcod occur abundantly in some seasons, and king crabs that feed and grow in deeper shelf and slope environments visit the shallower inner shelf to reproduce each year Because the eggs and larvae of many marine invertebrates and fishes drift with the plankton for

weeks or even months, the flow of the ACC serves to distribute these forms to the variety of coastal habitats found around the edge of the gulf

The same coastal flow that benefits so many species may also serve to distribute marine pollutants Oil spilled in the northeastern corner of Prince William Sound by the *Exaon Valdez* entered the coastal flow and was carried hundreds of miles to the west, fouling beaches along the outer Kenai Peninsula, in lower Cook Inlet, on Kodiak Island, and along the southern Alaska Peninsula A future toxic spill in shelf or coastal waters southeast of Prince William Sound could conceivably be spread across the entire northern GOA by the coastal flow

7.2.2.4 Offshore. Mid-shelf and Deeper Waters

These waters, which begin at the outer edge of the adjacent ACC region – about 20 to 30 miles offshore – delineate a huge marine ecosystem East of Prince William Sound, the shelf is narrow, so the mid-shelf and deeper waters are close to the coast, about 30 to 50 miles South and west of the sound, the shelf broadens to 100 to 120 miles in width before narrowing again south of the Alaska Peninsula and Aleutian Islands These differences in shelf width provide seabirds, seals, and sea lions at some coastal locations with easy access to the deepwater environments for feeding purposes when needed, at other sites, access to the shelf edge and open ocean is much farther away Spatial differences of this kind may be important to recognize when comparing the reproductive successes of birds and mammals in rookeries from different locations in the gulf Arrowtooth flounder, Pacific ocean perch, walleye pollock, Pacific halibut and Pacific cod (in descending order of importance) composed the bulk of the trawl-caught stock of ground fishes in shelf and continental slope environments of the GOA in 1996

The dominant flow in the offshore is counterclockwise, and it is designated the Alaska Current Because the Alaska Current has its southern origins in the oceanic Subarctic Current, marine pollution and floating refuse from as far away as Asia, or originating from deliberate deep-ocean dumping or accidents at sea, can be swept north and westward around the shelf edge in the GOA Trash from the international fishing industry operating 200 miles offshore is commonly found on beaches. Some of these pollutants can also be carried westward to the gulf in the atmosphere

7.2.3 Intermediate Levels of the Food Web

Food webs are really pyramids with seabirds, marine mammals, and fishes at the top that depend initially on energy captured by marine plants at their base Although there are hundreds—perhaps thousands—of different plant and animal plankters involved in the synthesis and initial transfer of organic matter through the food web, the pyramid of herbivores and predators narrows quickly

The diets of seabirds, marine mammals, and fishes are composed of a relatively modest variety of small schooling fishes and macroplankters, but they are consumed in very large numbers Seabirds are the clearest illustration Out of the hundreds of fish species in the gulf, a substantial portion of the diets of seabirds consists mainly of smelts (capelin, eulachon, and rainbow smelt), juvenile herring, pollock and salmon, Pacific sand lance, Pacific sandfish, lanternfishes, and adult euphausiids In shallow waters, small benthic fishes like pricklebacks and gunnels are also important Many of these forage species are rich in fats, and almost all exhibit schooling behaviors that concentrate them for their bird, mammal, and larger fish predators Herring, capelin, sand lance, and lanternfish are probably preferred for their high caloric content Juvenile pollock, cod, and salmon are less preferred, despite their abundance, because of their lower energy content

Despite the ecological importance of macroplankton and small schooling fishes, the distributions, abundances, and forage requirements of these species are poorly understood. The influence of climate change on their populations is also poorly known. This is partly because routine censusing techniques are used primarily to count and map adult stocks of commercial importance, and ignore the smaller forage fishes. Modern techniques that use high-speed mid-water and surface trawls, marine acoustics, LIDAR (light detection and ranging), aerial surveys, and monitoring the diets of top consumers like birds and large commercial fishes will make it possible to learn more about this vital link in the food web

Forage fishes are often taken in the bycatch of federal and state-regulated fisheries in the GOA, and while the proportion relative to the target species tends to be small, it may be ecologically significant in some cases Fisheries targeting herring, salmon, and pollock all have incidental catches of juveniles that might be avoided as the industry develops new equipment and techniques to minimize the impact of bycatch mortality Mortality of forage fishes associated with marine pollution and diseases is also poorly understood. There is some evidence that the failure of herring in Prince William Sound to recover from oil spill injuries may be due, in part, to an abnormally high incidence of *Viral Hemori hagic Septicemia* (VHS) and a marine fungus plaguing these stocks

7 2 4 Plankton and Linkages to the Physical Oceanography

Oceanic, shelf, and coastal plankton are the base of a vast food web supporting most seabirds, marine mammals, and fishes These tiny drifters are supplemented by rich populations of plants and mostly small benthic invertebrates that feed higher-level consumers in intertidal and shallow subtidal areas Although adult birds, fishes, and mammals rarely feed directly on plankton, there are notable exceptions, such as adult walleye pollock, Pacific herring, baleen whales, and some seabirds On the other hand, the plankton community does play a direct and important role during the early life history of most fishes Ichthyoplankters—larval and juvenile fishes and shellfishes—derive critical nutrition from the plankton, but are themselves also preyed upon by plankters, mostly small jellyfish

Because fish are highly vulnerable in the egg, larval, and early juvenile stages, only a fraction survive to join the adult populations Traditionally, this survival rate was estimated in field studies of the early life stages of fish, including the physical and chemical characteristics of the rearing waters These studies have led to several important ideas about critical ecological bottlenecks in the early development of fish larvae and juveniles linking changes in ocean currents and climate with distribution, growth, and survival This direct tie to ocean climate creates an important "handshake" that extends through the food web to adult fish stocks Unfortunately, the small number and patchy distribution of ichthyoplankters relative to the non-fish plankton creates some extremely serious difficulties with sampling and data interpretation that limit the early-life history approach

The bloom of plankton each spring defines the cycle of marine production for that and succeeding years as the impact of the planktonic biomass moves through the food web The plankton communities undergo huge seasonal changes in rates of photosynthesis and growth, and in their standing stocks each year Initiated in the spring by a stabilizing upper layer and increasing ambient light levels, the phytoplankton community undergoes explosive growth during April, May, and June before being controlled by nutrient depletion, sinking, and zooplankton grazing The organic matter produced in this burst of productivity mostly comprises a relatively small number of dominant species. In a similar way, shallow-water plants — microalgae, seaweeds, and sea grasses — provide much of the plant-derived organic matter in intertidal and shallow subtidal areas. In the late fall, plankton stocks plummet dramatically and remain low during winter and early spring

The timing, duration and intensity of marine plant blooms are controlled largely by the physical structure of the water column Depending on the variable conditions of any given spring, the plant bloom may be early or late by as much as three weeks Warming and freshening of the surface layers in response to longer and brighter days promote intense photosynthesis However, the seasonal stability of the upper layers that initiates the growth of phytoplankton stocks also restricts the vertical movement of dissolved nitrogen, phosphate, and silicon, resulting in a dramatic slowing of growth in early and mid-summer Previous work suggests that winter-conditioned temperature and salinity influences plankton production, working in concert with spring weather conditions to establish the overall success of the spring bloom Recent observations from moorings that monitor chlorophyll in the water indicate that a fall phytoplankton bloom also occurs in Prince William Sound in some years, but not others This burst of production peaks in September and can last through November The ecological importance of this late-season production and the physical forces that unleash the bloom are not yet understood

By definition, the plankton are drifters, they have little or no mobility Therefore, their geographical locations are determined primarily by ocean currents However, because many zooplankters are capable of daily and/or seasonal vertical migrations of 100 m or more, these migrations may interact with vertical or horizontal currents in ways that create localized swarms and layers (patches) of plankton in the ocean These patches provide food for birds, fishes, and marine mammals Whales feeding on surface or subsurface swarms of large copepods or euphusids, and adult pollock and herring filtering or gulping large calanoid copepods in surface layers, are examples of patch feeding Because the plankton can be concentrated or dispersed by ocean currents, fronts, and eddies, the physical oceanography plays a huge role in creating and maintaining "feeding stations" for marine birds, mammals, and fishes

The marine production cycle beyond the shelf edge is exceptionally complex Photic zone levels of nitrogen, phosphate, and silicon are apparently available in sufficient quantities to promote phytoplankton production during the spring, summer, and fall However, levels of chlorophyll (a measure of the concentration of living phytoplankton in the water) in the upper layers remain very low throughout the year at many locations. In the coastal regions and inner shelf, there is a burst of chlorophyll—the "bloom"—each spring. This bloom results from an imbalance between rates of phytoplankton growth and rates of plant loss to grazers or sinking. Over the deep ocean and outer shelf, this burst/bloom does not usually occur, meaning that growth and loss rates of the plants are nearly equal, and that there is very little "excess" plant matter in the water to sink to the deep sea bed This balancing act in offshore waters has generally been attributed to the ability of the micrograzers to efficiently "crop down" the plant stocks and prevent blooms

It has been suggested that inorganic iron from atmospheric sources is limiting plant productivity to very small cell sizes at the ocean surface These nucroscopic plants are cropped efficiently by oceanic protozoans and other microconsumers Unlike the shelf and coastal plankton, where large chain-forming diatoms feed the macrozooplankton directly, the oceanic food web instead supports an additional level of tiny consumers that are then grazed by larger zooplankters. On the basis of food-chain theory, this additional step at the base of the food web should reduce the open ocean's ability to feed consumer stocks higher in the food web. The fact that the open GOA is the preferred feeding ground for a majority of salmon stocks with origins in North America and Asia suggests that an additional step in the food web does not compromise the region's ability to feed hundreds of millions of these fish each year

Very little is known about how the plankton community responds to human activity Some recent and dramatic shifts in phytoplankton stocks in the Bering Sea, associated with a summer warming trend, were accompanied by very noticeable declines in seabird survivals in the shelf environment These observations suggest that any increased climate warming due to human influence could alter high-latitude food webs with drastic effects for some consumers

7 2 5 Influences of Weather and Climate

Gulf organisms are influenced by a variety of currents, frontal regions, eddies, water temperatures, and salinities These conditions define the ocean state and reflect the influence of weather and climate From September through April each year, weather in the GOA region responds to the position and intensity of the

Aleutian Low Pressure System (Aleutian Low) The cyclonic storms that develop in and around the GOA in association with the Aleutian Low cause strong easterly winds to blow along the northern coastline The friction of these winds on the sea surface promotes a net shoreward flow in the upper 60 to 90 meters, and a counterclockwise drift of the Alaska Gyre, the Alaska Current, Alaskan Stream, and Alaska Coastal Current The frequency and intensity of storms establishes a "conveyor belt," carrying ocean-derived plankton stocks shoreward, some reaching as far as the protected coastal waters By using carbon isotopes as indicators, a strong offshore signal can be found in inshore zooplankton and fishes at some locations In contrast, during June, July, and August, the conveyor belt slows or weakly reverses in response to the appearance of the North Pacific high-pressure system in the GOA. The reversal of the conveyor belt over the outer shelf allows deep water below the surface to overrun the shelf break at some locations, providing a crucial source of deep nutrients and oxygen renewal for deep coastal areas

The location and intensity of the Aleutian Low is not constant When the low is intense, the weather is stormy with increased precipitation in the coastal mountains, and elevated sea levels and warmer water temperatures in the eastern GOA Under these conditions, described as the positive phase of a weather phenomenon called the Pacific Decadal Oscillation (PDO), the wind-induced crossshelf transport increases, as does flow in the ACC During the long term, these conditions seem to favor production of salmon, pollock, cod, and flounder, but other species are disadvantaged, such as seabirds at many locations, some forage fishes, and shellfish like shrimp and crab When the PDO cycles back to its next negative phase - as it is predicted to do, with colder, less stormy, lower sea levels conditions should favor the recovery of shellfish stocks, with salmon and gadid populations expected to slip into decline Why these populations fluctuate the way they do in response to changes in ocean climate is unknown However, the cycling of nature's laboratory from year to year, and through longer periods, provides a strong basis for a number of intriguing studies to search for and describe the underlying mechanisms that create change, and sometimes complete reversals, in fish, bird, and mammal abundance

7 2 6 Toward a More Functional Understanding of GOA Ecosystems

Current knowledge about coastal, shelf, and oceanic ecosystems supporting the living marine resources of the GOA is limited and skewed heavily toward structural elements — species lists, historical patterns of production (catch and harvest statistics), crude maps of distribution and abundance, some diet information, migratory behaviors, and, in a few cases, rates of production. At the level of plankton, the seasonal cycle is quite well understood in relationship to factors like light and nutrients, but higher in the food web at the zooplankton level and that of the small schooling fishes, little information is available. Therefore, with a few exceptions, the "puzzle pieces" are beginning to form reasonably coherent pictures at the top and bottom of the food web, but are absent or mostly missing from the middle regions of the web The challenge for GEM will be to eventually understand how the major physical and biological components interact dynamically to produce the historical patterns in stock size and production of key species. Conventional population theory teaches that variability at the highest levels in food webs reflects the balance between reproduction and mortality (due to natural causes, predation, harvests, diseases, and pollution). A few statistical analyses point to significant correlations, however, between population levels and weather, climate, or physical oceanographic conditions, some apparently tied to recurring cycles like the PDO, the North Pacific Index (NPI), the 18.6 year Lunar Nodal Tidal Cycle, and episodic events like El Niño/La Niña. Unfortunately these intriguing and often ephemeral correlations suggest, but do not identify, the mechanisms behind these relationships. This critical missing information must be obtained at some point in comprehensive field and modeling studies that focus on selected ecosystem processes.

To be successful, these studies must be funded at levels sufficient to identify and collect the relevant data, and supported over periods of time that bridge the cycles in climate and ocean conditions Few studies anywhere have been able to sustain their activities long enough, or were sufficiently comprehensive to meet these criteria The GEM Program will be unique in that regard and could assume a strong leadership role in taking the next bold steps in marine ecological research In so doing, GEM will find ways to more fully exploit some emerging research "themes" that are suggesting new directions for process studies of large ecosystems

7.2.6.1 Nature Is Complex

Food web theory has played a major role in shaping quantitative approaches to studying marine systems. Since the early 1940s, when aquatic communities were perceived as a linear series of interconnected levels — producers (plants), first-order consumers (herbivores), higher-level consumers (predators), and recyclers (bacteria) — this powerful idea has pointed to ever more sophisticated inquiries about how matter and energy are cycled through these systems. However, in the last few years, there has been a growing awareness that the inability to more fully understand how nature works may be tied to a number of simplifying assumptions that have always been made about living systems. It is now understood that at some level of detail, natural processes cannot all be adequately explained by strict linear theory. This means that unless the complexity of nature is acknowledged and that constraint dealt with in a realistic manner, the GEM Program work will fall short, as will the ability to resolve resource management and other issues.

7.2.6.2 Survival Strategies Define Habitat Dependencies

There is a growing need to more fully understand what has been passed over as mostly "old science"—how the life history of a target species exploits the marine ecosystem during its entire life span For example, most marine fishes begin life as tiny pelagic or demersal eggs followed by a drifting larval stage that may last for weeks or months The drifting period is followed by successive juvenile and maturing older stages that may use different parts of the ecosystem from those that host the adults Understanding the entire ecological domain of a particular species will help establish the "connectiveness" needed to more fully understand how human influences and perturbations in climate and weather work their way though the marine ecosystem in the GOA

7.2.6.3 Use of Common Biological Currency

Oceanographers have traditionally used measures of carbon or nitrogen as common denominators to describe processes of organic matter synthesis and transfer at lower trophic levels At the other end of the food web, the fisheries literature tracks the abundance and biomass of exploited stocks, usually expressed in numbers or weight Recently, the energy content of species has been suggested as a useful measure for assessing the status of stocks and their principal prey Bioenergetic modeling is becoming more common and measures of whole body energy content easier to obtain For instance, the overwintering starvation mortality of juvenile Pacific herring residing in Prince William Sound can now be estimated through numerical analysis of the fat stores of the herring as they go into winter and the winter water temperatures

7.2.6.4 Problems of Time and Space

Attempts to understand how marine ecosystems react to climate and human influences pose huge sampling problems for systems on the scale of the GOA Current understanding suggests that the impacts of large-scale climate shifts and pollution are not uniform, but seem to be temporally and spatially distributed in ways that are not fully understood. For example, seabird colonies at some locations do well, while others do not. Two aspects may be important contributors to this uncertainty (1) variability in the timing, location, and duration of primary productivity each year as influenced by weather — a kind of "timing is everything" issue, and (2) spatial patchiness on a variety of length scales in forage stocks responding locally to changing temperature, salinity, currents, and other ocean characteristics. This suggests that GEM will have to study a number of different environments at different times to fully understand the ecological ramifications of climate-driven change, and that care must be taken in generalizing about cause and effect within the region.

7.2.6.5 Immigration or Emigration

Particularly for seabirds and marine mammals censused at nesting sites and rookeries, some population trends might be explained by migrations away from or to these locations If this is occurring, these migrations could pose serious problems in the interpretation of historical trends in the GOA Some believe that fish or shellfish stocks can also shift their distributions in response to environmental change, leading to increases in some areas and declines in others, although the overall stock production might remain unaltered This potential source of error must be addressed by GEM

7.2.6.6 Top-Down and Bottom-Up Controls

Historical approaches to studies of marine systems have led to a dichotomy of disciplines Oceanographers have focused on the base of the food web and relationships with ocean physics and chemistry, whereas fisheries scientists have studied exploited stocks and, occasionally, the forage resources that support them Top-down or bottom-up control has been debated endlessly for years without resolution It is now beginning to be understood, that this is not an either/or problem, but rather one of process interaction Top-down and bottom-up control of populations occurs simultaneously in all living systems and must be studied as such to refine understandings of system function For example, recent studies of juvenile pink salmon in Prince William Sound have demonstrated that top-down losses to fish predators, such as adult pollock and herring, are modulated by the kinds and amounts of zooplankton available, a bottom-up function The opportunistic pollock and herring prefer to feed on macrozooplankton when plentiful, thereby improving the chance of juvenile salmon to fatten up and escape their role as prey However, when macrozooplankton is not abundant, pollock and herring begin augmenting their diets by feeding more heavily on small fishes, including juvenile salmon In this way, bottom-up processes affecting the production of copepods not only help feed and fatten young salmon, but top-down processes of pollock feeding on copepods help protect the salmon fry

727 Conclusion

In the final analysis, the GEM Program will engage a complex ecosystem -aproduct of evolutionary adaptation through many thousands of years This robust living assemblage exhibits different characteristics of species dominance, distribution, and abundance in response to short-term and longer-period changes in climate forcing and human influences These different "states" have most recently been described as regimes In the GOA, at least two dominant physical states - El Niño/La Niña - and PDO are known to affect the production cycles of several marine species GEM proposes to investigate why some resources, but not others, benefit from these changing and interacting oceanic conditions This understanding will ultimately provide information to more prudently exploit and/or conserve species of high value for all users Knowing why a particular set of resources is performing at a given level of productivity will ultimately provide a means to more effectively manage the system under different states of species dominance and external influences This ambitious goal will be addressed through a long-term commitment to innovative science, and the thoughtful application of results

7.3 The Gulf of Alaska

The GOA encompasses watersheds and waters south and east of the Alaska Peninsula from Great Sitkin Island (176° W), north of 52° N to the Canadian mainland on Queen Charlotte Sound

(127° 30′ W) Twelve and a half percent of the continental shelf of the United States lies within GOA waters (Hood 1986)



Figure 7.1 Distribution of oil from the Exxon Valdez oil spill.

The area of the GOA directly affected by the EVOS (Figure 7.1) encompasses broadly diverse terrestrial and aquatic environments. Within the four broad habitat types of the watersheds, intertidal-subtidal, Alaska Coastal Current (ACC), and offshore (continental shelf break and Alaska Gyre), the geological, climatic, oceanographic, and biological processes interact to produce the highly valued natural beauty and bounty of this region.

Human uses of the GOA are extensive. The GOA is a major source of food and recreation for the entire nation, a source of traditional foods and culture for indigenous peoples, and a source of food and enjoyment for all Alaskans. Serving as a "lung" of the planet, GOA resources are part of the process that provides oxygen to the atmosphere. In addition, the GOA provides habitat for diverse populations of plants, fish, and wildlife and is a source of beauty and inspiration to those who love natural things.

The eastern boundary of the GOA is a geologically young, tectonically active area that contains the world's third largest permanent icefield, after Greenland and Antarctica. Consequently, the watersheds of the eastern boundary of the GOA lie in a series of steep, high mountain ranges. Glaciers head many watersheds in this area, and the eastern boundary mountains trap weather systems from the west, making orographic, or mountain-directed, forcing important in shaping the region's climate From the southeastern GOA limit (52° N at landfall) moving north, the eastern GOA headwater mountain ranges and height of the highest peaks are the Pacific Coast (10,290 feet [ft]), St Elias (18,000 ft), and Wrangell (16,390 ft) Northern boundary mountain ranges from east to west are the Chugach (13,176 ft), Talkeetna (8,800 ft), and Alaska (20,320 ft) The western boundary of the GOA headwaters is formed in the north by the Alaska Range and to the southsouthwest by the Aleutian Mountains (7,585 ft)

Relatively few major river systems manage to pierce the eastern boundary mountains, although thousands of small independent drainages dot the eastern coastline and islands of the Inside Passage Major eastern rivers from the south moving north to the perimeter of Prince William Sound (PWS) are the Skeena and Nass (Canada), the Stikine, Taku, Chilkat, Chilkoot, Alsek, Situk, and Copper All major and nearly all smaller watersheds in the GOA region support anadromous fish species For example, although PWS proper has no major river systems, it does have more than 800 independent drainages that are known to support anadromous fish species

To the west of PWS he the major rivers of Cook Inlet Two major tributaries of Cook Inlet, the Kenai and the Kasilof, originate on the Kenai Peninsula The Kenai Peninsula hes between PWS, the northern GOA and Cook Inlet Cook Inlet's largest northern tributary, the Susitna River, has headwaters in the Alaska Range on the slopes of North America's highest peak, Mt McKinley Moving southwest down the Alaska Peninsula, only two major river systems are found on the western coastal boundary of the GOA, the Crescent and Chignik, although many small coastal watersheds connected to the GOA abound Kodiak Island, off the coast of the Alaska Peninsula, has a number of relatively large river systems, including the Karluk, Red, and Frazer

The nature of the terrestrial boundaries of the GOA is important in defining the processes that drive biological production in all environments. As described in more detail below, the ice cap and the eastern boundary mountains create substantial freshwater runoff that controls salinity in the nearshore GOA and helps drive the eastern boundary current. The eastern mountains slow the pace of and deflect weather systems that influence productivity in freshwater and marine environments.

The GOA shoreline is bordered by a continental shelf ranging to 200 meters (m) in depth (Figure 7.2) Extensive and spectacular shoreline has been and is being shaped by plate tectonics and massive glacial activity (Hampton et al 1986) In the eastern GOA, the shelf is variable in width from Cape Spencer to Middleton Island It broadens considerably in the north between Middleton Island and the Shumagin Islands and narrows again through the Aleutian Islands The continental slope, down to 2,000 m, is very broad in the eastern GOA, but it narrows steadily southwestward of Kodiak, becoming only a narrow shoulder above the wall of the



Figure 7.2 Satellite radar image of the northern Gulf of Alaska. Continental shelf, seamounts, and abyssal plain can be seen in relief. (Composite image from Seaviewing Wide Field-of-view Sensor [SeaWiFS], a National Aeronautics and Space Agency remote-sensing satellite.)

deep Aleutian Trench just west of Unimak Pass. The continental shelf is incised by extensive valleys or canyons that may be important in cross-shelf water movement (Carlson et al. 1982), and by very large areas of drowned glacial moraines and slumped sediments (Molnia 1981).

7.4 Climate

7.4.1 Introduction

The weather in the northern GOA, and by extension that of adjacent regions such as PWS, is dominated for much of the year by extratropical cyclones. These storms typically form well to the south and east of the region over the warm waters of the central North Pacific Ocean and propagate northwestward into the cooler waters of the GOA (Luick et al. 1987, Wilson and Overland 1986). Eventually these storms make landfall in Southcentral or Southeast Alaska where their further progress is impeded by the extreme terrain of the Saint Elias Mountains and other coastal ranges. In fact, weather forecasters call the coastal region between Cordova and Yakutat "Coffin Corner," in reference to the frequency of decaying extratropical storms found there. The high probability of cyclonic disturbances in the northern GOA is significant to the local weather and climate of PWS Associated with these storms are large offshore-directed, low-level pressure gradients (tightly packed isobars roughly parallel to the coast) Depending on other factors (such as static stability, upperlevel wind profile) these gradients can produce strong gradient-balance winds parallel to the coastline or downslope (offshore-directed) wind events (Macklin et al 1988) Further, because of the complex glacially sculptured nature of the terrain in PWS, several regions experience significant upslope winds in certain favorable storm situations. This wind configuration, in concert with steep terrain and nearly saturated, low-level air masses, produces the local extreme in precipitation responsible for tidewater glaciers of PWS

The combination of general storminess, significant windiness (and concomitant wave generation), and orographically enhanced precipitation are essential features of the northern GOA and PWS, and have a strong impact on the variety and composition of the biota this region supports. In addition, the annual melting of seasonal snowfall accumulations, in combination with glacial ablation, is responsible for the bulk of freshwater input into PWS. In this context, any changes in climate–naturally induced or anthropogenic–that substantively alter the frequency and duration of these common yet transient weather features should also affect related parts of the regional ecosystem. In the following discussion, the factors responsible for climate change are identified and explained on a general level in preparation for specific relationships among climate, physical, and chemical oceanography, species, and groups of species that follow. Climate is recognized to be a major natural force influencing change in biological resources

The GEM mission is to promote, "greater understanding of how its productivity is influenced by natural changes and human activities" (EVOSTC 2000) Climatic forcing is an important natural agent of change in the region's populations of birds, fish, mammals, and other plant and animal species (Hare et al 1999, Mantua et al 1997, Anderson and Piatt 1999, Francis et al 1998) Human activities, or anthropogenic forcing, may have profound effects on climate There is growing evidence that human activities producing "greenhouse gases" such as carbon dioxide may contribute to global climate change by altering the global carbon cycle (Sigman and Boyle 2000, Allen et al 2000) Understanding how natural and human forcing influences biological productivity requires knowledge of the major determinants of climate change described in this section

Climate in the GOA results from the complex interactions of geophysical and astrophysical forces, and also in part by biogeochemical forcing Physical processes acting on the global carbon cycle and its living component, the biological pump, drive oscillations in climate (Sigman and Boyle 2000) The most prominent geophysical feature associated with climate change in the GOA is the Aleutian Low (Wilson and Overland 1986) The location and intensity of this system affects storm tracks, air temperatures, wind velocities, ocean currents and other key physical factors in the GOA and adjacent land areas Sharp variations, or oscillations, in the location and intensity of the Aleutian Low are the result of physical factors operating both proximally and at great distances from the GOA (Mantua et al 1997) Periodic changes in the location and intensity of the Aleutian Low are related to movements of adjacent continental air masses and the jet stream to oceanography and weather in the eastern tropical Pacific

Astrophysical forces contribute to long-term trends and periodic changes in the climate of the GOA by controlling the amount of solar radiation that reaches earth, or insolation (Rutherford and D'Hondt 2000) Climate also depends on the amount of global insolation and the proportion of the insolation stored by the atmosphere, oceans, and biological systems (Sigman and Boyle 2000) Changes in climate and biological systems occur through physical forcing of controlling factors, such as solar radiation, strength of lunar mixing of water masses, and patterns of ocean circulation Periodic variations in the earth's solar orbit, the speed of rotation and orientation of the earth, and the degree of inclination of the earth's axis in relation to the sun result in periodic changes in climate and associated biological activity

Understanding climatic change requires sorting out the effects of physical forcing factors that operate simultaneously at different periods Periodicities of physical forcing on factors potentially controlling climate and biological systems include are 100,000 years, 41,000 years, 23,000 years, 10,000 years, 20 years, 18 6 years, and 10 years, among many others For example, Minobe (1999) identified periods of 50 and 20 years in an analysis of the North Pacific Index (NPI) (Figure 7 3) (Minobe 1999) The NPI is a time series of geographically averaged sea-level pressures representing a univariate (depending on only one random variable) measure of location for the Aleutian Low (Trenberth and Hurrell 1994)

Advances and retreats of icefields and glaciers mark major changes in weather and biology Changes in the seasonal and geographic distribution of solar radiation are thought to be primarily responsible for the periodic advance and recession of glaciers during the past two million years (Hays et al 1976) The amount of solar radiation reaching earth changes periodically, or oscillates, in response to variations in the path of the earth's orbit about the sun. Geographic and seasonal changes in solar radiation caused by periodic variations in the earth's orbit around and orientation toward the sun have been labelled "Milankovich cycles," which are known to have characteristic frequencies of 100,000, 41,000, and 23,000 years (Berger et al 1984) Shifts in the periodicity of long-term weather patterns correspond to shifts from one Milankovich cycle to another. How and why shifts from one Milankovich cycle to another occur are among the most important questions in paleoeclimate research (Hays et al 76, Rutherford and D'Hondt 2000)

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7.4.2 Long Time Scales

7.4.2.1 Orbital Eccentricity and Obliquity

Shifts in the periodicity of glaciation from 41,000 to 100,000 years between 1.5 and 0.6 million years before present (Myr bp) emphasize the importance of the atmosphere and oceans in translating the effects of physical forcing into weather cycles. Glacial cycles may have initially shifted from the 41,000-year period of the "obliquity cycle" to the 100,000-year period of the "orbital eccentricity" perhaps caused initially by changes in the heat flux, from the equator to the higher latitudes (Rutherford and D'Hondt 2000). (Obliquity is the angle between the plane of the earth's orbit and the equatorial plane.) According to the theory advanced by Rutherford and D'Hondt (2000), interactions between long-period physical forcing (Milankovich cycles) and shorter-period forcing (precession) may have been a key factor in lengthening the time period between glaciations in the transition period of 1.5 and 0.6 Myr bp. Transitions from glacial to interglacial periods may be triggered by factors such as the micronutrient iron (Martin 1990) that control the activity of the biological pump in the Southern Ocean, described below.

Theories about regulation of heat flux from the equator to northern latitudes are central to understanding climate change. For example, the heat flux that occurs when the Gulf Stream moves equatorial warmth north to surround the United Kingdom, Iceland, and Northern Europe defines comfortable human life styles in these countries Anything that disrupts this heat flux process would drastically alter climate in Northern Europe

7.4.2.2 Day Length

Day length is increasing by one to two seconds each 100,000 years primarily because of lunar tidal action (U S Naval Observatory) Understanding the role of day length in climate variation is problematic because the rotational speed of the earth cannot be predicted exactly due to the effects of a large number of poorly understood sources of variation Short-term effects are probably inconsequential biologically, because variations in daily rotational speed are very small, but cumulative effects could be more substantial in the long term

7.4.2.3 Carbon Cycling and the Biological Pump

Changes in the amount of solar radiation available to drive physical and biological systems on earth are not the only causes of climate oscillations in the GOA, or elsewhere in earth Of critical importance to life on earth, changes in insolation result in changes in the amount of a "greenhouse gas," carbon dioxide in the atmosphere resulting from changes in physical properties, such as ocean temperature, and due to biological processes collectively known as the biological pump (Chisholm 2000) The importance of the biological pump in determining levels of atmospheric carbon dioxide is thought to be substantial, since the direct physical and chemical effects of changes in insolation on the carbon cycle alone (Sigman and Boyle 2000) (Figure 7.4) are not sufficient to account for the magnitude of the changes in atmospheric carbon dioxide between major climate changes, such as glaciations

The Biological Pump Photosynthesis and respiration by marine plants and animals play key roles in the global carbon cycle by "pumping" carbon dioxide from the atmosphere to the surface ocean and incorporating it into organic carbon during photosynthesis Organic carbon not liberated as carbon dioxide during respiration is "pumped" (exported) to deep ocean water where bacteria convert it to carbon dioxide Over a period of about 1,000 years, ocean currents return the deep water's carbon dioxide to the surface (through upwelling) where it again drives photosynthesis and ventilates to the atmosphere. The degree to which this deep-water's carbon dioxide is "pumped" back into the atmosphere or "pumped" back into deep water depends on the intensity of the photosynthetic activity, which depends on availability of the macronutrients phosphate, nitrate, and silicate, and on micronutrients such as reduced iron (Chisholm 2000)

Areas where nitrates and phosphates do not limit phytoplankton production, such as the Southern Ocean (60°S), can have very large effects on the global carbon cycle through the action of the biological pump When stimulated by the micronutrient iron, the biological pump of the Southern Ocean becomes very strong because of the presence of ample nitrate and phosphate to fuel photosynthesis, as demonstrated by the Southern Ocean Iron Release Experiment

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(SOIREE) at 61°S 140°E in February 1999 (Boyd et al. 2000). SOIREE stimulated phytoplankton production in surface waters for about two weeks fixing up to 3,000 metric ton (mt) of organic carbon. Although it has not been demonstrated that "iron fertilization" increases export of carbon to deep waters (Chisholm 2000), it clearly does enhance surface production. The Southern Ocean and much of the GOA share the equality of being "high nitrate, low chlorophyll" waters, so it is tempting to speculate that iron would play an important role in controlling production, if not export production, in the GOA.

The Carbon Cycle. An accounting of changes in the amount of carbon in each component of the earth's terrestrial and ocean carbon cycles (Sigmon and Boyd, Figure 7.4), as influenced and represented by the physical and chemical factors of ocean temperature, dissolved inorganic carbon, ocean alkalinity, and the deep reservoir of the nutrients phosphate and nitrate, has to incorporate changes in the strength of the ocean's biological pump to be complete (Sigman and Boyle 2000). The amount of atmospheric carbon dioxide decreases during glacial periods. Because physical-chemical effects do not fully account for these changes, the ruling hypothesis is that the biological pump is stronger during glaciations. But why would the biological pump be stronger during glaciations?

Two leading theories explain decreases in atmospheric carbon dioxide by means of increased activity in the ocean's biological pump during glaciations (Sigman and Boyle 2000) Both theories explain how increased export production of carbon from surface waters to long-term storage in deep ocean waters can lower atmospheric carbon dioxide during glacial periods The Broecker theory develops mechanisms based on increasing export from low- to mid-latitude surface waters (Broecker 1982, McElroy 1983), and the second theory relies on high-latitude export production of direct relevance to the GOA Patterns and trends in nutrient use in high-latitude oceans, such as the GOA, where nutrients usually do not limit phytoplankton production, could hold the key to understanding climate oscillations

7.4.2.4 Ocean Circulation

Because of the heat energy stored in seawater, oceans are vast integrators of past climatic events, as well as agents and buffers of climate change Wind, precipitation, and other features of climate shape surface ocean currents (Wilson and Overland 1986), and ocean currents in turn strongly feed back into climate Deep ocean waters driven by thermohaline circulation in the Atlantic and southern oceans influence air temperatures over these portions of the globe by transporting and exchanging large quantities of heat energy with the atmosphere (Peixoto and Oort 1992) Patterns of thermohaline (affected by salt and temperature) ocean circulation probably change during periods of glaciation (Lynch-Stieglitz et al 1999) The nature of changes in patterns of thermohaline circulation appear to determine the duration and intensity of climate change (Ganopolski and Rahmstorf 2001) Although the climate of the GOA is not directly affected by thermohaline circulation, climate in the GOA is influenced by thermohaline circulation through climatic linkages to other parts of the globe

Teleconnection between North Pacific and the Tropical Pacific can periodically strongly influence levels of coastal and interior precipitation Because changing patterns in precipitation alter the expression of the ACC (Figure 7.5), which is largely driven by runoff (Royer 1981a), periodically changing weather patterns such as the Pacific Decadal Oscillation (PDO) and the El Niño Southern Oscillation (ENSO) can profoundly alter the circulation and biology of the GOA (See Section 7.2.2.3.)

The effects of the cool ACC and the warmer Alaska Stream moderate air temperatures GOA ocean temperatures are important in determining climate in the fall and early winter in the northern GOA and may be influential at other times of the year Because the cool glacially influenced waters of the ACC moderate air temperatures along the coast, the strength and stability of the ACC are important in determining climate



Figure 7.5 Schematic surface circulation fields in the Gulf of Alaska and mean annual precipitation totals from coastal stations (black vertical bars) and for the central gulf (Baumgartner and Reichel 1975).

7.4.3 Multi-decadal and Multi-annual Time Scales

7.4.3.1 Precession and Nutation

Short period changes in the seasonal and geographic distribution of solar radiation are also due to changes in the earth's orientation and rotational speed (day length) (Lambeck 1980). Wobbling (precession) and nodding (nutation) of the earth as it spins on its axis are primarily due to the fluid nature of the atmosphere and oceans, the gravitational attraction of sun and moon, and the irregular shape of the planet.

Small periodic variations in the length of the day occur with periods of 18.6 years, 1 year, and 60 other periodic components. The periodic components are due to both lunar and solar tidal forcing. In addition to its effect on day length, lunar tidal forcing with a period of 18.6 years has been associated with highlatitude climate forcing, periodic changes in intensity of transport of nutrients by tidal mixing, and periodic changes in fish recruitment (Royer 1993, Parker et al. 1995). Biological and physical effects of the lunar tidal cycle may extend beyond effects associated with tidal mixing. About one-third of the energy input to the sea by lunar forcing serves to mix deep-water masses with adjacent waters (Egbert and Ray 2000). Oscillations in the lunar energy input could contribute to oscillations in biological productivity through effects on the rate of transport of nutrients to surface waters The lunar tidal cycle appears to be approximately synchronous with the PDO

Contemporary climate in the GOA is defined by large-scale atmospheric and oceanic circulation on a global scale Two periodic changes in ocean and atmospheric conditions are particularly useful for understanding change in the climate of the GOA, the PDO and the ENSO Although weather patterns in the Arctic and North Atlantic are also correlated with weather in the North Pacific, these relations are far from clear The PDO, ENSO, and other patterns of climate variability combine to give the GOA a variable and sometimes severe climate that serves as the incubator for the winter storms that sweep across the North American continent through the Aleutian storm track (Wilson and Overland 1986)

Increased understanding of the PDO has been made possible by simple yet highly descriptive indices of weather, such as the North Pacific Index (NPI) These indices are discussed below Changes in the annual values of these indices led to the realization that weather conditions in the GOA sometimes change sharply from one set of average conditions to a different set during a period of only a few years These rapid climatic and oceanographic regime shifts are associated with similarly rapid changes in the animals and plants of the region that are of vital interest to government, industry, and the general public

7.4.3.2 Pacific Decadal Oscillation

The PDO and associated phenomena appear to be major sources of oceanographic and biological variability (Mantua et al 1997) Associated with the PDO are three semi-permanent atmospheric pressure regions dominating climate in the northern GOA-the Siberian and East Pacific high-pressure systems and the Aleutian Low These regions have variable, but characteristic, seasonal locations A prominent feature of the PDO and the climate of the GOA is the Aleutian Low, for which average geographic location changes periodically during the winter Wintertime location of the Aleutian Low affects ocean circulation patterns and sealevel pressure patterns It is characteristic of two climatic regimes a southwestern locus called a negative PDO regime (as in 1972) and a northeastern locus called a positive PDO (1977) (Figures 7 6 and 7 7) The location of the Aleutian Low in the winter appears to be synchronized with annual abundances and strength of recruitment of some fish species (Hollowed and Wooster 1992, Francis and Hare 1994) The Aleutian Low averages about 1,002 millibars (Favorite et al 1976), is most intense in winter, and appears to cycle in its average position and intensity with about a 20- to 25-year period (Rogers 1981, Trenberth and Hurrell 1994)

The PDO is studied with multiple indices, including the anomalies of sea level pressure (as in the NPI, which is discussed below), anomalies of sea surface temperature, and wind stress (Mantua et al 1997, Hare et al 1999) The PDO changes, or oscillates, between positive (warm) and negative (cool) states (Figures 7.8 and 7.9) In decades of positive PDOs, below-normal sea surface


Figure 7.6 Oceanic circulation patterns in the far eastern Pacific Ocean proposed for negative PDO (left) and positive PDO (right) (Hollowed and Wooster 1992).



Figure 7.7 Mean sea-level pressure patterns from the winters of 1972 (left) and 1977 (right) (Emery and Hamilton 1985).

temperatures occur in the central and western North Pacific and above normal temperatures occur in the GOA. An intense low pressure is centered over the Alaska Peninsula, resulting in the GOA being warm and windy with lots of precipitation. In decades of negative PDOs, the opposite sea surface temperature and pressure patterns occur.

The NPI, a univariate time series representing the strength of the Aleutian Low, shows the same twentieth-century regimes defined by the PDO. The NPI is the anomaly, or deviation from the long-term average, of geographically averaged sealevel pressure in the region from 160° E to 140° W, 30° to 65° N, for the years 1899 to 1997 (Trenberth and Hurrell 1994, Trenberth and Paolino 1980). The NPI was used to identify climatic regimes in the twentieth century, for the years 1899 to 1924, 1925 to 1947, 1948 to 1976, and 1977 to 1997, and to explore the interactions of short (20-year) and long (50-year) period effects on the timing of regime shifts. Negative (cool) PDOs occurred during 1890 to 1924 and 1947 to 1976, and positive (warm) PDOs dominated from 1925 to 1946 and from 1977 to about 1995 (Mantua et al. 1997, Minobe 1997). Minobe's analysis of the NPI identified a characteristic



Positive PDO Index

Biological Production/ Transport



Figure 7.8 Schematic of physical processes during the winter in a positive PDO climatic regime in the Gulf of Alaska from offshore to nearshore areas showing the Alaska Current and the Alaska Coastal Current.

S-shaped waveform with a 50-year period (sinusoidal pentadecadal) (Figure 7.3). His analysis pointed out that rapid transitions from one regime to another could not be fully explained by a single sinusoidal-wavelike effect. The speed with which regime shifts occurred in the twentieth century led Minobe to suggest that the pentadecadal cycle is synchronized or phase locked with another climate variation on a shorter bidecadal time scale (Anderson and Munson 1972).

In addition to periodic and seasonal changes, there is evidence that the Aleutian storm track has shifted to an overall more southerly position during the

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Negative PDO Index





Figure 7.9 Schematic of physical processes during the winter in a negative PDO climatic regime in the Gulf of Alaska from offshore to nearshore areas showing the Alaska Current and the Alaska Coastal Current.

twentieth century (Richardson 1936, Klein 1957, Whittaker and Horn 1982, Wilson and Overland 1986).

7.4.3.3 El Niño Southern Oscillation

The ENSO is a weather pattern originating in the equatorial Pacific with strong influences as far north as the GOA (Emery and Hamilton 1985). ENSO is marked by three states: warm, normal, and cool (Enfield 1997). Under normal conditions,

the water temperatures at the continental boundary of the eastern Pacific are around 20° C, as cold bottom waters (8° C) mix with warmer surface water to form a large pool of relatively cool water of the coast of Peru When an El Niño (warm) event starts, the pool of cool coastal water at the continental boundary becomes smaller and smaller as warm water masses (20° C to 30° C) from the west move on top of them, and the sea level starts to rise At full El Niño, increases in the surface water temperatures of as much as 5 4° C have been observed very close to the coast of Peru El Niño also brings a sea level rise along the Equator in the eastern Pacific Ocean of as much as 34 centimeters, as warm buoyant waters moving in from the west override cooler, denser water masses at the continental boundary In a cool La Niña event, the sea levels are the opposite from an El Niño, and relatively cool (less than 20° C) waters extend well offshore along the equator Note that the sea surface temperature changes associated with ENSO events extend well into the GOA

The ENSO has effects in some of the same geographic areas as PDO, but there are two major differences between these patterns First, an ENSO event does not last as long as a PDO event, and second an ENSO event starts, and is easiest to detect, in the eastern equatorial Pacific, whereas PDO dominates the eastern North Pacific, including the GOA The simultaneous occurrence of two major weather patterns in one location illustrates Minobe's point that multiple forcing factors with different characteristic frequencies must be operating simultaneously to create regime shifts (Figure 7 3)

7.5 Marine-Terrestrial Connections

The role of marine inputs to the watershed phase of regional biogeochemical cycles has been recognized for some time (Mathisen 1972) Experiments in artificial and natural streams have shown that *chlorophyll a* and the biomasses of the

biofilm (bacteria and molds) and aquatic macroinvertebrates, such as insects, increase as the amount of salmon carcass biomass increases *Chlorophyll a* has been observed to increase over the full range of carcass biomass, whereas increases in macroinvertebrates stop at some limiting value of carcass loading (Wipfli et al 1998, Wipfli et al 1999) Salmon carcasses stimulate production of multiple trophic levels, including decomposers, in watersheds by providing carbon and nutrients In earlier studies of an Alaskan stream containing Chinook salmon, Piorkowski (1995) supported the hypothesis of Wipfli et al (1998) that salmon carcasses can be important in structuring aquatic food webs In particular, microbial composition and diversity may determine the ability of the stream ecosystem to use nutrients from salmon carcasses, a principal source of marine nitrogen

Marine nutrients and carbon move from the marine environment into terrestrial species in the watersheds of the GOA (Wipfli et al 1999), as has been shown to be the case in anadromous fish-bearing watersheds elsewhere in the north Pacific region (Bilby et al 1996) The following species have been found to transport marine nutrients within watersheds

- Anadromous species, such as salmon (Kline et al 1993, Ben-David et al 1998a),
- Marine-feeding land animals, such as river otters (Ben-David et al 1998b) and coastal mink (Ben-David et al 1997a),
- Opportunistic scavengers as riverine mink (Ben-David et al 1997a), wolf (Szepanski et al 1999), and martens (Ben-David et al 1997b), and
- Riparian zone plants such as trees (Bilby et al 1996)

In theory, any terrestrial plant or animal species that feeds in the marine environment or that receives nutrients from anadromous fish, such as Harlequin duck or Sitka spruce, is a pathway to the watersheds for marine carbon and nutrients Species that contain marine nutrients are widely distributed throughout watersheds, as determined from levels of marine nitrogen in juvenile fish, invertebrates, and aquatic and riparian plants (Bilby et al 1996, Piorkowski 1995, Ben-David et al 1998a, 1998b) The role of marine nutrients in watersheds is key to understanding the relative importance of climate and human-induced changes in population levels of birds, fish, and mammals Indeed, losses of basic habitat productivity because of low numbers of salmon entering a watershed (Kline et al 1993, Mathisen 1972, Piorkowski 1995, Finney et al 2000) may be confused with the effects of fisheries interceptions or marine climate trends Comparison of anadromous fish-bearing streams to non-anadromous streams has demonstrated differences in productivities related to marine nutrient cycling Import of marine nutrients and food energy to the lotic (flowing water) ecosystem may be retarded in systems that have been denuded of salmon for any length of time (Piorkowski 1995)

Paleoecological studies (which focus on ancient events) in watersheds bearing anadromous species can shed light on long-term trends in marine productivity Use of marine nitrogen in sediment cores from freshwater spawning and rearing areas to reconstruct prehistoric abundance of salmon offers some insights into long-

As agencies grapple with implementation of ecosystem-based management, conservation actions are likely to focus more on ecosystem processes and less on single species term trends in climate, and into how to separate the effects of climate from human impacts such as fishing and habitat degradation (Finney 1998, Finney et al 2000)

Watershed studies linking the freshwater and marine portions of the regional ecosystem could pay important benefits to natural resource management agencies As agencies grapple with implementation of ecosystem-based management, conservation actions are likely to focus

more on ecosystem processes and less on single species (Mangel et al 1996) In the long-term, protection of Alaska's natural resources will require extending the protection now afforded to single species, such as targeted commercially important

salmon stocks, to ecosystem functions (Mangel et al 1996) In process-oriented conservation (Mangel et al 1996), production of ecologically central vertebrate species is combined with measures of the production of other species and measures of energy and nutrient flow among trophic levels to identify and protect ecological processes such as nutrient transport Applications of ecological process measures in Alaska ecosystems have shown the feasibility and potential importance of such measures (Kline et al 1990, Kline et al 1993, Mathisen 1972, Piorkowski 1995, Ben-David et al 1997a, 1997b, 1998a, 1998b, Szepanski et al 1999), as have applications outside of Alaska (Bilby et al 1996, Larkin and Slaney 1997)

7.6 Physical and Geological Oceanography Coastal Boundaries and Coastal and Ocean Circulation

7 6 1 Physical Setting, Geology, and Geography

The GOA includes the continental shelf, slope, and abyssal plain of the northern part (north of 50° N) of the northeastern Pacific Ocean It extends 3,600 kilometers (km) westward from 127° 30′ W near the northern end of Vancouver Island, British Columbia, to 176° W along the southern edge of the central Aleutian Islands (Figure 7 10) It includes a continental shelf area of about 3 7 x 10⁵ km² (110,000 square nautical miles [Lynde 1986]) The area of the shelf amounts to about 17 percent of the entire Alaskan continental shelf area (2 86 x 10⁶ km² total) and approximately 12 5percent of the total continental shelf of the United States (McRoy and Goering 1974) This vast oceanic domain sustains a rich and diverse marine life that supports the economic and subsistence livelihood for both Alaskans and people living in Asia and North America The GOA is also an important transportation corridor for vessels carrying cargo to and from Alaska and vessels traveling the Great Circle Route between North America and Asia

The high-latitude location and geological history of the GOA and adjacent landmass strongly influence present-day regional meteorology, oceanography, and sedimentary environment The northern extension of the Cascade Range, with mountains ranging in altitude from 3 to 6 km, rings the coast from British Columbia to Southcentral Alaska (Royer 1982) The Aleutian Range spans the Alaska Peninsula in the western GOA and contains peaks exceeding 1000 m in elevation. All of the mountains are young and therefore provide plentiful sources of sediment to the ocean The region is seismically active because it lies within the converging boundaries of the Pacific and North American plates The motions of these plates control the seismicity, tectonics, volcanism, and much of the morphology of the GOA and make this region one of the most tectonically active regions on earth (Jacob 1986) Indeed, tectonic motion continuously reshapes the seafloor through faulting, subsidence, landslides, tsunamis, and soil liquefaction



Figure 7.10a Shelf topography of the northern Gulf of Alaska and adjacent waters (Martin 1997).

For example, as much as 15 m of uplift occurred over portions of the shelf during the Great Alaska Earthquake of 1964 (Malloy and Merrill 1972, Plafker 1972, von Huene et al. 1972). These geological processes influence ocean circulation patterns, delivery of terrestrial sediments to the ocean, and reworking of seabed sediments.

Approximately 20 percent of the GOA watershed is covered by glaciers today (Royer 1982) making the region the third greatest glacial field on earth (Meier 1984). The glaciers reflect both the subpolar, maritime climate and the regional distribution of mountains, or orography, of the GOA (see Section 7.3) of the GOA. The climate setting includes high rates of precipitation and cool temperatures, especially at high altitudes, that enhance the formation of the icefields and glaciers. The icefields are both a source and sink for the fresh water delivered to the ocean. In some years the glaciers gain and store the precipitation as ice and snow; in other years, the stored precipitation is released into the numerous streams and rivers draining into the GOA. Glacial scouring of the underlying bedrock provides an abundance of fine-grained sediments to the GOA shelf and basin (Hampton et al.



Figure 7.10b Shelf topography of the northern Gulf of Alaska and adjacent waters (Martin 1997).

1986). The major inputs of glacial sediment are the Bering and Malaspina glaciers and the Alsek and Copper rivers in the northern GOA and the Knik, Matanuska, and Susitna rivers that feed Cook Inlet in the northwest GOA (Hampton et al. 1986).

The bathymetry, or bottom depth variations, of the GOA reflects the diverse and complex geomorphological processes that have worked the region during millions of years. The GOA abyssal plain gradually shoals from a 5,000-m depth in the southwestern GOA to less than 3000 m in the northeastern GOA. Maximal depths exceed 7,000 m near the central Aleutian Trench along the continental slope south of the Aleutian Islands. Numerous seamounts, remnants of subsea volcanoes associated with spreading centers in the Pacific lithospheric plate (at the earth's crust), are scattered across the central basin. Several of the seamounts or guyots (flat-topped seamounts) rise to within a few hundred meters of the sea surface and

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provide important mesopelagic (middle depth of the open sea) habitat for pelagic (open sea) and benthic (bottom) marine organisms

The continental shelf varies in width from about 5 km off the Queen Charlotte Islands in the eastern GOA to about 200 km north and south of Kodiak Island Along the Aleutian Islands, the shelf break is extremely narrow or even absent, as depths plunge rapidly north and south of the island chain. The numerous passes between these islands control the flow between the GOA and the Bering Sea, with depths (and inflow) generally increasing in the westerly direction (Favorite 1974) In the eastern Aleutians, most of the passes are shallow and nairow, the largest being Amukta Pass with a maximal depth of 430 m and an area of about 20 km² (Favorite 1974) Unimak Pass is the easternmost pass (of oceanographic significance) and connects the southeast Bering Sea shelf directly to the GOA shelf near the Shumagin Islands This pass is about 75 m deep and has a cross-sectional area of about 1 km² (Schumacher et al 1982)

The shelf topography in the northern GOA is enormously complex because of both tectonic and glacial processes (Figures 7 10a and b) Numerous troughs and canyons, many oriented across the shelf, punctuate the sea floor Subsea embankments and ridges abound as a result of subsidence, uplift, and glacial moraines These geological processes have also shaped the immensely complicated coastline that includes numerous silled and unsilled fjords, embayments, capes, and island groups

The northwestern GOA includes several prominent geological features that influence the regional oceanography Kayak Island, which extends about 50 km across the shelf east of the mouth of the Copper River, can deflect inner shelf waters offshore Interaction of shelf currents with this island can also spawn eddies that transport nearshore waters, which have a high suspended sediment load, onto the outer shelf (Ahlnaes et al 1987)

PWS, which lies west of Kayak Island, is a large complex, fjord-type estuarine system with characteristics of an inland sea (Muench and Heggie 1978) The sound communicates with the GOA shelf through Hinchinbrook Entrance in the eastern sound and Montague Strait and several smaller passes in the western sound. The shelf is relatively shallow (about 125 m deep) south of Hinchinbrook Entrance and along the eastern shore of Montague Strait. Hinchinbrook Canyon, however, has depths of about 200 m and extends southward from Hinchinbrook Entrance and opens onto the continental slope. This canyon is a potentially important conduit by which slope waters can communicate directly with sound. Central PWS is about 60 km by 90 km with depths typically in excess of 200 m and a maximal depth of about 750 m in the northern sound. The entrances to PWS are guarded by the shelf, sills, or both of about 180-m depth. Numerous islands are scattered throughout the sound and bays, fjords, and numerous glaciers are interspersed along its rugged coastline.

Several silled fjords indent the northern GOA coast, between PWS and Cook Inlet Inner fjord depths can exceed 250 m, which are greater than the depths over the adjacent shelf To the west of the Kenai Peninsula is Cook Inlet, which extends about 275 km from its mouth to Anchorage at its head The inlet is about 90 km wide at its mouth, narrows to about 20 km at the Forelands some 200 km from the mouth, and then widens to about 30 km near Anchorage Upper Cook Inlet branches into two narrow arms (Turnagain and Knik) that extend inland another 70 km Depths range from 100 m to 150 m at the mouth of Cook Inlet to less than 40 m in the upper end, with the upper arms being so shallow that extensive mudflats are exposed during low tides The bottom topography throughout the inlet reflects extensive faulting and glacial erosion (Hampton et al 1986)

At its mouth, Cook Inlet communicates with the northern shelf through Kennedy Entrance, to the east, and with Shelikof Strait, to the west The latter is a 200-km by 50-km rectangular channel between Kodiak Island and the Alaska Peninsula with numerous fjords indenting the coast along both sides of the strait The main channel, with depths between 150 and 300 m, veers southeastward at the lower end of Kodiak Island and intersects the continental slope west of Chirikof Island Southwest of Shelikof Strait bottom depths shoal to 100 to 150 m, and the shelf is complicated by the passes and channels associated with the Shumagin and Semidi islands

7 6 2 Atmospheric Forcing of GOA Waters

The climate over the GOA is largely shaped by three semi-permanent atmospheric pressure patterns the Aleutian Low, the Siberian High, and the East Pacific High (Wilson and Overland 1986) These systems represent statistical composites of many individual pressure cells moving across the northern North Pacific The climatological position of these pressure systems varies seasonally, as shown in Figure 7.11 From October through April, the cold air masses of the Siberian High deepen over northeastern Siberia, and the East Pacific High is centered off the southwest coast of California From May through September, the Siberian High weakens and the East Pacific High migrates northward to about 40° N and attains its greatest intensity (highest pressure) in June The seasonal changes in intensity and position of these high-pressure systems influence the strength and propagation paths of low-pressure systems (cyclones) over the North Pacific In winter, the Siberian High forces storms into the GOA, and lows are strong, in summer, these systems are weaker and propagate along a more northerly track across the Bering Sea and into the Arctic Ocean.

The low-pressure storm systems that compose the Aleutian Low form in three ways Many are generated in the western Pacific when cold, dry air flows off Asia and encounters northward-flowing, warm ocean waters along the Asian continent Additional formation regions occur in the central Pacific along the Subarctic Front (near 35° N) where strong latitudinal gradients of ocean temperature interact with unstable, winter air masses (Roden 1970) Finally, the GOA can also be a region of



Figure 7.11 Typical summer (left) and winter (right) examples of the Aleutian Low and Siberian High pressure systems. Contours are sea-level pressure in millibars. (Hollowed and Wooster 1987)

active cyclogenesis (low-pressure formation), particularly in winter when frigid air spills southward over the frozen Bering Sea, the Alaska mainland, or both (Winston 1955). Such conditions can be hazardous to mariners because the accompanying high wind speeds and subfreezing air temperatures can lead to rapid vessel icing (Overland 1990).

Regardless of origin, these lows generally strengthen as they track eastward across the North Pacific. This intensification results from the flux of heat and moisture from the ocean to the atmosphere. The lows attain maximal strength (lowest pressure) in the western and central GOA. Once in the GOA, the coastal mountains inhibit inland propagation, so that the storms often stall and dissipate here. Indeed, Russian mariners refer to the northeastern GOA as the "graveyard of lows" (Plakhotnik 1964).

The mountains also force air masses upward, resulting in cooling, condensation, and enhanced precipitation. The precipitation feeds numerous mountain drainages that feed the GOA or, in winter, is stored in snowfields and glaciers where it can remain for periods ranging from months to years.

Seasonal variations in the intensity and paths of these low-pressure systems markedly influence meteorological conditions in the GOA. Of particular importance to the marine ecosystem are the seasonal changes in radiation, wind velocity, precipitation, and coastal runoff. The incoming short-wave radiation that warms the sea surface and provides the energy for marine photosynthesis is strongly affected by cloud cover Throughout the year, cloud cover of more than 75 percent occurs over the northern GOA more than 60 percent of the time (Brower et al 1988), and cloud cover of less

than 25 percent occurs less than 15 percent of the time Interannual variability in cloud cover, especially in summer, can affect sea-surface temperatures and possibly the mixed-layer structure (which also depends heavily on salirity distribution) The anomalously warm surface waters observed in the summer and fall of 1997 were probably due to unusually low cloud cover and mild

Seasonal variations in the intensity and paths of low-pressure systems influence meteorological conditions in the GOA

winds (Hunt et al 1999) The characteristic cloud cover is so heavy that it hinders the effective use of passive microwave sensors, such as Advanced Very High Resolution Radar and Sea-viewing Wide Field of view Sensor (SeaWifs), in ecosystem monitoring

The cyclonic (counterclockwise) winds associated with the low-pressure systems force an onshore surface transport (Ekman transport) over the shelf and downwelling along the coast Figure 7 12 shows the mean monthly upwelling index on the northern GOA shelf This index is negative (implying downwelling) in most months, indicating the prevalence of onshore Ekman transport and coastal convergence Downwelling favorable winds are strongest from November through March, and feeble or even weakly anticyclonic (upwelling favorable) in summer when the Aleutian Low is displaced by the East Pacific High (Royer 1975, Wilson, and Overland 1986) Over the central basin, these winds exert a cyclonic torque (or wind-stress curl) that forces the large-scale ocean circulation

The high rates of precipitation are evident in long-term average measurements Figure 7.5 is a composite of long-term average annual precipitation measurements from stations around the GOA Precipitation rates of 2 to 4 meters per year (m-yr¹) are typical throughout the region, but rates in southeast Alaska and PWS exceed 4 m-yr¹ Except over the Alaska Peninsula in the western GOA, the coastal precipitation rates are much greater than the estimated net precipitation rate of 1 m-yr¹ over the central basin (Baumgartner and Reichel 1975) The coastal estimates are undoubtedly biased because most of the measurements are made at sea level and therefore do not fully capture the influence of altitude on the precipitative flux

Figure 7 12 also includes the mean monthly coastal discharge from Southeast and Southcentral Alaska as estimated by Royer (1982) On an annual average this freshwater influx is enormous and amounts to about 23,000 m³ s¹, or about 20 percent greater than the mean annual Mississippi River discharge, and accounts for nearly 40 percent of the freshwater flux into the GOA This runoff enters the shelf mainly through many small (and ungauged) drainage systems, rather than from a few major rivers Consequently, the discharge can be thought of as a diffuse, coastal "line" source around the GOA perimeter, rather than arising from a few,



Figure 7 12 Mean monthly upwelling index 1946 to 1999 (red) and mean monthly coastal discharge 1930 to 1999 (blue) (Royer 1982 2000) in the northern GOA Negative values of the Index imply onshore Ekman transport and coastal downwelling Discharge is shown in cubic meters per second a measure of flow

large "point" sources The discharge is greatest in early fall and decreases rapidly through winter, when precipitation is stored as snow There is a secondary runoff peak in spring and summer, because of snowmelt (Royer 1982) The phasing and magnitude of this freshwater flux is important, because salinity primarily affects water densities (and therefore ocean dynamics) in the northern GOA

Figure 7 12 shows that the seasonal variation in wind stress and freshwater discharge is large, but also that these variables are not in-phase with one another, downwelling is maximal in winter and minimal in summer, whereas discharge is maximal in fall and minimal in late winter Both winds and buoyant discharge affect the vertical density stratification and contribute to the formation of horizontal pressure (and density) gradients over the shelf and slope The wind field over the shelf is spatially coherent (Livingstone and Royer 1980) because the scales of the storm systems that enter the GOA are comparable to the size of the basin The alongshore coherence of the wind field and the distributed nature of the coastal discharge suggest that forcing by winds and buoyancy is approximately uniform along the length of the shelf Both the winds and buoyant flux force the mean cyclonic alongshore flow over the GOA shelf and slope (Reed and Schumacher 1986, Royer 1998), as shown schematically in Figure 7 5 On the inner shelf, the flow consists of the ACC, and over the slope, it consists of the Alaska Current (eastern and northeastern GOA) and the Alaskan Stream (northwestern GOA) These current systems are extensive, swift, and continuous over a vast alongshore extent Thus, the shelf and slope are strongly affected by advection (transport of momentum, energy, and dissolve and suspended materials by ocean currents), implying that climate perturbations, even those occurring far from the GEM study area, can be efficiently communicated into the northwestern GOA by the ocean

circulation The strong advection also implies that processes occurring far upstream might substantially influence biological production within the GEM area

7 6 3 Physical Oceanography of the Gulf of Alaska Shelf and Shelf Slope

The GOA shelf can be divided on the basis of water-mass structure and circulation characteristics into three domains

- The inner shelf (or ACC domain) consisting of the ACC,
- The outer shelf, including the shelf-break front, and
- The mid-shelf region between the inner and outer shelves

Because the boundaries separating these regions are dynamic, their locations vary in space and time Although dynamic connections among these domains undoubtedly exist, the nature of these links is poorly understood

The ACC is the most prominent aspect of the shelf circulation It is a persistent circulation feature that flows cyclonically (westward in the northern GOA) throughout the year This current originates on the British Columbian shelf (although in some months or years, it might originate as far south as the Columbia River [Royer, T C 1998, Thomson et al 1989]), about 2,500 km from its entrance into the Bering Sea through Unimak Pass, in the western GOA (Schumacher et al 1982)

The ACC is a swift (20 to 180 centimeters per second [cm s⁻¹] [0 4 to 3 6 knots]), coastally trapped flow typically found within 35 km of the shore (Royer 1981b, Johnson et al 1988, Stabeno et al 1995) Much or all of the ACC loops through southern PWS, entering through Hinchinbrook Entrance and exiting through Montague Strait (Niebauer et al 1994) Therefore, the ACC potentially is important to the circulation dynamics of PWS, clearly, it is a critical advective and migratory path for material and organisms between the GOA and sound West of PWS, the ACC branches northeast of Kodiak Island The bulk of the current curves around the mouth of Cook Inlet and continues southward through Shelikof Strait (Muench et al 1978), the remainder flows southward along the shelf east of Kodiak Island (Stabeno et al 1995) Although there are no long-term (multivear) estimates of transport in the ACC, direct measurements (Schumacher et al 1990, Stabeno et al 1995) along the Kenai Peninsula and upstream of Kodiak suggest an average transport of about 0.8 Sverdrup (Sv, a unit of flow equal to 1 million cubic meters per second [1 Sv equals 10⁶ m³ s⁻¹]), with a maximum in winter and a minimum in summer

The large annual cycle in wind and freshwater discharge is reflected in the mean monthly temperatures and salinities at hydrographic station GAK 1, near Seward, on the inner shelf (Figure 7 13) Mean monthly sea-surface temperatures range from about 3 5° C in March to about 14° C in August The amplitude of the annual temperature cycle, however, diminishes with depth, with the annual range



Figure 7.13 The mean annual cycle of temperature (upper) and salinity (lower) at various depths at station GAK1 on the inner shelf of the northern GOA. The monthly estimates are based on data collected from 1970 through 1999. (The figure includes updated information [Xiong and Royer 1984].)

being only about 1°C at depths greater than 150 m. Surface temperatures are colder than subsurface temperatures from November through May, and the water column has little thermal stratification from December through May.

Surface salinities range from a maximum of about 31 practical salinity units (psu) in late winter to a minimum of 25 psu in August. Vertical salinity (density) gradients are minimal in March and April and maximal in the summer months.

Surface stratification commences in April or May (somewhat earlier in PWS), as cyclonic wind stress decreases and runoff increases, and is greatest in mid- to late summer The inner shelf and PWS stratify first, because runoff initially is confined to nearshore regions and only gradually spreads offshore through ocean processes Solar heating provides additional surface buoyancy by warming the upper layers uniformly across the shelf However, the thermal stratification remains weak until late May or June As winds intensify in fall, the stratification erodes, resulting from stronger vertical mixing and increased downwelling, which causes surface waters to sink along the coast

Within the ACC, the annual amplitude in salinity diminishes with depth and has a minimum of about 0.5 psu at about the 100-m depth. At greater depths, the annual amplitude increases but the annual salinity cycle is out of phase with nearsurface salinity changes. For example, at and below the 150 m depth, the salinity is minimal in March and maximal in late summer-early fall. The phase difference between the near-surface and near-bottom layers reflects the combined influence of winds and coastal discharge. In summer, when downwelling relaxes, salty, nutrient-rich water from offshore invades the inner shelf (Royer 1975). The upper portion of the water column is freshest in summer, when the winds are weak (little mixing) and coastal discharge is increasing. Vertical mixing is strong through the winter and redistributes fresh water, salt, and possibly nutrients throughout the water column

The effects of the seasonal cycle of wind and buoyancy forcing are also reflected in both the hydrographic properties and the along-shore velocity structure of the shelf The seasonal transitions in temperature and salinity properties are shown in Figure 7 14, which is constructed from cross-shore sections along the Seward Line in the northern GOA for April (representative of late winter), August (summer), and October (fall)

The ACC domain, or inner shelf, is within 50 km of the coast From February through April, the vertical and cross-shelf gradients of salinity and temperature are weak, and the ACC front lies within about 10 km of the coast and extends from the surface to the bottom. Vertical shears (gradients) of the along-shelf velocity are weak and the current dynamics are primarily wind-driven and barotropic (controlled by sea-surface slopes setup by the winds) at this time (Johnson et al 1988, Stabeno et al 1995). In summer (late May to early September), the vertical stratification is large, but cross-shelf salinity (and density) gradients are weak. The ACC front extends from 30 to 50 km offshore and usually no deeper than 40 m. The along-shelf flow is weak, although highly variable, in summer. Vertical stratification weakens in fall, but the cross-shelf salinity gradients and the ACC front are stronger than at other times of the year. As coastal downwelling increases, the front moves shoreward to within 30 km of the coast and steepens so that the base of the front intersects the bottom between the 50 and 100 m isobaths.



Figure 7.14 Seasonal cross-shore distributions of temperature (left) and salinity (right) along the Seward Line in the northern GOA. The graphs are based on data collected in 1999 as part of the GOA GLOBEC program (Weingartner 2001). The vertical axis is in pressure units (decibars [db]), with 1 db the equivalent of about 1 m.

Theory (Garrett and Loder 1981, Yankovsky and Chapman 1997, Chapman and Lentz 1994, Chapman 2000) suggests that seasonal variations in the ACC frontal structure should strongly influence the vertical and horizontal transport and mixing of dissolved and suspended material, both across and along the inner shelf. Royer et al. (1979) showed that surface drifters released seaward of the ACC front first drifted onshore (in accordance with Ekman dynamics) and then drifted alongshore upon encountering the ACC front. Conversely, Johnson et al. (1988) showed that, inshore of the front, the surface layer spreads offshore, with this offshore flow increasing as discharge increases in fall. Taken together, these results suggest cross-frontal convergence arising from differing dynamics on either side of the ACC front. Buoyancy effects dominate at the surface inshore of the front (at least for part of the year), wind forcing dominates offshore of the front Convergence across the front would tend to accumulate plankton along the frontal boundary, possibly attracting foraging fish, seabirds, and marine mammals (Haldorson 2001) The front might also be a region of significant vertical motions Downwelling velocities of about 30 meters per day (m-d¹) in the upper 30 m of the water column are possible in fall (This estimate is based on the assumption that the cross-frontal convergence occurs over a frontal width of 15 km with an onshore Ekman flow of 3 cm-s⁻¹ seaward of the front and an offshore flow of ~15 cm-s⁻¹ [Johnson et al 1988] inshore of the front)

PWS is an important part of the GOA ecosystem providing both habitat to numerous organisms and being a potential sink and source for dissolved and suspended materials carried by shelf waters The sound has a large central basin of about 60 by 90 km Depths in the central basin are about 350 m deep However, maximum depths exceed 750 m in the northwest sound and are typically about 500 m along the western side of the sound It is surrounded by numerous bays and fjords that provide a diversity of habitats for marine organisms (Schmidt 1977, Niebauer et al 1994, Gay III, S M and Vaughan 2001) The mountains and glaciers that ring PWS comprise its watershed and provide a plentiful supply of freshwater and sedument to the sound through numerous streams and rivers Flow through this semi-enclosed sea is generally counterclockwise with shelf waters entering through Hinchinbrook Entrance in the east and exiting through Montague Strait in the west The circulation varies seasonally in accordance with the seasonal cycle of winds and runoff, and it appears that the clockwise circulation might reverse seasonally, or at least occasionally, in summer with surface waters exiting through Hinchinbrook Entrance and entering through Montague Strait (Vaughan et al 2001) Most of the exchange with the shelf occurs with the ACC as indeed at least a portion if not most of the ACC flows through the lower sound However, Hunchinbrook Entrance can also communicate directly with the continental slope through Hinchinbrook Canyon, which extends from the entrance southward for more than 100 km to the shelfbreak Deep water exchange appears to be most prominent in the summer, however, deep water inflow events occur throughout the year (Niebauer et al 1994, Vaughan et al 2001) The canyon therefore represents a potential conduit by which slope waters can enter the sound Because these deep waters are relatively rich in nutrients they could be important to the nutrient budgets of the sound and may provide an advective pathway by which oceanic plankton can be carried into the sound Reliable transport estimates of mass and property exchanges between the sound and the shelf are not available, although Niebauer et al (1994) suggest that as much as 40 percent of the sound's volume is exchanged in summer (May – September) and 200 percent of the volume is exchanged in winter (October through April) While these estimates need to be verified, they nevertheless suggest efficient exchange between the shelf and sound and imply that the sound ecosystem is intimately linked to shelf processes Water property distributions and stratification in the sound are generally similar to those of the ACC on the shelf However, because of the sheltering effects of land, the

sound water column stratifies earlier in spring and persists longer in fall than does the shelf

The mid-shelf domain covers the region between the ACC and the shelfbreak Cross-shelf temperature and salinity gradients are weak in all seasons In general, the strongest horizontal density gradients occur within the bottom 50 m of the water column, probably associated with the inshore location of the shelfbreak front (which does not always have a surface expression) The bottom of the shelfbreak front is generally found farther inshore in summer than in fall or winter Over the upper portion of the mid-shelf water column, the vertical stratification is largely controlled in most months by salinity, although vertical salinity gradients are weaker here in summer and fall than on the inner shelf Consequently, in summer, thermal stratification plays an important role in stratifying the mid-shelf water column Here, the along-shelf flow is weakly westward on average because of the feeble horizontal density gradients It should also vary seasonally strengthening in the winter and weakening in the summer in accordance with the winds However, both the flow and horizontal density gradients are highly variable because of energetic mesoscale (10 – 50 km) flow features Potential sources for the mesoscale variability include (1) separation of the ACC from capes (Ahlnaes et al 1987), (2) instabilities of the ACC (Mysak et al 1981, Bogard et al 1994), (3) interactions of the shelf flow with topography (Lagerloef 1983), and (4) meandering of the Alaska Current along the continental slope (Niebauer et al 1981) This mesoscale variability is very difficult to quantify, for it depends on spatial variations in the coastline and the bottom topography and on seasonal variations in the winds and shelf density structure Nevertheless, these mesoscale features appear to be biologically significant For example, Incze et al (1989), Vastano et al (1992), Schumacher and Kendall, (1991), Schumacher et al (1993), and Bogard et al (1994) show the coincidence between larval pollock numbers and the presence of eddies in Shelikof Strait Moreover, the nutritional condition of first-feeding larvae is significantly better inside than outside of eddies (Canino et al 1991) Although the mid-shelf region is poorly studied and understood compared to other portions of the GOA shelf and slope, it is critically involved in the cross-shelf transport and vertical mixing of nutrients, sediments, organisms, heat, and salt At the very least it serves as an important link between the inner shelf and the continental slope

The mid-shelf domain covers the region between 50 and 125 km from the coast Here cross-shelf temperature and salinity gradients are weak in all seasons. In general, the strongest horizontal density gradients occur within the bottom 50 m of the water column, probably associated with the inshore location of the shelf-break front (which does not always have a surface expression). The bottom of the shelfbreak front is generally found farther inshore in summer than in fall or winter Over the upper portion of the mid-shelf water column, the vertical stratification is largely controlled by salinity in most months, although vertical salinity gradients are weaker here in summer and fall than on the inner shelf. Consequently, in summer, thermal stratification plays an important role in stratifying the mid-shelf water column. Here, the along-shelf flow is weakly westward on average because of the feeble horizontal density gradients Both the flow and horizontal density gradients are highly variable, however, because of energetic mesoscale (10- to 50-km) flow features Potential sources for the mesoscale variability are as follows

- 1 Separation of the ACC from capes (Ahlnaes et al 1987),
- 2 Instabilities of the ACC (Mysak et al 1981, Bogard et al 1994),
- 3 Interactions of the shelf flow with topography (Lagerloef 1983), and
- 4 Meandering of the Alaska Current along the continental slope (Niebauer et al 1981)

This mesoscale variability is very difficult to quantify, because it depends on spatial variations in the coastline and the bottom topography and on seasonal variations in the winds and shelf density structure Nevertheless, these mesoscale features appear to be biologically significant. For example, Incze et al. (1989), Vastano et al. (1992), Schumacher and Kendall (1991), Schumacher et al. (1993), and Bograd et al. (1994) show the coincidence between larval pollock numbers and the presence of eddies in Shelikof Strait. Moreover, the nutritional condition of firstfeeding larvae is significantly better inside than outside of eddies (Canino et al. 1991).

The inner and mid-shelf domains share two other noteworthy characteristics First, during much of the year, the cross-shelf sea surface temperature contrasts are generally small (about 2°C) The small thermal gradients and heavy cloud cover reduce the utility of thermal infrared radiometry in assessing circulation features and frontal boundaries in the northern GOA

Second, the bottom-water properties of the shelf change markedly throughout the year The above figures show that the high-salinity bottom waters carried inshore are drawn from over the continental slope in summer This inflow occurs annually and probably exerts an important dynamical influence on the shelf circulation by modifying the bottom boundary layer (Gawarkiewicz and Chapman 1992, Chapman 2000, Pickart 2000) It might also serve as an important seasonal onshore pathway for oceanic zooplankton These animals migrate diurnally over the full depth of the water column, during the long summer day length, the zooplankton will spend more time at the bottom than at the surface The bottom flow that transports the high-salinity water shoreward might then result in a net shoreward flux of zooplankton in summer The summertime inflow of saline water onto the inner shelf is one means by which the slope and basin interior communicates directly with the nearshore, because (as discussed below) this water is drawn from within the permanent halocline (depth horizon over which salinity changes rapidly) of the GOA The deep summer inflow is a potentially important conduit for nutrients from offshore to onshore Inflow, however, is not the only means by which nutrient-rich offshore water can supply the shelf Other mechanisms include flow-up canyons intersecting the shelf break (Klinck 1996,

Allen 1996, Allen 2000, Hickey 1997), topographically-induced upwelling (Freeland and Denman 1982), and shelf-break eddies and flow meanders (Bower 1991)

The third domain, consisting of the shelf break and continental slope is influenced by the Alaska Current, which flows along the northeastern and northern GOA, and its transformation west of 150°W, into the southwestward-flowing Alaskan Stream These currents comprise the poleward limb of the North Pacific Subarctic Gyre and provide the oceanic connection between the GOA shelf and the Pacific Ocean The Alaska Current is a broad (300 km), sluggish (5 to 15 cm/s) flow with weak horizontal and vertical velocity shears The Alaskan Stream is a narrow (100 km), swift (100 cm/s) flow with large velocity shear over the upper 500 m (Reed and Schumacher 1986) The stream continues westward along the southern flank of the Alaska Peninsula and Aleutian Islands and gradually weakens west of 180° W (Thomson 1972) The convergence of the Alaska Current into the Alaskan Stream probably entails concomitant changes in the velocity and thermohaline gradients along the shelf break Insofar as these gradients influence fluxes between the shelf and slope (Gawarkiewicz 1991), the transformation of the Alaska Current into the Alaskan Stream implies that shelf-break exchange mechanisms are not uniform around the GOA Moreover, the effects of these exchanges on the shelf will also be influenced by the shelf width, which varies from 50 km or less in the eastern and northeastern GOA to about 200 km in the northern and northwestern GOA

The Alaskan Stream has a mean annual volume transport (flow of water) of between 15 and 20 Sv (Sv=Sverdrup=measure of volume) (Reed and Schumacher 1986, Musgrave et al 1992), and although seasonal transport variations appear small, interannual transport variations may be as great as 30 percent (Royer 1981a) Thomson et al (1990) found that the Alaska Current is swifter and narrower in winter than in summer Surface salinities within the Alaska Current vary by only about 0 5 psu throughout the year, whereas the seasonal change in sea surface temperature (SST) is comparable to that of the shelf (about 10° C) Nevertheless, horizontal and vertical density gradients are controlled by the salinity distribution Maximal stratification occurs between depths of 100 and 300 m and is associated with the permanent halocline of the GOA Halocline salinities range between 33 and 34 psu, and temperatures are between 5° C and 6° C (Tully and Barber 1960, Dodimead et al 1963, Reid Jr 1965, Favorite et al 1976, Musgrave et al 1992) These water-mass characteristics are identical to the properties of the deep water that floods the shelf bottom each summer (Figure 7 14)

Although eddy energies of the Alaskan Stream appear small (Royer 1981a, Reed and Schumacher 1986), significant alteration of the slope and shelf-break circulation is likely during occasional passage of large (200-km-diameter) eddies that populate the interior basin (Crawford et al 1999) Musgrave et al. (1992) show considerable alteration in the structure of the shelf-break front off Kodiak Island during the passage of one such eddy These eddies are long-lived (two to three years) and energetic, having typical swirl speeds of 20 to 50 cm/s (Tabata 1982, Musgrave et al 1992, Okkonen 1992, Crawford et al 1999) They form in the eastern GOA, primarily in years of anomalously strong cyclonic wind forcing along the eastern boundary (Willmott and Mysak 1980, Melsom A et al 1999, Meyers and Basu 1999) and then propagate westward at about 2 to 3 cm/s Most of the eddies remain over the deep basin and far from the continental slope, however, some propagate along the slope, requiring several months to transit from Yakutat to Kodiak Island (Crawford et al 1999, Okkonen 2001)

Eddies that impinge upon the continental slope could significantly influence the shelf circulation and exchanges between the shelf and slope of salt, heat, nutrients, and plankton Their influence on shelf-slope exchange in the northern GOA has not been ascertained, but because they propagate slowly, are long-lived, and form episodically, they could be a source of interannual variability for this shelf. These eddies have many features in common with the Gulf Stream rings that significantly modify shelf properties along the East Coast of the United States (Houghton et al 1986, Ramp 1986, Joyce et al 1992, Wang 1992, Schlitz submitted) In the eastern GOA, Whitney et al (1998) showed that these eddies cause a net offshelf nutrient flux. In the northern GOA, they might have the opposite effect, because nutrient concentrations are generally higher over the slope than on the shelf (Whitledge 2000, Childers 2000)

764 Biophysical Implications

The magnitude of the spring phytoplankton bloom depends on surface nutrient concentrations and water-column stability The annual resupply of nutrients to the euphotic zone is not understood for the inner shelf, however Cross-shelf, surface Ekman transport in winter cannot account for the high nutrient concentrations observed on the inner shelf in spring (Childers 2000, Whitledge 2000) Turbulent mixing during late fall and winter could mix the nutrient-rich deep water (brought onto the shelf in summer) up into the surface layer in time for the spring bloom If so, vernal nutrient levels might result from a two-stage preconditioning process occurring during the several months preceding the spring bloom The first stage occurs in summer and is related to the onshelf movement of saline, nutrient-rich, bottom water as described above The quantity of nutrients carried onshore then depends upon the summer wind field and the properties of the slope source water that contributes to this inflow The second step occurs in fall and winter and depends on turbulence Current instabilities, downwelling-induced convection, and diffusion accomplish the vertical mixing The extent of this mixing depends upon the seasonally varying stratification and the vertical and horizontal velocity structure of the ACC Each of these mechanisms probably varies from year to year, suggesting that spring nutrient concentrations will also vary

Another potentially important nutrient source for the inner shelf in spring is PWS Winter mixing in the sound could bring nutrient-rich water to the surface, where it is exported to the shelf by that portion of the ACC that loops through PWS The timing of the spring bloom depends on development of stratification within the euphotic zone. The euphotic zone extends from the surface to a depth where sufficient light still exists to support photosynthesis. Stratification within the euphotic zone is influenced by freshwater discharge and solar heating Preliminary GLOBEC data (Whitledge 2000, Stockwell 2000) suggest that the spring bloom begins in protected regions of PWS in late March as day length increases and stratification builds as a result of snowmelt, rainfall, and the sheltering effect of the PWS from winds. The bloom on the shelf lags that of PWS by from two to six weeks and may not proceed simultaneously across the shelf. This delay results from the time required to stratify the shelf. Because density is strongly affected by salinity and, therefore, by the spreading of fresh water on the shelf, stratification does not evolve by vertical (one-dimensional) processes phase-locked to the annual solar cycle. Rather, stratification depends primarily on the rate at which fresh water spreads offshore, which is a consequence of three-dimensional circulation and mixing processes intimately associated with ocean dynamics

Several implications follow from this hypothesis First, spring bloom dynamics on the shelf are not as tightly coupled to the solar cycle as on mid-latitude shelves where temperature controls density Second, mixed-layer development depends on processes operating spanning a range of time scales and involves a plethora of variables that affect vertical mixing and the offshore flux of fresh water from the nearshore These variables include the fractions of winter precipitation delivered to the coast as snow and rain, the timing and rate of spring snowmelt (a function of air temperature and cloudiness), and the wind velocity The relevant time scales range from a few days (storm events) to seasonal or longer The long time scales follow from the fact that the shelf circulation, particularly the ACC, can advect the freshwater that contributes to stratification from very distant regions Third, interannual variability in the onset and strength of stratification on the GOA continental shelf is probably greater than for mid-latitude shelves This expectation follows from the fact that several potentially interacting parameters affect stratification, and each or all can vary considerably from year to year Therefore, application of Gargett's (1997) hypothesis of the optimal stability window to the GOA shelf involves more degrees of freedom than its use on either mid-latitude shelves or the central GOA (where temperature exerts primary control on stratification in the euphotic zone)

All of these considerations suggest that stratification probably does not develop uniformly in space or time on the GOA shelf The implications are potentially enormous with respect to feeding opportunities for zooplankton in spring These animals must encounter abundant prey shortly after migrating to the surface from their overwintering depths Emergence from diapause (a period of reduced metabolism and inactivity) is tightly coupled to the solar cycle, rather than the onset of stratification Conceivably then, zooplankton recruitment success might depend on shelf physical processes occurring over a period of several months prior to the onset of the bloom. In particular, the magnitude and phasing of the spring bloom might be preconditioned by shelf processes that occurred throughout the preceding summer and winter Perturbations in the magnitude and phasing of the spring bloom might propagate through the food chain and affect summer and fall feeding success of juvenile fishes (Denman et al 1989)

765 Tides

The tides in the GOA are of the mixed type with the principal lunar semidiurnal (M_2) tide being dominant and the luni-solar diurnal (K_1) tide being, in general, of secondary importance Tidal characteristics (amplitudes and velocities) are strongly influenced by the complex shelf and slope bathymetry and coastal geometry, however Consequently, spatial variations in the tidal characteristics of these two species are large For example, Anchorage has the largest tidal amplitudes in the northern GOA, with the M_2 tide being about 3 6 m and the K_1 tide being about 0.7 m In contrast, the amplitudes of both of these constituents in Kodiak and Seward are less than half those of Anchorage Foreman et al (Foreman et al 2000) found that the cross-shelf flux of tidal energy onto the northwest GOA shelf is enormous and is accompanied by high (bottom) frictional dissipation rates Their model estimates indicate that the tidal dissipation rate in Kennedy Entrance accounts for nearly 50 percent of the total dissipation of the M_2 constituent in the GOA Further, about one-third of the energy of the K₁ tide in the GOA is dissipated in Cook Inlet Some of the energy lost from tides is available for mixing, which would reduce vertical stratification and enhance the transfer of nutrients into the euphotic zone

The interaction of the tidal wave with varying bottom topography can also generate shelf waves at the diurnal frequency and generate residual flows The waves are a prominent feature of the low-frequency circulation along the British Columbian shelf (Crawford 1984, Crawford and Thomson 1984, Flather 1988, Foreman and Thomson 1997, Cummins and Oey 2000) and could affect pycnocline displacements (The pycnocline is a vertical layer across which water density changes are large and stable) The model of Foreman et al (2000) predicts diurnalperiod shelf waves in the northwest GOA and especially along the Kodiak shelf break Although no observations are available to confirm the presence of such waves along the Kodiak shelf, their presence could influence biological production here as well as the dispersal of planktonic organisms Residual flows resulting from non-linear tidal dynamics could (locally) influence the transport of suspended and dissolved materials on the shelf

Seasonal changes in water-column stratification can also affect the vertical distribution of tidal energy over the shelf through the generation of internal (baroclinic) waves of tidal period Such motions are likely to occur in summer and fall in the northwestern GOA where the flux of barotropic tidal energy (which is nearly uniformly distributed over the water column) across the shelf break (Foreman et al 2000) interacts with the highly stratified water column on the shelf The internal waves generated can have small spatial scales (10s of km) in contrast to the large scale (1,000s of km) of the generating barotropic tidal waves

Moreover, the phases and amplitudes of the baroclinic tides will vary with seasonal changes in stratification Although no systematic investigation of internal tides on the GOA shelf has been conducted, Danielson (2000) found that the tidal velocities in the ACC near Seward in winter are about 5 cm/s and are barotropic However, in late summer, tidal velocities in the upper 50 m are about 20 cm/s whereas below 100-m depth they are about 5 cm/s Internal tides will also displace the pycnocline sufficiently to have biological consequences, including the pumping of nutrients into the surface layer, the dispersal of plankton and small fishes, and the formation of transitory and small-scale zones of horizontal divergence and convergence that affect feeding behaviors (Mann and Lazier 1996) Stratified tidal flows might also be significant for some silled fjords The interaction of the tide with the sill can enhance mixing and exchange (Farmer and Smith 1980, Freeland and Farmer 1980) and can resupply the inner fjord with nutrient-rich, high-salinity water and plankton through Bernoulli suction effects (Thompson and Golding 1981, Thomson and Wolanski 1984)

7 6 6 Gulf of Alaska Basın

The circulation in the central GOA consists of the cyclonically (counterclockwise) flowing Alaska Gyre, which is part of the more extensive subarctic gyre of the North Pacific Ocean The center of the gyre is at about 53° N, and 145° to 150° W The gyre includes the Alaska Current and Stream and the eastward-flowing North Pacific Current along the southern boundary of the GOA The latter is a trans-Pacific flow that originates at the confluence of the northwardflowing Kuroshio Current and the southward-flowing Oyashio Current in the western Pacific Some water from the Alaska Stream apparently recirculates into the North Pacific Current, but the strength and location of this recirculation is poorly understood and appears to be extremely variable (Favorite et al 1976) The North Pacific Current bifurcates off of the western coast of North America, with the northward flow feeding the Alaska Gyre and the southward branch entering the California Current The bifurcation zone is located roughly along the zero line in the climatological mean for the wind stress curl The gyral flow reflects the largescale cyclonic wind-stress distribution over the GOA Mean speeds of drifters deployed in the upper 150 m of this gyre (far from the continental slope) are 2 to 10 cm/s, but the variability is large (Thomson et al 1990) These cyclonic winds also force a long-term average upwelling rate of about 10 to 30 m/yr in the gyre center (Xie and Hsieh 1995)

The vertical thermohaline structure of the Alaska Gyre is described by Tully and Barber (1960) and Dodimead et al (1963) and consists of the following components

1 A seasonally varying upper layer that extends from the surface to about the 100-m depth,

- 2 A halocline that extends from 100 m to about the 200-m depth over which salinity increases from 33 to 34 psu and temperatures decrease from 6 to 4° C, and
- 3 A deep layer, extending from the bottom of the halocline to about the 1,000m depth, over which salinity increases more slowly to about 34 4 psu and temperatures decrease from 4° to 3° C

Below the deep layer salinity increases more slowly to its maximal value of about 34 7 psu at the bottom

The seasonal variations of the upper layer reflect the effects of wind-mixing and heat exchange with the atmosphere–essentially one-dimensional mixing processes. The ocean loses heat to the atmosphere from October through March and gains heat from April through September. The upper layer is isohaline and isothermal in winter down to the top of the halocline. At this time, upper-layer salinities range from 32.5 to 32.8 psu, and temperatures range from 4° to 6° C. The upper layer is fresher and colder in the northern GOA and saltier and warmer in the southern GOA. The upper layer gradually freshens and warms in spring, as wind speeds decrease and solar heating increases. A summer mixed layer forms that includes a weak secondary halocline and a strong seasonal thermocline, with both centered at about the 30 m depth. The seasonal pycnocline erodes and upper layer properties revert to winter conditions as cooling and wind-mixing increase in fall.

The halocline is a permanent feature of the Subarctic North Pacific Ocean and represents the deepest limit over which winter mixing occurs within the upper layer The halocline results from the high (compared with other ocean basins) rates of precipitation and runoff in conjunction with large-scale, three-dimensional circulation and interior mixing processes occurring over the North Pacific (Reid Jr 1965, Warren 1983, Van Scoy et al 1991, Musgrave et al 1992) The strong density gradient of the halocline effectively limits vertical exchange between saline and nutrient-rich deep water and the upper layer The deep waters of the GOA consist of the North Pacific Intermediate Water (formed in the northwestern Pacific Ocean) and, at greater depths, contributions from the North Atlantic Mean flows in the deep interior are feeble (1 cm/s), and the flow dynamics are governed by both the climatological wind stress distribution (Koblinsky et al 1989) and the global thermohaline circulation (Warren and Owens 1985) modified by the bottom topography The thermohaline circulation carries nutrient-rich waters into the North Pacific and forces a weak and deep upwelling throughout the region (Stommel and Arons 1960a, 1960b, Reid 1981)

7.7 Chemical Oceanography: Marine Nutrients and Fertility The overall fertility of the GOA depends primarily on nutrient resupply from deep-water sources to the surface layer were plants grow Rates of carbon fixation by phytoplankton in the euphotic zone are limited seasonally and annually by changing light levels and the kinds and supply rates of several dissolved inorganic chemical species Three elements-nitrogen, phosphorus, and silicon-are essential to the photosynthetic process (Parsons et al 1984) Other dissolved inorganic constituents such as iron are also believed to control rates of photosynthesis at some locations and times (Freeland et al 1997, Martin and Gordon 1988, Pahlow and Riebsell 2000)

Organic matter synthesized by plants in the lighted surface layer is consumed there or sinks down into the deeper water column where some may eventually reach the seabed The unconsumed portion is oxidized to inorganic dissolved forms by bacteria at all depths In the euphotic zone, inorganic nutrients excreted by zooplankton and by micronekton and macronekton (fish), liberated by bacterial oxidation (a process referred to as remineralization), or both excreted and liberated are immediately recycled by phytoplankton (Nekton is swimming marine life) In contrast, living cells, organic detritus (remains of dead organisms), and fecal pellets that escape the euphotic zone by sinking are remineralized below the lighted upper layer, and the resulting inorganic forms are lost to surface plant stocks The result of these combined processes leads to vertical distributions of dissolved inorganic nitrogen, phosphorus, and silicon in which the surface concentrations are much lower than those found deeper in the water column Such is the case for the GOA (Reeburgh and Kipphut 1986) Geostrophic (shaped by the earth's rotation) and wind-forced upwelling and deep seasonal overturn provide local mechanisms that bring nutrient enriched deep water back into the surface layer each year (Schumacher and Royer 1993) Additionally, at depths shallower than about 100 m, tidal mixing resulting from friction across the bottom can interact with the windmixed surface layer to provide an intermittent avenue for surface nutrient replenishment during all seasons

Concentrations of the dissolved inorganic forms of nitrogen (nitrate, nitrite, and ammonia), phosphorus (phosphate), and silicon (silicate) occur at some of the highest levels measured anywhere in the deep waters of the GOA (Mantyla and Reid 1983) A permanent pycnocline, resulting from the relatively low salinity of the upper 120 to 150 m, limits access to this valuable pool, however, deep winter mixing rarely reaches below about 110 m in waters over the deep ocean (Dodimead et al 1963, Favorite et al 1976) Although upwelling occurs in the center of the Alaska Gyre, it is believed to be only on the order of a meter (or considerably less) per day (Sugimoto 1993, Xie and Hsieh 1995), a relatively modest rate compared to some regions of high productivity like the Peru or Oregon coastal upwellings Away from the Alaska Gyre upwelling along the northern continental margin of the GOA, the prevailing winds drive a predominately downwelling environment over the shelf for seven to eight months each year Although this condition usually moderates during the summer, there is little evidence that wind-forced coastal upwelling is ever well developed Instead, during the period of relaxed downwelling or sporadic and weak upwelling, a rebound of isopycnal (density boundaries, waters having the same densities) surfaces along the shelf edge permits the run-up of dense slope water onto and across the shelf This subsurface water, containing elevated concentrations of dissolved nutrients, flows into the deeper

coastal basins and fjords (Muench and Heggie 1978, Heggie and Burrell 1981) Presumably the timing and duration of this coastal bottom renewal is related to the nature of the Pacific High pressure dominance in the GOA each summer

The coastal and inshore waters in the northern GOA are also influenced by runoff from a large number of streams, rivers, and glaciers in the rugged coastal margin In these areas that are largely untouched by agriculture, this input

probably contributes little to the coastal nutrient cycle, except possibly as a source for silicon and iron (Burrell 1986) Therefore, the major pool of plant nutrients for water column production in ocean, shelf, and coastal regions is derived from marine sources and resides in the deep waters below the surface production zone

The major pool of plant nutrients for water column production in ocean, shelf, and coastal regions is in deep waters

Because light limits carbon fixation during the winter months, there is a strong seasonal signal in nutrient concentrations of the euphotic zone in upper-layer shelf, coastal, and inside waters During the winter, dissolved inorganic plant nutrients build their concentrations in the deepening wind-mixed layer as deeper, nutrient rich water becomes involved in the seasonal overturn at a time when uptake by phytoplankton is minimal Under seasonal light limitation, surface nutrient concentrations probably peak in early March, just before the onset of the annual plankton production cycle By mid- to late-May and early June, euphotic zone nutrients are drawn down dramatically to seasonal lows as the stratification that initiates the spring "bloom" of plant plankton severely restricts the vertical flux of new nutrients (Goering et al 1973) Nitrate can become undetectable or nearly so during the summer months in many shelf and coastal areas, and ammonia (excreted by grazers) becomes important in sustaining the much-reduced primary productivity Later in fall, with the onset of the Aleutian Low and the storms that it produces, a cooling and deepening wind-mixed layer can reinject sufficient new nutrients into a shrinking euphotic zone to initiate a fall plant bloom in some years (Eslinger et al 2001)

The strong seasonal signal of nutrients and plant stocks evident on the continental shelf is diminished in surface waters seaward of the shelf break in the GOA The region beyond the continental shelf break is described as "high nutrient, low chlorophyll" It was believed historically that grazing by a collective of large calanoid copepods (species of zooplankton endemic to the subarctic Pacific) consumed enough plant biomass each year to control the overall productivity below levels needed to completely exhaust the surface nitrogen (Heinrich 1962, Parsons and Lalli 1988)

More recently, iron limitation has been posed as a mechanism controlling primary production in the GOA and in several other offshore regions of the world's oceans (Martin and Gordon 1988) Contemporary research in the GOA has revealed that control of the amount of food produced by phytoplankton through grazing of zooplankters is probably important, although the species of zooplankton involved are not the large calanoid copepods (Dagg and Walser 1987, Frost 1991, Dagg 1993) Production of phytoplankton is thought to be controlled by an assemblage of microzooplankters, microconsumers, represented by abundant ciliate protozoans and small flagellates, rather than by large calanoid copepods (Booth et al 1993) Because the growth rates of these grazers are higher than those of the plants, it is hypothesized that these microconsumers are capable of efficiently tracking and limiting the overall oceanic productivity by eating the primary producers, the phytoplankton (Banse 1982) The control mechanism is made possible because the plant communities are dominated by very small cells, 10 micrometers or less, that can serve as food for the microconsumers

A counter-hypothesis asserts that the small size of the plants is actually in response to low levels of iron. It is known that faced with nutrient limitation, phytoplankton communities generally shift to small-sized species whose surfacearea-to-volume ratios are high. Resolution of these related ideas is sought in continuing studies of the oceanic production cycle.

Surprising recent observations demonstrate a trend in increasing temperatures in the upper layers that may be causing a shift in the seasonal nutrient balance offshore (Freeland et al 1997, Polovina et al 1995) For the first time, there are reports that nitrogen has been drawn down to undetectable levels along line P in the southern GOA out to a distance of 600 km from the coast (Welch 2001) Line P is an oceanographic transect run by the Canadian government that is the oldest source of data from the southern GOA In addition, the evidence provided by Welch indicates that the winter mixed layer is shoaling under long-term warming conditions

An essential issue for the GEM Program will be to understand how, at a variety of spatial and temporal scales, the supply rates of inorganic nitrogen, phosphorus, silicon, and other essential nutrients for plant growth in the euphotic zone are mediated by climate-driven physical mechanisms in the GOA Inorganic nutrient supplies might be influenced by climate changes in the following ways

- Upwelling in the Alaska Gyre,
- Deep winter mixing,
- Shelf and coastal upwelling and downwelling,
- Vertical transport in frontal zones and eddies, and
- Deep and shallow cross-shelf transports

In addition to these mechanisms, the ACC may play a role that has yet to be determined in the supply rates of dissolved inorganic nutrients to nearshore habitats (Schumacher and Royer 1993) Finally, the import of marine-derived nitrogen associated with the spawning migrations of salmon and other anadromous fishes has been described as a novel means by which the oceanic GOA enriches the terrestrial margin each year This allochthonous input (food from an outside source) to the drainages bordering the GOA is clearly important in many freshwater nursery areas hosting the early life stages of Pacific salmon (Finney 1998) and must vary with interannual and longer-term changes in salmon abundance

7.8 Biological Oceanography Plankton and Productivity

7 8 1 Plankton Investigations in the Gulf of Alaska

Much of what is presently understood about the plankton communities and their productivity in the GOA has arisen from several programs examining the open ocean and shelf environments These programs have included the following-

- U S -Canada NORPAC surveys (LeBrasseur 1965),
- Subarctic Pacific Ecosystem Research (SUPER) project of the National Science Foundation (NSF) (Miller 1993),
- The multi-decadal plankton observations from Canadian Ocean Station P (OSP) and Line P (McAllister 1969, Fulton 1983, Frost 1983, Parsons and Lalli 1988),
- Annual summer Japanese vessel surveys by Hokkaido University (Kawamura 1988),
- The Outer Continental Shelf Energy Assessment Program (OCSEAP) by Minerals Management Service (MMS) and National Oceanic and Atmospheric Administration (NOAA) (Hood and Zimmerman 1986), and
- The Shelikof Strait Fisheries Oceanography Cooperative Investigation (FOCI) study by NOAA and NMFS (Kendall et al 1996)

Additional and more recent programs include the North Pacific GLOBEC of the NSF and those supported by the EVOS Trustee Council The above-mentioned programs and a few other studies provide a reasonably coherent first-order picture of the structure and function of lower trophic levels in the northeastern subarctic

Pacific Ocean A serious gap in the detailed understanding of relationships between the observed inshore and offshore production cycles remains, however-namely how these quite different ecosystems are phased through time and interact at their boundaries over the shelf As a result, information is lacking about how the effects of future climate change may manifest in food webs supporting higher level consumers

It is not understood how the quite different ecosystems of lower trophic levels in the northeastern subarctic Pacific Ocean are phased through time and interact at their boundaries over the shelf

CHAPTER 7

782 Seasonal and Annual Plankton Dynamics

The composition, distribution, abundance, and productivity of plant and animal plankton communities in the GOA have been reviewed by Sambrotto and Lorenzen (1986), Cooney (1986), Miller (1993), and Mackas and Frost (1993) In general, dramatic differences are observed between pelagic communities over the deep ocean, and those found in shelf, coastal, and protected inside waters (sounds, fjords, and estuaries) Specifically, the euphotic zone seaward of the shelf edge is dominated year round by very small phytoplankters-tiny diatoms, naked flagellates, and cyanobacteria (Booth 1988) Most are smaller than 10 microns in size, and their combined standing stocks (measured as chlorophyll concentration) occur at very low and seasonally stable levels It was originally hypothesized that a small group of large oceanic copepods (Neocalanus spp and Eucalanus bungu) limited plant numbers and open ocean production by efficiently controlling the plant stocks through grazing (Heinrich 1962) More recent evidence, however, indicates the predominant grazers on the oceanic flora are not the large calanoids (Dagg 1993), but instead abundant populations of ciliate protozoans and heterotrophic microflagellates (Miller et al 1991a, 1991b, Frost 1993) It has been further suggested that in these high nutrient, low chlorophyll oceanic waters, very low levels of dissolved inorganic iron (coming mainly from atmospheric sources) are ultimately responsible for structuring the composition of the primary producers and consumers (Martin and Gordon 1988, Martin 1991) Close reproductive and trophic coupling between the nanophytoplankton and microconsumers appears to restrict levels of primary productivity below that needed to exhaust all of the seasonally available nitrogen each year (Banse 1982) Moreover, the excreta of the microconsumers is diffuse, with low sinking rates, and is easily oxidized by bacteria Ammonia (derived from grazer-released urea) is a preferred plant nutrient, and the first oxidation product recycled in this way Wheeler and Kokkınakıs (1990) demonstrated that as long as ammonia is available for the plants, nitrate uptake in the euphotic zone is much reduced Together, these findings are painting a considerably revised picture of lower trophic level relationships and nutrient balances at the base of the offshore pelagic ecosystem in the GOA

In contrast, shelf, coastal, and inside waters host a more traditional plankton community in which large and small diatoms and dinoflagellates support a copepod-dominated grazing assemblage (Sambrotto and Lorenzen 1986, Cooney 1986) Here, the annual production cycle is characterized by well-defined spring (and sometimes fall) blooms of large diatom species (most larger than 50 microns) whose productivities are limited annually by the rapid utilization of dissolved inorganic nitrogen, phosphorus, and silicon in the euphotic zone (Eslinger et al 2001, Ward 1997) These blooms typically begin in late March and early April in response to a seasonal stabilization of the winter-conditioned deep mixed layer High rates of photosynthesis typically last only four to six weeks (Goering et al 1973) Strong periods of wind, tidal mixing, or both during the bloom can prolong these events by interrupting the conditions of light and stability needed to support plant growth When the phytoplankton bloom is prolonged in this way, its intensity is lessened, but considerably more organic matter is apparently directed into pelagic food webs, rather than sinking to feed seabed consumers (Eslinger et al 2001) Accelerated seasonal warming and freshening of the upper layers in May and June provide increasing stratification that eventually restricts the vertical flux of new nutrients and limits summer primary productivity to very low levels. In some years, a fall bloom of diatoms occurs in September and October in response to a deepening wind-mixed layer and enhanced nutrient levels. The ecological significance of the fall portion of the pelagic production cycle remains largely undescribed.

In both the ocean and shelf domains, strong seasonal signals occur in standing stocks and estimates of daily and annual rates of production for the phytoplankton and zooplankton Some of the earliest measurements of photosynthesis at OSP placed the annual primary production in the southern part of the Alaska Gyre at about 50 grams of carbon per square meter per year (g C m² y ¹) (McAllister 1969), or somewhat lower than the overall world ocean average of 70 g C m 2 y 1 More recent studies using other techniques, however, have suggested higher annual rates, somewhere between 100 to 170 g C m 2 y $^{-1}$ (Welschmeyer et al 1993) Unlike the production cycle over the shelf, the oceanic primary productivity does not produce an identifiable spring/summer plant bloom Instead, the oceanic phytoplankton stock remains at low levels (about 0.3 milligrams [mg] of *chloi ophyll* $a \,\mathrm{m}^{3}$) year-round for reasons discussed above In stark contrast, oceanic stocks of zooplankton (upper 150 m) do exhibit marked seasonality Late winter values of 5 to 20 mg m³ (wet weight) rise to 100 to 500 mg m³ in mid-summer, when upperlayer populations of large calanoids dominate the standing stock Assuming the zooplankton production is roughly 15 percent of the oceanic primary productivity (Parsons 1986), annual estimates of zooplankton carbon production estimated from primary productivity range between 8 and 26 g C m² Given that the carbon content of an average zooplankter is approximately 45 percent of the dry weight, and that dry weight is about 15 percent of the wet weight (Omori 1969), the carbon production can be converted to estimates of biomass Results from this calculation suggest that between 119 and 385 g of biomass m² may be produced each year in the upper layers of the oceanic regime from sources thought to be largely zooplankton

The shelf, coastal, and inside waters present a mosaic of many different pelagic habitats. The open shelf (depths less than 200 m) is narrow in the east between Yakutat and Kayak Island (20 to 25 km in some places), but broadens in the north and west beyond the Copper River (about 100 to 200 km). The shelf is punctuated by submarine canyons and deep straits, but also rises to extensive shallow shoals at some locations. The rugged northern coastal margin is characterized by numerous islands, coastal and protected fjords, and estuaries. Only PWS is deeper than 400 m.

Although the measurements are sparse, the open shelf and coastal areas of the northern GOA are believed to be quite productive, particularly the region between

PWS and Shelikof Strait (Sambrotto and Lorenzen 1986) Coastal transport and turbulence along the Kenai Peninsula, in lower Cook Inlet, and around Kodiak and Afognak islands appears to enhance nutrient supplies during the spring and summer Annual rates of primary production approaching 200 to 300 g C m 2 y 1 have been described In other coastal fjords, sounds, and bays, the estimates of annual primary production range from 140 to more than 200 g C m 2 y 1 (Goering et al 1973, Sambrotto and Lorenzen 1986) Assuming again that the annual zooplankton production is roughly 15 percent of the primary productivity, yearly zooplankton growth in shelf and coastal areas probably ranges between about 21 and 45 g C m 2 y $^{-1}$, or 311 to 667 g m 2 y 1 wet weight In PWS, the wet-weight biomass of zooplankton caught in nets (net-zooplankton) in the upper 50 m varies from a low in February of about 10 mg m³ to a high of more than 600 mg m³ in June and July (Cooney et al 2001a) For selected other coastal areas outside PWS, the seasonal range of zooplankton biomass includes winter lows of about 40 mg m³ to spring/summer highs approaching 5,000 mg m³ (in outer Kachemak Bay, for which a conversion of settled volumes may have been contaminated by large phytoplankton in the samples, see (Cooney 1986)

In addition to strong seasonality in standing stocks and rates of production, plankton communities also exhibit predictable seasonal species succession each year in the oceanic and shelf environments. Over the shelf, the large diatom-dominated spring bloom gives way to dinoflagellates and other smaller forms as nutrient supplies diminish in late May and early June. Ward (1997) described the phytoplankton species succession in PWS. She found that early season dominance in the phytoplankton bloom was shared by the large chain-forming diatoms. *Skeletonema, Thalassiosina,* and *Chaetoceros*. Later in June, under post-bloom nutrient restriction, diatoms were dominated by smaller *Rhizosolenia* and tiny flagellates. This seasonal shift in dominance from larger to smaller plant species in response to declining nutrient concentrations and supply rates is commonly observed in other high-latitude systems and is believed to be responsible for driving the succession in the grazing community.

The zooplankton succession is somewhat more complex and involves interchanges between the ocean and shelf ecosystems In the late winter and spring, the early copepodite stages of *Neocalanus* spp begin arriving in the upper layers from deepwater spawning populations (Miller 1988, Miller and Nielsen 1988, Miller and Clemons 1988) This arrival occurs in some coastal areas (at depths of more than 400m) in late February and early March, but is delayed about thirty days in the open ocean Both *Neocalanus* spp and *Eucalanus bungu* are interzonal seasonal migrators, living a portion of their life cycle in the upper layers as developing copepodites, and later resting in diapause in the deep water preparing for reproduction at depth While maturing in the oceanic surface water, *Neocalanus plumchrus* and *N flemingeri* inhabit the wind-mixed layer above the seasonal thermocline (upper 25 to 30 m), while *N cristatus* (the largest of the subarctic copepods) and *Eucalanus bungu* are found below the seasonal stratification (Mackas et al 1993) This unusual partitioning of the surface ocean environment by these species has not yet been verified for shelf and coastal waters, although it has been suggested that the partitioning may occur in the deep-water fjords and sounds (Cooney unpublished)

Along with the early copepodites of the interzonal migrators, the late winter and spring shelf zooplankton community also hosts small numbers of Pseudocalanus spp, Metridia pacifica, M okhotensis, and adult Calanus maishallae Because these copepods must first feed before reproducing, their seasonal numbers and biomass are set by the timing, intensity and duration of the diatom bloom By May and early June, the abundances of small copepods like Pseudocalanus and Acan tra are increasing, but the community biomass is often dominated by relatively small numbers of very large developmental stages (C4 and C5) of *Neocalanus* (Cooney et al 2001a) After Neocalanus leaves the surface waters in late May and early June for diapause deep below the surface (at locations where depths permit), Pseudocalanus, Acarta, and Centropages (small copepods), the pteropod Limicina pacifica, and larvaceans (Okioplein a and Fritillana) occur in increasing abundance Later, from summer to fall and extending into early winter, carnivorous ellyplankters represented by ctenophores, small hydromedusae, and chaetognaths (Sagitta elegans) become common These shifting seasonal dominants are joined by several different euphausuds (Euphausia and Thysanoessa) and amphipods (Cyphocans and Parathemisto) throughout the year Despite the fact that the subarctic net-zooplankton community consists of a large number of different types of animal (taxa), most of the biomass and much of the abundance in the upper 100 m is accounted for by fewer than two dozen species (Cooney 1986)

783 Interannual and Decadal-Scale Variation in Plankton Stocks

Few measurements and estimates are available for year-to-year and decadalscale variability in primary and secondary productivity in all marine environments in the northern GOA (Sambrotto and Lorenzen 1986) Fortunately, some information is available about variable levels of zooplankton stocks Frost (1993) described interannual changes in net-zooplankton sampled from 1956 to 1980 at Canadian OSP Year-to-year variations in stocks of about a factor of five were characteristic of that data set, and a slight positive correlation with salinity was

observed Cooney et al (2001b) examined an 18-year time series of zooplankton settled volumes from eastern PWS collected near salmon hatcheries by the personnel of the Prince William Sound Aquaculture Corporation, Cordova Once again, annual springtime differences of about a factor of five were apparent in that data In

Few measurements are available for variability of marine environment productivity in the northern GOA

addition, from 1981 to 1991, settled zooplankton volumes in PWS were also strongly and positively correlated with the strength of the Bakun upwelling index calculated for a location near Hinchinbrook Entrance This correlation completely disappeared after 1991, however (Eslinger et al 2001) Also of some interest, the years of highest settled volumes in eastern PWS (1985 and 1989) were only moderate years for zooplankton reported by Incze et al (1997) for Shelikof Strait, suggesting the Kodiak shelf and PWS regions were phased differently for at least those years Sugimoto and Tadokoro (1997) report a regime shift in the subarctic Pacific and Bering Sea in the early 1990s that generally resulted in lower zooplankton stocks in both regions Perhaps in response to this phenomenon, springtime settled zooplankton volumes in PWS also declined by about 50 percent after 1991 (Cooney et al 2001b)

The most provocative picture of decadal-scale change in zooplankton abundance in the GOA is provided by Brodeur and Ware (1992) (Figure 7 15) With the use of spatially distributed oceanic data sets reporting zooplankton biomass from 1956 to 1962, and again from 1980 to 1989, these authors were apparently able to capture large-scale properties of the pelagic production cycle during both positive and negative aspects of the PDO (Mantua et al 1997) A doubling of netzooplankton biomass was observed under conditions of increased winter winds responding to an intensified Aleutian Low (the decade of the 1980s) This sustained doubling of biomass was also reflected at higher trophic levels in the offshore food web (Brodeur and Ware 1995) It is generally believed the observed production stimulation during the decade of the 1980s was created by increased nutrient levels associated with greater upwelling in the Alaska Gyre The observed horizontal pattern of upper layer zooplankton stocks (Figure 7 15) was an impressive areal expansion (positive PDO) or contraction (negative PDO) Under periods of intensified winter winds, some of the highest oceanic zooplankton concentrations were developed in a band along the shelf edge in the northern regions in the GOA Unfortunately, data from the shelf itself during this same time period are not sufficient to ascertain how this elevated biomass may have intruded the continental margin or reached the coastal areas

784 Factors Effecting Trophic Exchanges Between the Plankton and Larger Consumers

Most would concede that the general theory of trophodynamics articulated by Lindeman (1942) nearly fifty years ago to represent ways in which matter and energy are transferred through aquatic communities (by different levels of producers and consumers) is an overly simplistic picture of complex interactions and non-linear relationships. Useful in the lecture hall as a teaching tool, and successfully applied to certain problems where first-order estimates of production at hypothetical levels are sought based on estimates of plankton productivity, these formulations usually lack any dynamic connection with the physical environment or nutrient levels. They also generally fail to delineate seasonality or other important temporal variability. Nonetheless, because of the ease of their application and the acceptance of certain simplifying assumptions (generalized ecological transfer efficiencies and lumping taxa within trophic levels), the linear food-web or carbon budget approach continues to be used for selected purposes

Bottom-up trophic models of food web structure supporting the production of fishes, birds, and mammals in open ocean, slope, estuarine, and fjord environments in the GOA were formulated by Parsons (1986) in a synthesis of information



Figure 7.15 Biomass of plankton for the spring and summer period contrasted for a negative PDO period (top) and a positive PDO period (bottom). The shaded boxes present zooplankton biomass as follows: A represents 100 to 200 g/1,000 m³, B represents 201 to 300 g/m³, and C represents more than 300 g/m^3 . (Brodeur and Ware 1992)

compiled primarily as the result of the Minerals Management Service (MMS)funded Outer Continental Shelf (OCS) studies. More recently Okey and Pauly (1998) developed a mass balance formulation with the Ecopath model of trophic mass balance for a PWS food web as the result of the EVOS Restoration Program. These models are certainly instructive at some level of generality, but their usefulness for describing specific climate-related mechanisms that might modify food-web transfers is probably limited by their detachment from the physical

CHAPTER 7
environment and their reliance on annually or seasonally averaged stock sizes and productivities

Instead, it may be more instructive to examine how evolved behavioral traits and other aspects of the life histories of the dominant plankters (and other forage taxa) lend themselves to food-web transfers that could be affected by climate change To do this, it will be important to study how the biology at lower trophic levels interacts (on a variety of time and space scales) with the physical environment to create enhanced (or diminished) trophic opportunities in the consumer matrix of different habitats and seasonal characterizations that pervade the marine ecosystem in the northern GOA The compressed nature of the annual plankton production cycle in oceanic, shelf, and coastal waters seemingly places a premium on "timing" as a strategy to maximize the chances for successfully linking consumers to each year's burst of organic matter synthesis Paul and Smith (1993) found that yellowfin sole replenished their seasonally depleted energy reserves each year in a short period of about one month following the peak in primary productivity This rapid replenishment of energy reserves is presumably possible because of the structural properties of forage populations that occur abundantly during the short and intense production cycle Patch-dependent feeding is a term used to describe how many consumers respond to the grainy time and space distributions of food in their feeding environments (Valiela 1995) In the case of plankters, which by definition move with the water, temporal and spatial patchiness can be created or dissipated through interactions with (1) physical processes such as vertical and horizontal transport and diffusion, and (2) biological attributes such as rapid growth and swarming or layering in association with feeding, reproductive behaviors, or both

For example, the more than two month maturation process for the large oceanic copepods (Neocalanus spp) growing in the near-surface of the open ocean, shelf, and some coastal environments concludes with a short period (fifteen to thirty days) in which the biomass peaks each year, is concentrated in the largest (C4 and C5) copepodites, and is compressed into relatively thin layers and swarms contiguous for tens, possibly hundreds of km (Mackas et al 1993, Cooney 1989, Coyle 1997, Kirsch et al 2000) In its most concentrated form, this seasonally ephemeral biomass is an important source of food for diving sea birds (Coyle 1997), whales, and planktivorous fishes such as adult Alaska pollock and Pacific herring (Willette et al 1999) Acoustic observations suggest the degree of plankton swarming or layering depends, in part, on the strength of water column mixing and stability Numerical models of the production cycle in PWS demonstrated that interannual variations in the timing of the annual peak in zooplankton probably reflects differences in the timing of the earlier phytoplankton bloom each year Eslinger et al (2001) reported that the spring diatom bloom varied by as much as three weeks from year to year in PWS, but that the annual peak in zooplankton always lagged the plants by about twenty-five to thirty days Year-to-year shifts of a week or more in the peak of zooplankton biomass may profoundly influence the effectiveness of food-web transfers to fishes, birds, and other consumers with

severe consequences Pacific herring have apparently evolved a reproductive strategy to place age-0 juveniles in the water column precisely at the time of the mid-summer peak in plankton forage Failure to successfully provision themselves by missing the most optimal summer feeding conditions may contribute to high rates of winter starvation for age-0 herring in PWS (Cooney et al 2001b)

In another example, Cooney (1983) reported a possible interaction between the movements occurring over the life cycle of large oceanic calanoid zooplankton, ontogentic migrations and an enrichment of feeding habitats for fishes, birds, and mammals over the shelf forced by localized convergences in the late winter and spring months As pieviously mentioned, Neocalanus spp arrive in the surface waters of the deep ocean in March and April each year Early copepodite stages are presumably carried across the shelf in the wind-forced Ekman flow (upper 60 to 90 m) where they eventually encounter zones of surface convergence (Cooney 1986) *Neocalanus* spp in the shelf environment depends on the spring diatom bloom for growth and maturation Because the developing copepodites have an affinity for the upper layers where the phytoplankton production occurs (Mackas et al 1993), they may be able to counteract regions of downwelling and convergence by continuing to migrate upward in these zones (a few tens of m per day at most) Where they successfully detach themselves from the downwelling water, populations advected shoreward into convergences (possibly in the frontal region of the ACC) will accumulate These zones of high copepod (and perhaps other taxa) biomass should represent regions of potentially high trophic efficiency for planktivores built and maintained for a few weeks by wind-forced horizontal and vertical transport

In a related exercise, Cooney (1988) calculated that nearly 10 million metric tons of zooplankton could be introduced to the shelf annually over 1,000 km of coastline in the northern GOA by the wind-forced shoreward Ekman transport each year If only a portion of this biomass is retained in shelf and coastal food webs, the "lateral input" of ocean-derived zooplankton (much of it represented by the large interzonal calanoids) may partially explain how the seasonally persistent downwelling shelf sustains the observed high annual production at higher trophic levels Kline (1999a), in studies of carbon and nitrogen isotopes of zooplankton sampled in PWS, found that 50 percent or more of the diapausing *Neocalanus cristatus* overwintering in the deep water originated from populations outside PWS each year Similar isotopic signals in herring and other coastal fishes seem to confirm a partial role for the bordering ocean in "feeding" at least some coastal habitats

Coyle (1997) described the dynamics of *Neocalanus cristatus* in frontal areas along the northern and southern approaches to the Aleutian Islands In regions near water column instabilities that fostered nutrient exchange for nearby stratified phytoplankton populations, these large oceanic copepods occurred along pycnoclines in subsurface swarms and layers that were in turn attractive feeding sites for diving least auklets These trophic associations (observed acoustically)

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formed and dissipated in response to weather and tidal modified forcing of the waters over the shelf north and south of the Aleutian Islands

Kirsch et al (2000) described dense layers (10 to 20 m in vertical extent) of C4 and C5 *Neocalanus plunchrus, N flemingen,* and *Calanus marshalle* in the upper 50 m of PWS that serve as seasonally important feeding zones for adult Alaska pollock and Pacific herring Swarming behavior in the upper layers by these copepods, responding to the distribution of their food in the euphotic zone, compresses *Neocalanus* into layers stretching for tens of km that are readily located and utilized by planktivores Other observations at the time found the layers of copepods were absent or only weakly developed in areas with high mixing energy like outer Montague Strait

Diel migrations of many taxa bring deep populations into the surface waters each night The large bodied copepod *Metridia* spp and many Pacific euphausids (*Euphausia* and *Thysanoessa*) represent zooplankters that undergo substantial daily migrations from deep to shallow waters at night A variety of reasons have been proposed for this behavior (Longhurst 1976) Regardless of the "why," vertically migrating populations that build local concentrations near the sea surface during darkness represent another way that behavioral traits are responsible for creating patchiness that may enhance trophic exchange Cooney (1989) and Stockmar (1994) studied diel and spatial changes in the biomass of net-zooplankton and micronekton in the upper 10 m of the open ocean and shelf habitats in the northern GOA They found a consistent enrichment of biomass in the surface waters at night caused by *Metridia pacifica* and several different euphausids that often exceeded daylight levels by a factor of five or six

Springer, et al (1996) make a strong case for the enhancement of primary and secondary productivity along the shelf edge of the southeastern Bering Sea Citing tidal mixing, transverse circulation, and eddies as mechanisms to increase nutrient supplies, this so-called "greenbelt" is described as 60 percent more productive than the outer-shelf environment and 270 percent more productive than the bordering deep ocean Earlier, Cooney and Coyle (1982) documented the presence of a high-density band of upper-layer zooplankton along the shelf edge of the eastern Bering Sea Comprised primarily of *Metridua* spp , *Neocalanus* spp , and *Eucalanus bungi*, this narrow zone of elevated biomass is apparently also a part of the greenbelt Although these features have yet to be described for the northern GOA, the present North Pacific GLOBEC study (Weingartner 2000) is monitoring primary productivity and zooplankton stocks along cross-shelf transects that should intercept a shelf-edge greenbelt if one is present in the northern GOA

Finally, meso and large-scale eddy formation over the shelf and slope regimes may also influence the patchiness of plankton in ways that could be susceptible to changing climate forcing A permanent feature (eddy) in the coastal water west of Kayak Island is often visible because of entrained sediment from the Copper River Formed by a branch of the ACC, this eddy may help concentrate plankton populations of the upper layer in ways that could later influence PWS (Reed and Schumacher 1986) Vaughan et al (2001) and Wang (2001) describe surface eddies in the central region of PWS with implications for the transport and retention of icthyoplankton. These eddies (cyclonic and anticyclonic) are believed to form in response to seasonal changes in freshwater outflow and wind forcing. Large-scale coastal and shelf eddies apparently form near Sitka and propagate north and west around the periphery of the GOA (Musgrave et al. 1992). Similar features on the east coast of the United States have been shown to be long-lived (many months) and capable of sustaining unique biological assemblages as they move through time and space. These same characteristics are also expected for the northern GOA.

785 Climate Forcing of Plankton Production in the Gulf of Alaska

A major challenge for the GEM Program will be to eventually produce a detailed understanding of lower trophic level processes that arise through biological interactions with the spatially distributed geological and physical properties of the northern GOA This evolving understanding must take into account the flow-through nature of the northern and eastern regions-downstream from southern Southeast Alaska and Northern Canada (through the ACC) and also downstream from portions of the southern oceanic Subarctic and Transition Zone domains (through the North Pacific and Alaska currents) The "open" condition places increasing importance on understanding levels of plankton imports (from the south) and exports (to the west) in the periphery of the GOA affected by the ACC (Napp et al 1996) and shelf-break flows (Alaska Current and Alaska Stream) It will also be necessary to understand the effects that the open ocean gyre may exert on shelf and coastal plankton stocks and their seasonal and annual production within the northern GOA Here too the import (or export) of nutrients, organic detritus, and living plankton stocks to (or from) the shelf must be evaluated under different conditions of climate and weather

The picture that emerges from the aggregate of previous and ongoing plankton studies portrays a large oceanic ecosystem forced strongly by physical processes that are meteorologically driven Physical processes such as deep and shallow currents, large-scale and localized upwelling and downwelling, seasonally phased precipitation, and runoff may bring about changes in the ecosystem. The reproduction, growth and death processes of the plants and animals of the oceanic ecosystem appear to be responding primarily to marked seasonality and interannual and longer-period shifts in the intensity and location of the winter Aleutian Low Increased upwelling in the offshore Alaska Gyre may promote higher rates of nutrient renewal in the oceanic surface waters with attendant increases in primary and secondary productivity Elevated wind-forcing probably accelerates the transport of upper-layer oceanic zooplankton shoreward to the shelf edge and beyond The frequency and degree to which this ocean-derived biomass "feeds" the food webs of the continental shelf and coastal areas will depend, in part, on biological interactions with a large array of physical processes and phenomena Processes and phenomena active in regions of horizontal and vertical currents associated with oceanographic fronts, eddies, coastal jets, shelf-break

flows, and turbulence are expected to have a strong influence on the movement of ocean biomass onto the shelf and coastal areas The actual effect of such processes and phenomena on distribution of oceanic biomass also depends on responses of plankton production to changes in levels of freshwater runoff in these regions, and on the seasonal and longer cycles in temperature and salinity Specific mechanisms by which surface zone nutrient levels are cycled and maintained in the variety of different habitats that compose the open shelf and rugged coastal margins must be understood in much greater detail to be useful to the overall GEM mission

It seems likely that the sophisticated understanding sought by the GEM Program of climate influences on the coupled nutrient and plankton production regimes that support selected consumer stocks may have to come from studies that abandon the practice of lumping taxa within broad ecologically functional units, and instead focus on "key species" Fortunately, the subarctic pelagic ecosystem (oceanic, shelf, and coastal) is dominated by a relatively small number of plankton species that serve as major conduits for matter and energy exchange to higher-level consumers each year In the case of the zooplankton, fewer than fifty species within a handful of major taxa comprise 95 percent or more of the abundance and biomass throughout the year Because of this pattern of dominance, and further because of the different life history strategies employed by these species, a more comprehensive understanding of their ecological roles is both necessary and feasible A decision to conduct dominant species ecology must be understood at all levels of the study so that, for instance, technicians conducting future stomach analyses of fishes, birds, or mammals will report not just "large copepods and amphipods," but rather Neocalanus cristatus and Parathemisto libellula This nuance holds particular importance for future modelers working on numerical formulations that include "plankton" Without this degree of specificity, it is unlikely that further (field and numerical) studies will forge the understanding of lower trophic level function sought by the GEM Program in the northern GOA

7.9 Nearshore Benthic Communities

Because the GOA covers a vast and diverse area, its benthic communities exhibit tremendous variation (Feder and Jewett 1986) As in any marine benthic system, however, the composition, functioning, and dynamics of the GOA benthic

communities change predictably with certain universally important variables The most important two environmental variables are water depth and substratum type (Rafaelli and Hawkins 1996) The following depth zones are typically distinguished

- The intertidal zone,
- The shallow subtidal zone (bounded by depth of light penetration sufficient for photosythesis of benthic algae),

- The continental shelf (to about 200 m), and
- The continental slope (from 200 to 4,000 m)

The most fundamental substratum distinctions are hard bottom (rocks, boulders, cobbles) and soft bottom (mobile sedimentary habitats like sands and muds) Within these two types, geomorphology varies substantially, with biological implications that often induce further habitat partitioning (Page et al 1995, Sundberg et al 1996)

Understanding of community composition and seasonal dynamics of GOA benthos has grown dramatically over the past thirty years, with two distinct pulses of research First, in contemplation of exploration and development of the oil and gas resources of the region, the MMS, NOAA NMFS, and Alyeska Consortium funded geographically focused benthic survey and monitoring work in the 1970s This work provided the first windows into the quantitative benthic ecology of the region Focus was most intense on lower Cook Inlet, the Aleutian Islands, the Alaska Peninsula, Kodiak Island, and northeast GOA, including the Valdez Arm in PWS (Rosenberg 1972, Hood and Zimmerman 1986) The second phase of growth in knowledge of the benthos of the GOA region was triggered by the EVOS in 1989 This work had broad geographic coverage of the rocky intertidal zone The area receiving the most intense study was PWS, where the spill originated Geographic coverage also included two other regions, the Kenai Peninsula-lower Cook Inlet and the Kodiak archipelago-Alaska Peninsula (Page et al 1995, Gilfillan et al 1995a, Gilfillan et al 1996b, Highsmith et al 1994b, Highsmith et al 1996, Houghton et al 1996a, Houghton et al 1996b, Sundberg et al 1996) Some of this benthic study following the oil spill was conducted in other habitats (soft substrata [Driskell et al 1996]) and at other depths (shallow and deep subtidal habitats (Houghton et al 1993, Armstrong et al 1995, Dean et al 1996a, Dean et al 1996b, Dean et al 1998, Dean et al 2000, Feder and Blanchard 1998, Jewett et al 1999) Herring Bay on Knight Island in PWS was a site of especially intense monitoring and experimentation on rocky intertidal communities following the oil spill (van Tamelen et al 1997)

791 Intertidal Communities

The intertidal habitat is the portion of the shoreline in between the high and low (0 0-m datum) tide marks This intertidal zone occupies the unique triple interface among the land, sea, and air The land provides substrate for occupation by intertidal organisms, the seawater the vehicle to supply necessary nutrients, and the air a medium for passage of solar energy, yet a source of physical stresses (Connell 1972, Underwood and Denley 1984, Peterson 1991) Interfaces between separate systems are locations of typically high biological activity As a triple interface, the intertidal zone is exceptionally rich and biologically productive (Ricketts and Calvin 1968, Leigh et al 1987) Wind and tidal energy combine to subsidize the intertidal zone with planktonic foods produced in the photic (sun-lit) zone of the coastal ocean Runoff from the adjacent land mass injects new supplies of inorganic nutrients to help fuel coastal production of benthic algae, although such runoff in Alaska is typically nutrient-poor and can be very turbid (Hood and Zimmerman 1986) The consequent abundance and diversity of life and life forms in the intertidal zone serves many important consumers, coming from land, sea, and air, and including humans The aesthetic, economic, cultural, and recreational values of the intertidal zone and its resources augment its significance, especially in the GOA region (Peterson 2001)

The biota of intertidal habitats varies with changes in physical substrate type, wave energy regime, and atmospheric climate (Lubchenco and Gaines 1981) Substrata in the GOA intertidal zone differ as a function of size, ranging from immobile rock walls and platforms, to boulders and cobbles, to gravel, to sands, and finally to muds at the finest end of this particle-size spectrum Rock surfaces in the intertidal zone are populated by epibiota, which are most commonly attached macro- and microalgae, sessile, or immobile, suspension-feeding invertebrates, and mobile grazing invertebrates, as well as predatory seastars and gastropods (Connell 1972, Rafaelli and Hawkins 1996) Unconsolidated (soft) substrata-the sands and muds-are occupied by large plants in low-energy environments, such as marshes, and microalgae and infaunal (buried) invertebrates in all energy regimes (Peterson 1991) Mobile scavenging and predatory invertebrates occur on both types of substratum Intertidal communities vary with wave energy because of biomechanical constraints (especially on potentially significant predators), changing levels of food subsidy, and interdependencies between wave energy and substratum type (Leigh et al. 1987, Denny 1988) Intertidal communities tend to be most luxurious in temperate climates, ice scour and turbid fresh water limit intertidal biota at high latitudes such as those in the eastern GOA The rocky intertidal communities of the Pacific Northwest, including the rocky shores of Islands in the GOA region, are highly diverse, although less so than those in Washington These communities are also productive, although limited by disturbance of winter storms and reduced solar insulation (Bakus 1978)

The rocky intertidal ecosystem may represent the best understood natural community of plants and animals on earth Ecologists realized more than forty years ago that this system was uniquely well suited to experimentation because the habitat was accessible and basically two-dimensional and the organisms were manipulable and observable Consequently, ecological science has used sophisticated experimental manipulations to produce a detailed understanding of the complex processes involved in determining patterns of distribution and abundance of rocky intertidal organisms (Paine et al 1996, Dayton 1971, Connell 1972, Underwood and Denley 1984) Plants and animals of temperate rocky shores exhibit strong patterns of vertical zonation in the intertidal zone Physical stresses tend to limit the upper distributions of species populations and to be more important higher onshore, competition for space and predation tend to limit distributions lower on the shore Surface space for attachment is potentially limiting to both plants and animals in the rocky intertidal zone. In the absence of disturbance, space becomes limiting, and competition for that limited space results

In competitive exclusion of inferior competitors and monopolization of space by a competitive dominant Physical disturbance, biological disturbance, and recruitment limitation are all processes that can serve to maintain densities below the level at which competitive exclusion occurs (Menge and Sutherland 1987) Because of the importance of such strong biological interactions in determining the community structure and dynamics in this system, changes in abundance of certain keystone species can produce intense direct and indirect effects on other species that cascade through the ecosystem (Menge et al 1994, Wootton 1994, Menge 1995, Paine et al 1996)

Intertidal communities occupying unconsolidated sediments (sands and muds) are quite different from those found on rocky shores (Peterson 1991) These softbottom communities are composed of infaunal (buried) invertebrates, mobile microalgae, and abundant transient consumers, such as shorebirds, fishes, and crustaceans (Rafaelli and Hawkins 1996) Macroalgae are sparse, and are found attached to large shell fragments or other stable hard substrata In very low energy environments, large plants, such as salt marsh grasses and forbs high on shore and seagrasses low on shore, occur in intertidal soft sediments (Peterson 1991) The large stretch of intertidal soft-sediment shore in between those vegetated zones has an empty appearance, which is misleading The plants are microscopic and productive, the invertebrate animals are buried out of sight The soft-bottom intertidal habitat represents a critically important feeding ground, especially for shorebirds, because the flat topography allows easier access than is provided by steep rocky coasts and because invertebrates without heavy protective calcium carbonate shells are common, particularly polychaetes and amphipods (Peterson 1991)

The intertidal shorelines of the GOA exhibit a wide range of habitat types True soft-sediment shores are not common, except in Cook Inlet Marshes, fine-grained and coarse-grained sand beaches, and exposed and sheltered tidal flats represent a small fraction of the coastline in the GOA Sheltered and exposed rocky shores, wave-cut platforms, and beaches with varying mixtures of sand, gravel, cobble, and boulders are the dominant habitats in this region (Page et al 1995, Sundberg et al 1996) Abundance, biomass, productivity, and diversity of intertidal communities on the shores of the eastern GOA with nearby glaciers are depressed by proximity to sources of runoff from glacier ice melt. The islands in PWS and the Aleutian Islands, for example, have richer intertidal communities than the mainland of the northeast GOA, and the intertidal communities of Kodiak and Afognak tend to be richer than those of the Shelikof Strait mainland on the Alaska Peninsula (Bakus 1978, Highsmith et al 1994b) Glacier ice melt depresses intertidal biotic communities by introducing turbidity and freshwater stresses

Winter ice scour seasonally denudes epibiota along the Cook Inlet shores (Bakus 1978) Intense wave exposure can cause substratum instability on intertidal cobble and boulder shores, thereby removing intertidal epibiota directly through abrasion (Sousa 1979) Shores with well rounded cobbles and boulders have accordingly poorer intertidal biotas than those with reduced levels of physical disturbance Bashing from logs also represents an agent of disturbance to those rocky shores exposed to intense wave action in this region (Dayton 1971) Consequently, exposed rocky coastlines may experience more seasonal fluctuations in epiblotic coverage than communities on similar substrata in protected fjords and embayments (Bakus 1978)

The rocky intertidal shores of the spill area exhibit a typical pattern of vertical zonation, although the particular species that dominate vary in importance as a function of changing habitat conditions (Highsmith et al 1996, Houghton et al 1996a, Houghton et al 1996b) Vertical zonation on intertidal rocky shores is a universal feature, caused by a combination of direct and indirect effects of height-specific duration of exposure to air (Paine 1966, Connell 1972)

The uppermost intertidal zone on rocky shores of the GOA is characterized by a dark band of the alga *Verruccana* The rockweed (*Fucus gaidneri*) dominates the upper intertidal zone, which also includes two common barnacles (*Balanus glandula* and *Chthamalus dalli*), two abundant limpets (*Tectus a persona* and *Lottia pelta*), and the periwinkle (*Littorina sitkana*) (SAI 1980, Hood and Zimmerman 1986, Highsmith et al 1994b)

The middle intertidal zone commonly has even higher cover of *Fucus*, along with beds of blue mussels (*Mytilus ti ossulus*), the periwinkle (*Littorina scutulata*), barnacles, and the predatory drilling snail (*Nucella lamellosa and N lima*) (Carroll and Highsmith 1996) In the low intertidal zone, a red alga (*Rhodymenia palmata*) often is dominant, although mussel beds often occupy large areas and the grazing chitons (*Katharina tunicata, Mopalia mucosa,* and *Tonicella lineata*) and predatory seastars (*Leptasterias hexactis* and others) occur here (SAI 1980, Highsmith et al 1994b) The blue mussel is a very significant member of this community because it is a potential competitive dominant (VanBlaricom 1987) and because its byssus and between-shell interstices provide a protected habitat for a diverse suite of smaller mobile invertebrates, including isopods, amphipods, polychaetes, gastropods, and crabs (Suchanek 1985)

Abundances of rocky intertidal plants and animals in the GOA are controlled by the same suite of factors that affect rocky shore abundances and dynamics elsewhere, especially in the Pacific Northwest Physical factors, such as wave action from winter storms, exposure to air high on shore, ice scour, and low salinity and turbidity from glacial and land runoff, have important effects on waveexposed areas (Dayton 1971, Dayton 1975, Bakus 1978)

Biological controls also exert significant influences Probably the most significant of these likely controlling factors for intertidal biota are predation and recruitment limitation Predation by seastars is an important control of invertebrate prey population abundances and, therefore, of community composition low on intertidal rocky shores (Paine 1966, Dethier and Duggins 1988) Because blue mussels are typically the preferred prey and represent the dominant competitor for potentially limited attachment space, this predation by seastars has important cascading effects of enhancing abundances of poorer competitors on the rock surfaces (Paine 1966) Predation by gastropods occasionally helps control mussel abundances (Carroll and Highsmith 1996) and barnacle populations higher on shore in the GOA (Ebert and Lees 1996) Shorebird predation, especially by black oystercatchers, is also known to limit abundances of limpets on horizontal rock surfaces of the Pacific Northwest intertidal zones, and this process can be readily disrupted by human interference with the shy shorebirds (Lindberg et al 1998) The presence of numerous strong biotic interactions in this rocky intertidal community of the GOA led to many indirect effects of the EVOS in this system (Peterson 2001) Because of the influence of current flows and mortality factors such as predation in the water column, larval recruitment can also limit population abundances of marine invertebrates on intertidal rocky coasts (Gaines and Roughgarden 1987, Menge and Sutherland 1987) With a short warm season of high production in the GOA, the potential for such recruitment limitation seems high, but process studies to characterize and quantify this factor have not been conducted in the GOA Changes in primary production, water temperature (and thus breeding season), and physical transport dynamics associated with regional climate shifts could reasonably be expected to regulate the intensity of recruitment limitation on some rocky shores in the GOA

The consequences of change caused by various natural and human-driven factors on the structure and dynamics of the rocky intertidal communities are not well developed in the scientific literature For example, human harvest by fisheries or subsistence users of important apex predators that exert top-down control on intertidal communities could cause substantial cascading effects through the system But the seastars and gastropods that are the strong predatory interactors in this community in the GOA region are not targets for harvest. The mussels that are taken in subsistence harvest provide important ecosystem services as structural habitat for small invertebrates (Suchanek 1985), as a dominant space competitor (Paine 1966), and as a widely used prey resource (Peterson 2001), but mussels do not appear limited in abundance in the GOA region

Oceanographic processes related to climate change, either natural or humandriven through global warming, have the potential to either enhance or reduce recruitment of component invertebrate species of the rocky intertidal communities, but studies of the connections between coastal physical dynamics and shoreline communities are in their infancy (Caley et al 1996) Perhaps the best documented driver of change in composition and dynamics of rocky intertidal communities is the impact of oil spills The cleanup treatments after the spill, either dispersants (Southward and Southward 1978) or pressurized washes (Mearns 1996), have far more serious impacts than the oil itself Because of the important strong interactions among species in rocky shore communities, the multiple indirect effects of oil spills on this system take about a decade to work their way out of the system (Southward and Southward 1978, Peterson 2001) Intensive sampling and experimental work on rocky intertidal communities on sheltered shores in PWS following the EVOS make this region data-rich relative to most other Alaskan shores

Intertidal soft sediments in the spill region of the GOA typically possess lower biomass of macroalgae and invertebrates than corresponding rocky shores at the same elevations (SAI 1980, Highsmith et al 1994b) The taxonomic groups that dominate intertidal soft bottoms are polychaete worms, mollusks (especially bivalves), and amphipods (Driskell et al 1996) Sandy sediments have higher representation by suspension-feeding invertebrates, whereas finer, muddy seduments are dominated by deposit-feeding species (Bakus 1978, Feder and Jewett 1986) Intertidal sandy beaches are habitat for several large suspension-feeding clams in the GOA that represent important prey resources for many valued consumers and that support commercial, recreational, and subsistence harvest (Feder and Kaiser 1980) Most important are the littleneck clam (Piotothaca stammea), the butter clam (Sandomus giganteus), the razor clam (Siliqua patula), the cockle (*Chnocarduum nuttallu*), the pink-neck clam (*Spisula polynyma*), the gapers (Tresus nuttallu and T capax), and others (Feder and Paul 1974) In mudflats, such as those along the shores of Cook Inlet, dense beds of a deposit-feeding clam, Macoma balthuca, and the soft-shell clam (Mya arenaria) frequently occur (Feder et al 1990) These two relatively soft-shelled clams are significant food resources for many seaducks, and the hard-shelled clams are important prey for sea otters (Kvitek and Oliver 1992, Kvitek et al 1992), black and brown bears (Bakus 1978), and several invertebrate consumers Intertidal soft-bottom habitats are also important feeding grounds for shorebirds and for demersal (deep-water) fishes and crustaceans (Peterson 2001) In addition to macrofaunal invertebrates, smaller meiofaunal invertebrates are abundant on intertidal sedimentary shores Macrofauna describes animals that are retained on a 0 5-mm mesh, meiofauna refers to animals passing through a 0 5-mm mesh but retained on 0 06-mm mesh, and microfauna are animals smaller than 0 06 mm Nematode worms and harpacticoid copepods are the most common meofaunal taxa in the GOA region (Feder and Paul 1980b) Harpacticoids serve an important role in the coastal food chain as prey for juvenile fishes, including salmonids (Sturdevant et al 1996)

Little information exists on the dynamics of long-term change in structure and composition of intertidal communities in soft sediments anywhere Some of the

The intertidal habitats of the GOA are critically important feeding grounds for marine, terrestrial, and avian consumers best understanding of important processes actually comes from the northern GOA region The Alaska earthquake of 1964 had a tremendous influence on soft-sediment intertidal communities because of the geomorphological modifications of habitat (NRC 1971) Uplift of the shoreline around Cordova, for example, was great enough to elevate the sedimentary shelf habitat out of the depth range that

could be occupied by many species of clams Clam populations in Cordova, a town once called the clam capital of the world, have never recovered from the earthquake The re-invasion of sea otters has similarly caused tremendous changes in clam populations in shallow soft-sediment communities of the northern GOA,

mostly in subtidal areas, but also in intertidal sedimentary environments (Kvitek et al 1992)

Human impacts can cause change in soft-sediment intertidal communities as well Probably the most common means by which human activities modify softsediment communities in intertidal habitats is through alteration of sediments themselves The application of pressurized wash after the EVOS, for example, eroded fine sediments from intertidal areas (Driskell et al 1996) and may be responsible for long delay in recovery of clams and other invertebrates because of a slow return of sediments (Coats et al 1999, Shigenaka et al 1999) Addition of organic enrichment can stimulate growth, abundance, and production of opportunistic infaunal invertebrates such as several polychaetes and oligochaetes in intertidal sediments Such responses were documented following the EVOS (Gilfillan et al 1995a, Jewett et al 1999), presumably because the oil itself represented organic enrichment that entered the food chain through enhanced bacterial production (Peterson 2001) Other types of organic enrichment, such as biochemical oxygen demand in treated wastewater from municipal treatment facilities or industrial discharges, can create these same responses Deposits of toxic heavy metals from mining or other industrial activities and of toxic synthetic organic or natural organic contaminants, like PAHs in oil, can cause change in intertidal benthic communities by selectively removing sensitive taxa such as echinoderms and some crustaceans (Jewett et al 1999)

Intertidal communities are open to use by consumers from other systems The great extent and importance of this habitat as a feeding grounds for major marine, terrestrial, and aerial predators render the intertidal system a key to integrating understanding of the function in the entire coastal ecosystem (Peterson 2001) The intertidal habitats of the GOA are critically important feeding grounds for many important consumers

- Marine-sea otters, juvenile Dungeness and other crabs, juvenile shrimps, rockfishes, cod, cutthroat trout, and Dolly Varden char in summer, and juvenile fishes of other stocks exploited commercially, recreationally, and for subsistence, including pink and chum salmon,
- Terrestrial-brown bears, black bears, river otters, Sitka black-tailed deer, and humans, and
- Avian-black oystercatchers and other shorebirds, harlequin ducks, surf scoters, goldeneyes, and other seaducks, and bald eagles

Intertidal gravels in anadromous streams are important spawning grounds for pink salmon, especially in PWS Therefore, the intertidal habitat provides vital ecosystem services in the form of prey resources, spawning habitat, and nursery, as well as human services in the form of commercial, recreational, and subsistence harvest of shellfishes and aesthetic, cultural, and recreational opportunities In short, a habitat that represents only a small fraction of the total area of the seafloor may be the most valuable for the services it provides to the coastal ecosystem and to humans

792 Subtidal Communities

The subtidal habitat is the portion of the seafloor found at depths below the low tide (0 0 m datum) mark on shore This habitat includes a relatively narrow band of shallow subtidal bottom at depths in the photic zone (the zone penetrated by light), where plants can live, and a large area of unlit seafloor, the deep subtidal bottom extending across the continental shelf and slope to depths of 4,000 m in the GOA (Feder and Jewett 1986) The depth to which sufficient light penetrates to support photosynthesis and the slope of the subtidal seafloor determine the width of the shallow subtidal zone Along a tectonic coastline like the GOA, depth gradients are typically steep In addition, injection of turbidity from glacier ice melt along the coast reduces light penetration through the seawater These factors combine to produce a shallow subtidal zone supporting benthic plant production in the region of the spill that is very narrow Consequently, the vast majority of the subtidal ecosystem, the deep subtidal area on the continental shelf and slope, depends on an energy subsidy in the form of inputs of organic matter from other marine and, to some small extent, even terrestrial habitats These organic inputs include most importantly detritus from production of intertidal seaweeds and from shallow subtidal seagrasses, seaweeds, and kelps, as well as particulate inputs from phytoplankton, zooplankton, and zooplankton fecal pellets sinking down from the photic zone above to settle on the seafloor In addition, the carcasses of large animals such as whales, other marine mammals, and fishes occasionally sink to the bottom and provide large discrete packages of detritus to fuel subsequent microbial and animal production in the deep subtidal ecosystem

Although narrow, the shallow subtidal zone in which primary production does occur is of substantial ecological significance Many of these vegetated habitats, especially seagrass beds, macrophyte beds, and kelps, provide the following:

- 1 Nursery grounds for marine animals from other habitats,
- 2 Unique habitat for a resident community of plant-associated animals,
- 3 Feeding grounds for important consumers, including marine mammals, seaducks, and many fishes and shellfishes, and
- 4 A source of primary production for export as detritus to the deeper unlit seafloor ecosystem (Schiel and Foster 1986, Duggins et al 1989)

In the spill area, eelgrass (*Zoster a marına*) beds are common in shallow sedimentary bottoms at the margins of protected embayments (McRoy 1970), whereas on shallow rocky subtidal habitats, the kelps *Agarum, Lamınarıa*, and *Nereocystis* form dense beds along a large fraction of the coast (Calvin and Ellis 1978, SAI 1980, Dean et al 1996a) Productivity estimates in wet weight for larger kelps *Nereocystis* and *Lamınarıa* in the northeastern GOA range up to 37 to 72 kg/m²/yr (O'Clair and Zimmerman 1986) In this shallow subtidal zone, primary production also occurs in the form of single-celled algae These microbial plants include both the phytoplankton in the water column and benthic microalgae on and in the sediments and rocks of the shallow seafloor Both the planktonic and the benthic microalgae represent ecologically important food sources for herbivorous marine consumers The typically high turnover rates and high food value of these microalgal foods in the shallow subtidal zone helps explain the high production of invertebrate and vertebrate consumers in this environment

The sessile of slow-moving benthic invertebrates on the seafloor represent the bulk of the herbivore trophic level in the subtidal ecosystem This benthic invertebrate fauna in the shallow subtidal zone differs markedly as a function of bottom type (Peterson 1991) Rocky bottoms are inhabited by epifaunal benthic invertebrates, such as sponges, bryozoans, barnacles, anthozoans, tunicates, and mussels Sand and mud bottoms are occupied largely by infaunal (buried) invertebrates, such as polychaete worms, clams, nematodes, and amphipods The feeding or trophic types of benthic invertebrates vary with environment, especially with current flow regime (Rhoads and Young 1970) Under more rapid flows, the benthos is dominated by suspension feeders, animals extracting particulate foods out of suspension in the water column Under slower flows, deposit feeders dominate the benthos, feeding on organic materials deposited on or in the seafloor The benthos also includes some predatory invertebrates, such as seastars (for example, leather star, Der masterias imbricata, and sunflower star, Pycnopodia *helianthoides*), crabs (for example, helmet crab, *Telmessus chen agonus*), some gastropods, and some scavenging invertebrates (Dean et al 1996b) Benthic invertebrates of soft sediments are distinguished by size, with entirely different taxa and even phyla occurring in the separate size classes Macrofauna include the most widely recognized groups such as polychaete worms, clams, gastropods, amphipods, holothurians, and seastars (Hatch 2001, Driskell et al 1996) Meiofauna include most prominently in the GOA nematodes, harpacticoid copepods, and turbellarians (Feder and Paul 1980b) Finally, microfauna include most prominently foraminifera, ciliates, and other protozoans Because the actual species composition of the benthos changes with water depth, the shallow and deep subtidal benthic faunas in the spill zone hold few species in common Softsediment communities of Alaska are best described and understood in various locations within PWS, as a consequence of the intense study after the oil spill

The shallow subtidal rocky shores that are vegetated also include suites of benthic invertebrates unique to those systems These benthic invertebrates either directly consume the large plants, such as sea urchins, or else are associated with the plant as habitat Those species that Predation and biogenic habitat influence the shallow subtidal community on rocky shores of the GOA

depend upon the plant as habitat, such as several species of amphipods, crabs and other crustaceans, gastropods, and polychaetes, often are grazers as well, taking some mixture of macrophytic and epiphytic algae in their diets Grazing by sea urchins on kelps is sufficiently intense in the absence of predation on the urchins, especially by sea otters in the spill area, to create what are known as "urchin barrens" in which the macrophytic vegetation is virtually removed from the seafloor (Estes and Palmisano 1974, Simenstad et al 1978) In fact, this shallow subtidal community on rocky shores of the GOA represents the best example in all of marine ecology of a system controlled by top-down predation Sea otters control abundance of the green sea urchin, Strongylocentrotus droebachuensis When released from that otter predation, sea urchin abundance increases to create fronts of urchins that overglaze and denude the kelps and other macroalgae, leaving only crustose forms behind (Simenstad et al 1978) This loss of macroalgal habitat then reduces the algal associated invertebrate populations and the fishes that use the vegetated habitat as nursery These reductions in turn can influence productivity and abundance of piscivorous seabirds (Estes and Palmisano 1974) Recently, reduction of traditional marine mammal prey of killer whales has induced those apex consumers to switch to eating sea otters in the Aleutians, thereby extending this trophic cascade of strong interactions to yet another level (Estes et al 1998, Estes 1999)

Consequently, the shallow subtidal community on rocky shores of the GOA is strongly influenced by predation and provision of biogenic habitat (Estes and Duggins 1995) Human disruption of the apex predators by hunting them (as historically occurred on sea otters [Simenstad et al 1978]) or by reducing their prey (as may conceivably be occurring in the case of the Steller sea lions and harbor seals through overfishing their own prey fishes [NRC 1996]) has great potential to create tremendous cascading effects through the shallow subtidal benthic ecosystem Furthermore, if concentration and biomagnification of organic contaminants such as PCBs, DDT, DDE, and dioxins in the tissues of apex predators, in particular in transient killer whales (Matkin unpublished data), causes impaired reproductive success, then human industrial pollution has great potential to modify these coastal subtidal communities on rocky shores

The shallow subtidal community on rocky shores of the GOA is also strongly influenced by larval distribution and recruitment Recent studies by Partnership for the Interdisciplinary Study of Coastal Oceans (PISCO) (see Appendix A for web link) have shown that not only are the effects of competition and predation important in structuring benthic communities, but the sources and sinks of larvae are equally important Larval abundance and behavior, where they come from, how they respond to ocean conditions, where they are retained, where they are reflected, and the dynamics regulating their recruitment are all important processes that ultimately control what lives where Furthermore, knowledge about life histories is insufficient to make broad generalizations about the successes and failures of recruitment events

The shallow subtidal benthic communities in soft sediments of the GOA region function somewhat differently from their counterparts on rocky substrata These communities are important for nutrient regeneration by microbial decomposition and for production of benthic invertebrates that serve as prey for demersal shrimps, crabs, and fishes In some protected areas within bays, however, the shallow subtidal benthos is structured by emergent plants, specifically eelgrass in the GOA These eelgrass beds perform ecological functions similar to those of macrophyte-dominated rocky shores, namely nursery functions, phytal habitat roles, feeding grounds, and sources of primary production (Jewett et al 1999) In the vegetated habitats of the shallow subtidal zone, the demersal fish assemblage is typically more diverse than and quite different from the demersal fishes of the deeper subtidal zone (Hood and Zimmerman 1986) In eelgrass (Zostera) beds as well as in the beds of small kelps and other macrophytes (Aganum, Nereocystis and *Lanunaria*) in the GOA, juveniles of many species that live in deeper waters as adults use this environment as a nursery for their young because of high production of food materials and protection from predators afforded by the shielding vegetation (Dean et al 2000) Furthermore, several fishes are associated with the plant habitat itself, including especially pickers that consume crustaceans and other invertebrates from plant surfaces, a niche that is unavailable in the absence of the vegetation Both types of vegetated habitats in the shallow subtidal zone of the GOA contain larger predatory invertebrates, specifically seastars and crabs In some cases, the same species occupy both eelgrass and kelp habitats (Dean et al 1996b)

Microbial decomposers play an extremely significant role in both shallow and deep subtidal sedimentary habitats of the sea (Braddock et al 1996) Fungi and especially bacteria become associated with particulate organic matter and degrade the organic compounds This decomposition process releases the nutrients such as phosphorus and nitrogen in a form that can be reused by plants when the water mass is ultimately recycled into the photic zone In short, benthic decomposers of the subtidal seafloor play a necessary role in the nutrient cycling upon which sustained production of the sea depends In addition, these decomposers themselves represent the foods for many deposit-feeding invertebrates of the subtidal seafloor Much of the detritus that reaches the seafloor is composed of relatively refractive organic compounds that are not readily assimilated in the guts of animal consumers The growth of microbial decomposers on this detritus acts to convert these materials into more utilizable nitrogen-rich biomass, namely fungi and especially bacteria Bacteria also scavenge dissolved organic materials and repackage them into particulate bacterial biomass, which is then available for use in consumer food chains

In the subtidal habitats, the benthic invertebrates serve as the prey for mobile epibenthic invertebrates and for demersal fishes (Hood and Zimmerman 1986, Jewett and Feder 1982) Mobile epibenthic invertebrates are distinguished from the benthos itself by their greater mobility and their only partial association with the seafloor The vast majority of this group is composed of crustaceans, namely crabs, shrimps, tanaids, and some larger amphipods (Armstrong et al 1995, Orensanz et al 1998) In the GOA, this group includes Dungeness crabs, king crabs, snow crabs, Tanner crabs, both *Crangon* and *Pandalus* shrimps, such as spot shrimp, coon-

striped shrimp, pink shrimp, and gray shrimp, and other shellfish resources that had great commercial importance before the climatic phase shift of the mid 1970s (Anderson and Piatt 1999, Mueter and Norcross 1999, Mueter and Norcross 2000) Climate and physical oceanography have the potential to exert important influences on recruitment and year-class strength of subtidal fishery stocks in the GOA (Zheng and Kruse 2000b), but the mechanisms and processes are poorly understood Demersal fishes are those fishes closely associated with the seafloor, including flounders, halibut, sole, rockfishes, Pacific Ocean perch, and gadiids like cod and walleye pollock They feed predominantly on the epibenthic invertebrates-the shrimps, crabs, and amphipods-but in addition prey directly on some sessile benthic invertebrates as well. Juvenile flatfish feed heavily by cropping (partial predation) on exposed siphons of clams and exposed palps of polychaetes. This role of provision of benthic invertebrate prey for demersal crustaceans and fishes is an important ecosystem service of the shallow subtidal seafloor

The shift in the late 1970s from crabs and shrimps to dominance by demersal fishes associated with the shift in climatic regime implies a strong role for environmental forcing of community composition in this shallow subtidal system, although mechanisms of change dynamics are not understood (NRC 1996) Because of the effects of trawling on biogenic habitat, such as sponges and erect bryozoans, in subtidal soft sediments and the potential for fisheries exploitation to modify abundances of both targeted stocks and species caught as by-catch (Dayton et al 1995), fishery impacts to the soft-bottom benthic community are a possible driver of community change Because the demersal fishes that are taken by trawl and other fisheries represent the prey of threatened and endangered marine mammals such as Steller sea lions, the possible implications of fishing impacts to this community are important (NRC 1996)

The benthic invertebrate community of shallow unvegetated subtidal seduments has served worldwide as an indicator system for the biological influence of marine pollution The infaunal invertebrates that compose this bottom community are sessile or slow-moving They are diverse, composed of many phyla and taxa with diverse responses to the suite of potential pollutants that deposit upon the sedimentary seafloor Consequently, this system is an ideal choice to monitor and test effects of marine pollution (Warwick 1993) The subtidal benthic community on the sedimentary seafloor is limited by food supply Consequently, community abundance and biomass reflect the effects of organic enrichment This is evident from variation in biomass among subtidal benthic communities geographically within the GOA (Feder and Jewett 1986) Therefore, changes in primary productivity in the water column above, allocation of that production between zooplanktonic herbivores and benthic invertebrates, and physical transport regimes combine to cause spatially explicit modification of soft-sediment benthic communities in unvegetated subtidal sediments that can serve to monitor ecosystem status Furthermore, the taxonomic composition of soft-sediment benthic communities responds differentially to organic loading and toxic pollution

(Warwick and Clarke 1993, Peterson et al 1996), thereby rendering this system an excellent choice for monitoring to test among alternative drivers of ecosystem change Among common invertebrate taxa of subtidal sedimentary habitats, the echinoderms and crustaceans (especially amphipods) are highly sensitive to toxic accumulation of heavy metals, PAHs, and synthetic organic compounds Other taxa such as polychaetes include many opportunistic species that bloom with loading with organic pollutants, thereby allowing inferences about causation of anthropogenic responses (Peterson et al 1996) This capability of subtidal benthic communities in soft sediments may prove useful in testing among alternative explanations for ecosystem change in the GOA

The deeper subtidal habitats on the outer continental shelf and the continental slope are not well studied in the GOA system (Bakus 1978, SAI 1980a, SAI 1980b) There has been some description of the mobile epibenthic communities and the demersal fish communities of these deeper benthic habitats (Feder and Jewett 1986) Most sampling of these deeper benthic habitats involves trawling and focuses on the stocks of crabs, shrimps, and demersal fishes that are commercially exploited (Rosenberg 1972, Bakus 1978) The continental shelf as a whole (shallow to deep) represents a key fishing grounds in the GOA and has correspondingly high value to humans Because community structure of benthic systems can be modified dramatically by the physical damage done by trawls to biogenic habitat such as sponges and soft corals (Dayton et al 1995), this human activity is the object of concern The continental slope, on the other hand, does not experience great fishing pressure

7.10 Forage Species

7 10 1 Definition

Forage species include a broad suite of species that are commonly consumed by higher trophic level species (fish, seabirds, and marine mammals) Specifc species included in the forage species complex vary among authors and management agencies The North Pacific Fisheries Management Council (NPFMC) groundfish fisheries management plan defines the forage species complex as a group of species that includes the following (NMFS 2001)

- Smelts (capelin, rainbow smelt, eulachon, and family Osmeridae),
- Pacific sand lance (Ammodytes hexapterus),
- Lantern fishes (family Myctophidae),
- Deep-sea smelts (family Bathylagidae),
- Pacific sandfish (Trichodon trichodon),
- Euphausuds (Thysanopoda, Euphausia, Thysanoesssa, and Stylochen on),

- Gunnels (family Pholidae),
- Pricklebacks (family Stichaeidae), and
- Bristlemouths, lightfishes, and anglemouths

Springer and Speckman (1997) extend this definition to include juvenile stages of commercially exploited species such as Pacific herring (*Chipea pallasi*), walleye pollock (*Ther agra chalcogramma*), and Pacific salmon (*Oncorhynchus* sp.) For the purposes of this background review, the GEM Program focuses on a subset of species that are commonly found in coastal or oceanic regions of the GEM study region. In the shelf environment, this subset includes euphausiids, capelin, eulachon, sand lance, juvenile pollock, juvenile herring and juvenile pink salmon (*Oncorhynchus gorbuscha*). In the offshore environment, this subset includes common myctophids, such as small-finned lantern fishes (*Stenobr achuis leucopsarus* and *Diaphus theta*), and bathylagids, such as the northern smoothtounge (*Leu oglossus schmidti*). This partitioning allows GEM to highlight several key research questions that could be the focus of future GEM research

A more complete description of the life history characteristics of the forage species identified by the GEM Program can be found in Hart (1973, NMFS 2001) Table 7.2 summarizes key features of the life history characteristics

7 10 2 Resource Exploitation in the GEM Region

Small amounts of non-commercial forage species are taken as bycatch in federal and state fisheries in the GOA (NPFMC 2000, NMFS 2001) In an attempt to discourage the development of target fisheries for forage species, the NPFMC restricts the catch of forage species to no more than 2 percent of the total landed catch of commercial fisheries in federal waters (NMFS 2001) Although the bycatch of non-commercial forage species tends to be low relative to target fisheries for commercially exploited species, the percentage of the bycatch relative to regional abundances of individual forage species is often not known because of the difficulty involved in assessing these species

Pacific salmon fisheries off the coast of Alaska are managed by a complex system of treaties, regulations, and international agreements State and federal agencies cooperate in managing salmon resources The State of Alaska regulates commercial fisheries for salmon within state waters where the majority of the catch occurs Federal agencies control the bycatch of juvenile salmon in groundfish fisheries through prohibited-species bycatch restrictions (NMFS 2001) In the GEM study region, pink salmon are primarily harvested by purse seines Most of the pink salmon taken in PWS are of hatchery origin

State and federal agencies also cooperate in managing Pacific herring fisheries Most of the directed herring removals occur within state waters and are regulated by ADF&G In federal waters, the removals of Pacific herring in groundfish fisheries are regulated through prohibited-species bycatch restrictions (NMFS 2001)

Characteristics	Euphausııds 11 species	Capelın Mallotus vıllasus	Eulachon Thaleichthyes pacificus	Pacific sand lance Ammodytes hexapterus	Walleye Pollock Theragra chalcogramma	Pacific herring Clupea pallasii	Pink salmon Oncorhynchus gorbuscha	Northern Ianternfish Stenobrachius Ieucopsarus
Maximum age (years)	2	4	5	3	21	18	2	6
Maxımum length (centımeters)	4	25	25	15	80	45~	65	9
Prey	planktivorous	planktivorous	planktivorous	planktivorous	plankton and fish	planktivorous	plankton and fish	planktivorous
Peak spawning	spring	spring	spring	winter	winter-spring	winter-spring	summer	unknown– winter?
Spawn location	unknown	ıntertıdal	rivers	late fall early winter	pelagic on shelf	nearshore	rivers	unknown
Abundance trend	unknown (uncertaın)	low stable (uncertaın)	low stable (uncertaın)	unknown	low stable	low	hıgh stable	unknown
Foraging habitat	pelagıc– mıd water over shelf	pelagıc– mıd-water over shelf	pelagıc– mıd-water over shelf	demersal– 0-100 m	mesopelagic– demersal and over shelf	pelagic shelf	pelagic shelf and open ocean	mesopelagıc– outer shelf and open ocean

 Table 7 2 Summary of Key Life History Characteristics of Selected Forage Species

State and federal agencies regulate commercial removals of walleye pollock The majority of the catch occurs in federal waters, however, small state fisheries have started in PWS In federal waters, the catch is regulated by federal agencies based on recommended harvest regulations provided by the NPFMC The catch of juvenile pollock is assessed within the stock assessment and fisheries evaluation (SAFE) reports Juvenile pollock catch is included in considerations regarding annual quotas for this species. The lack of a market for juvenile pollock less than 30 cm in length serves as an incentive to industry to minimize the bycatch of juvenile pollock. Efforts to minimize bycatch of juvenile pollock in pollock target fisheries include the voluntary adoption of alternative mesh configurations designed to reduce the retention of small pollock (Erickson et al. 1999)

7 10 3 Assessment Methods and Challenges

There are several impediments to the development of forage species assessments The diversity of life history characteristics confound efforts to develop a multipurpose survey to assess forage species as a single complex In addition, several forage species are small and pelagic, making them less vulnerable to the standard trawl gear used in broad-scale surveys to assess stocks conducted by ADF&G or NMFS A high priority should be placed on research designed to overcome these impediments

Several authors have reported on possible trends in forage species abundance in the shelf and offshore environment (Hay et al 1997, Anderson and Piatt 1999, Blackburn and Anderson 1997, Beamish et al 1999a) These papers rely on anecdotal information from surveys that were designed to assess the abundance of another species (such as shrimp, salmon, crab, or groundfish) Indices of abundance based on these data may be subject to error because of problems with the selectivity of the gear or the limited spatial or temporal scope of the surveys

An assessment designed for forage species is needed to develop an accurate evaluation of the distribution and abundance of this important group of species It is unlikely that a single survey would be adequate for all forage species, therefore, a variety of survey methods should be considered Potential survey methods for forage species are identified in Table 7.3

7 10 4 Hypotheses About Factors Influencing Food Production for Forage Fish Production

Several hypotheses (summarized below) have been advanced to explain trends in forage fish distribution and abundance For the most part, these hypotheses are based on research in the shelf and coastal waters of the western central GOA ecosystem, including PWS Detailed process-oriented research has been conducted to confirm hypotheses for a small number of forage species, although these studies

Туре	Candidate Species
Small mesh mid water surveys	Euphausııds capelın eulachon juvenile pollock (age 0 and age 1) juvenile herring, small finned lanternfishes, northern smoothtongue
High-speed near-surface trawls	Juvenile salmon
Acoustic mid-water trawl surveys	Capelin eulachon juvenile pollock juvenile herring euphausiids
Small-mesh beach seines	Sand lance
Aerial spawning surveys	Pacific herring and capelin
Light detection and ranging (LIDAR)	Useful for species within the upper 50 m
Monitoring diets of key bird predators	Juvenile pollock capelin and sand lance

T-61- 7 2	Detential	Currenter for		of Colorford	Carago Species
rapie / S	Potential	Surveys to	r Assessment	of Selected	rorage opecies

were often conducted in a limited geographic area representing only a fraction of the range of the species

- 1 Feeding opportunities for early feeding larvae Shifts in large-scale atmospheric forcing controls the structure of marine fish communities in the western central GOA ecosystem through its role in determining the timing of peak production Species that spawn in the winter and early spring will be favored by periods of early peak production, while species that spawn in the late spring and summer will be favored by periods of delayed production (Mackas et al 1998, Anderson and Piatt 1999)
- 2 Concentration of prey for early feeding larvae Ocean conditions that favor concentration of forage fish and their prey will enhance production of forage species The FOCI program identified a potential mechanism linking increased precipitation to enhanced eddy formation and reduced larval mortality Eddies are believed to provide a favorable environment for pollock larvae by increasing the probability of encounters between larvae and their prey (Megrey et al 1996) Research is needed to determine whether this mechanism may be important for other forage fishes within the western and central GOA
- 3 Prey dispersal for early feeding larvae An inverse or dome-shaped relationship exists between the amount of wind mixing and forage fish production Bailey and Macklin (1995b) compared hatch date distributions of larval pollock with daily wind mixing This analysis showed that firstfeeding larvae exhibited higher survival during periods of low wind mixing Megrey et al (1996) speculated that extremes in wind mixing would result in reduced pollock survival because low-wind mixing would reduce the availability of nutrients in the mixed layer and high-wind mixing would lead to reduced encounters between pollock and their prey

- 4 Competition for prey At finer spatial scales, prey resources for forage fish may be limited, leading to resource partitioning to minimize competition between forage fish species that occupy similar habitats Willette et al (1997) examined the diets of juvenile walleye pollock, Pacific herring, pink salmon, and chum salmon in PWS Their study revealed that two species pairs (walleye pollock and Pacific herring, and pink and chum salmon) exhibited a high degree of dietary overlap This finding suggests that in PWS, competition for food resources may occur within these pairs when food abundance is limited Purcell and Sturdevant (2001) found evidence of potential competition between zooplantivorous jellyfish and juvenile fishes in PWS Their study showed high diet overlaps in the diets of pelagic coelenterates and forage species and that these species co-occur spatially and temporally in PWS
- 5 Prey utilization Overwintering mortality of forage species is dependent on the amount of energy accumulated during the summer Field and laboratory experiments suggest that the overwintering success of both age-0 Pacific herring and age-0 walleye pollock may be dependent on the amount of energy accumulated during summer (Foy and Paul 1999, Sogard and Olla in press) However, the early life history strategy of walleye pollock may make them less susceptible to starvation during the winter period Paul and Paul (1999) compared the growh strategies of larval and age-0 walleye pollock and Pacific herring This comparison revealed that walleye pollock metamorphose early, allowing for an extended growth period, while Pacific herring metamorphose later and accumulate energy for overwintering Rapid growth provides increased swimming speed leading to more successful prey capture and predator avoidance The benefits of the pollock strategy may allow them to continue to grow through the winter (Paul et al 1998)

7.10.4.1 Food Quality

Efforts to improve understanding of the mechanisms underlying the production of forage species would benefit from an improved understanding of the principal prey utilized by forage species. Although detailed information exists for commercial species such as juvenile pollock, salmon, and herring (Cianelli and Brodeur 1997, Willette et al. 1997), only limited information is available to describe the prey preferences of many members of the forage fish complex. In particular, information is lacking in the case of offshore species.

7 10 5 Hypotheses About Predation on Forage Fish

By definition, forage species represent an important prey resource for many higher-trophic-level consumers (fish, seabirds, and marine mammals) Top-down predation pressure on forage fish depends on several factors, including predator abundance, the abundance of alternative prey, the density of prey, and the patchiness of prey Changes in these factors will influence the relative importance of top trophic-level forcing on forage fish production

Evidence suggests that in some years, fish predation may exhibit a measurable effect on forage species production in the GEM region Anderson and Piatt (1999) noted that the post regime shift increase in gadoid and pleuronectid fishes coincided with marked declines in capelin and shrimp populations They proposed that this inverse relationship could be caused by increased predation mortality due to an increase in picivorous (fish-eating) species Consistent with this hypothesis, Bailey (2000) performed a retrospective analysis of factors influencing juvenile pollock survival He provided evidence that during the 1980s, pollock populations were largely influenced by environmental conditions, and after the mid-1980s, juvenile mortality was higher, resulting from the buildup of large fish predator populations In PWS, Cooney (1993) speculated that pollock predation could explain some of the observed trends in juvenile salmon survival He suggested that years of high copepod abundance were associated with high juvenile salmon survival, because pollock relied on an alternative prey resource In the open ocean, Beamish et al (1999a) proposed that mesopelagic fishes transfer and redistribute energy through two primary trophic pathways (1) abundant zooplankton to S leucopsarsus and then squid, and (2) S leucopsarsus, D theta, and L schmidti to walleye pollock, salmon, dolphin, and whales The division of energy through these pathways is thought to influence the amount of energy reaching the sea floor

The importance of forage fish in seabird and marine mammal diets has been demonstrated by a number of authors (Hatch and Sanger 1992, Springer et al 1996, Kuletz et al 1997, Ostrand et al 1998) There is little evidence that seabird predation is sufficient to regulate the production of forage fishes in the GEM region, however Therefore, key research elements for predation of forage species by marine mammals and seabirds should focus on the role of oceanographic features in concentrating forage species within the foraging range of seabirds and marine mammals

While only a few studies have examined the importance of gradients (fronts) or water mass characteristics in aggregating forage species for top predators in the GEM region, the importance of these features is well known in other regions. In the Atlantic, aggregations of capelin appear to be associated with strong thermal fronts (Marchland et al 1999) Likewise, climate impacts on the distribution and productivity of Antarctic krill (*Euphausia sepei ba*) have been shown to produce important impacts on higher trophic level consumers (Reid and Croxall 2001, Loeb et al 1997) Hay et al (1997) found that, in warm years, eulachon off the coast of British Columbia were more abundant in the offshore environment, while in cool years, eulachon were more common in the nearshore environment Consistent with the hypothesis of Hay et al , Carscadden and Nakashima (1997) noted a marked decline in offshore capelin abundance during a cool period in 1990s in the Atlantic

7 10 6 Hypotheses Concerning Contamination

Because of the broad distribution and abundance of contaminants, there is little evidence to suggest that contaminants regulate the production of forage species in Alaska waters If forage species exhibit subpopulation genetic structure, contaminants could be influential in the local mortality rate of forage fish subpopulations The small size, short life span, and importance as a prey item for higher trophic level foragers make forage species ideal indicators of regional contaminant levels (Yeardley 2000) For example, Roger et al (1990) noted that the high lipid content of eulachons suggests that they may be potential integrators of low-level contaminants. If forage species are to be used as a regional indicator of ecosystem conditions, research is needed to determine whether forage species bioaccumulate toxic chemicals. Studies are needed to determine whether observed accumulations of toxic chemicals are sufficient to change mortality rage of forage species. If forage species accumulate lethal levels of toxic chemicals at the regional level, genetic studies are needed to determine whether these populations represent genetically unique subpopulation segments

7.11 Seabirds

7 11 1 Overview

The GOA supports huge numbers of resident seabirds twenty-six species nest around the periphery of the GOA, with an estimated total on the order of eight million birds (Table 7 4) Note that sea ducks are not considered seabirds for the purposes of this discussion Most species of seabirds are colonial and aggregate during summer at about 800 colonies A variety of habitats are used for nesting, such as cliff faces, boulder and talus fields, crevices, and burrows in soft soil Two species, Kittlitz's and marbled murrelets, are not colonial and nest in very atypical habitats Kittlitz's murrelets nest on scree fields in high alpine regions often many kilometers from the coast, and marbled murrelets nest mainly in mature trees in old-growth conifer forests, also often distant from the coast

Predation by terrestrial mammals and rapacious birds undoubtedly is responsible for the nesting habitats and habits adopted by seabirds Cliff-nesting species are free to nest on mainland sites, because mammals cannot reach them and they are large enough to defend themselves and their nests against most avian predators Ground-nesting species do not have this option and must nest only on islands free from predatory mammals Additionally, some ground-nesting species come and go to and from colonies only at night, apparently to further thwart avian predators

Foxes, rats, voles, and ground squirrels were variously introduced to most islands in the Aleutians and GOA between the late 1700s and early 1900s and severely reduced the abundances of many species of ground-nesting seabirds, such

		Abundance ¹	Biomass ²	Nesting	Foraging
English Name Scientific Name		(thousands)	(tonnes)	Habıtat ³	Mode⁴
Northern fulmar	Fulmarus glacialis	440	268	Cliff	SF
Fork-tailed storm-petrel	Oceanodroma furcata	640	32	Burrow	SF
Leach s storm-petrel	Oceanodroma leucorhoa	1 067	53	Burrow	SF
Double crested cormorant	Phalacrocorax auritus	33	6	Cliff	CD
Brandts cormorant	Phalacrocorax penicillatus	0 086	0 2	Cliff	CD
Pelagic cormorant	Phalacrocorax pelagicus	21	40	Cliff	CD
Red-faced cormorant	Phalacrocorax unle	20	38	Cliff	CD
Unidentified cormorant	Phalacrocorax spp	15	29	Cliff	CD
Mew gull	Larus canus	15	11	Ground	SF
Herring gull	Larus argentatus	1	1	Ground	SF S
Glaucous winged gull	Larus glauscescens	185	241	Ground	SF S
Black-legged kittiwake	Rıssa trıdactyla	675	270	Cliff	SF
Arctic tern	Sterna paradisaea	89	12	Ground	SF
Aleutian tern	Sterna aleutica	94	12	Ground	SF
Unidentified tern	Sterna spp	17	0 22	Ground	SF
Common murre	Uria aalge	589	589	Cliff	DD
Thick-billed murre	Uria lomvia	55	55	Cliff	DD
Unidentified murre ⁵	Uria spp	1 197	1 197	Cliff	DD
Pigeon guillemot	Cepphus columba	24	13	Crevice	CD
Marbled murrelet	Brachyramphus marmoratus	200	48	Tree	CD
Kıttlıtz s murrelet	Brachyramphus brevirostris	+	+	Scree	CD
Ancient murrelet	Synthliboramphus antiquum	164	38	Burrow	CD
Cassin s auklet	Ptychoramphus aleuticus	355	71	Burrow	DD
Parakeet auklet	Cerorhinca monocerata	58	17	Crevice	DD
Least auklet	Aethia pusilla	0 02	0 0018	Talus	DD
Crested auklet	Aethia cristatella	46	14	Talus	DD
Rhinoceros auklet	Cyclorrhynchus psittacula	170	90	Burrow	DD
Tufted puffin	Lunda cırrhata	1 093	874	Burrow	DD
Horned puffin	Fratercula corniculata	773	425	Crevice	DD
Total		7,826	4,423		

Table 7 4	Nostina	Seahirds in	the Gu	If of Alaska
I able 1 4	ь мезану	Seaning in	ine Gu	II UI AIASKA

¹From U S Fish and Wildlife Service (USFWS), seabird colony database marbled murrelet in Gulf of Alaska from Piatt and Ford (1993)

²Based on weights of seabirds presented by DeGange and Sanger (1986)

³Principal type

SF = surface-feeder, CD = coastal diver, DD = deep diver, S = scavenger From DeGange and Sanger (1986) ⁵Essentially all common murres

as storm-petrels, auklets, murrelets, and puffins (Bailey and Kaiser 1993, Boersma and Groom 1993, Springer et al 1993) Today, even though foxes no longer exist on most islands, numbers of these species of ground-nesting seabirds still likely reflect the effects of introduced mammals Moreover, predators that occur naturally occasionally have large, local effects on nesting seabirds in the GOA (Oakley and Kuletz 1996, Seiser 2000)

The distribution and abundance of nesting seabirds in the GOA is therefore governed primarily by the availability of suitable, safe nesting habitats, as well as by the availability of prey For example, cliff-nesting species, such as murres and kittiwakes, require cliffs facing the sea Therefore, regardless of the biomass of potential forage species in the eastern GOA, there are no muries or kittiwakes in much of the region because of the lack of sea cliffs Where suitable nesting habitat does exist, seabirds nearly always occupy it, and fluctuations in their productivity and abundance through time are thought to be determined for the most part by fluctuations in prey populations

Species that nest on cliff faces, such as murres and kittiwakes, are the most well-studied because of their visibility Completing censuses of cliff-nesting seabirds is comparatively easy, as is measuring several components of their breeding biology, including the study of recurring natural phenomena such as migration (phenology) and reproductive success Consequently, precise estimates of abundance and productivity, and trends in these variables through time, are available for murres and kittiwakes at many colonies in the GOA In addition to their visibility, murres and kittiwakes are extremely numerous and widelydistributed, and more is known about them than about any other species

In contrast, seabirds that nest underground are difficult to study A further complication is that some of these are nocturnal as well Despite huge numbers and broad distributions of some diurnal species, such as puffins, and nocturnal species, such as storm-petrels, much less is known about population sizes and productivity or trends in these parameters through time and space They do have scientific value, however, because other characteristics of their biology offer valuable opportunities for obtaining information on the distribution and dynamics of prey populations important to a variety of seabirds and marine mammals

Most seabirds in the GOA are primarily piscivorous (fish eating) during the nesting season. The principal exceptions include northern fulmars, storm-petrels, and thick-billed murres, which consume large amounts of squid, auklets, which specialize on zooplankton, and gulls, terns, and guillemots, which consume considerable amounts of crustaceans in addition to fish. Many species of fishes are taken, although a comparatively small number contribute the bulk of the biomass to diets of most seabirds. Overall, the three most important species of fishes are sand lance, capelin, and pollock. At certain colonies, at certain times, in certain years, or any combination of these conditions, the myctophids, Pacific cod, saffron cod, herring, sablefish, pricklebacks, prowfish, and salmon are also important to some species (Hatch 1984, Baird and Gould 1986, DeGange and Sanger 1986, Sanger 1987, Hatch and Sanger 1992, Irons 1992, Piatt and Anderson 1996, Suryan et al. 2000, Gill and Hatch unpublished data)

Resident GOA seabirds can be divided into three groups based on their foraging behavior (Table 7 4) Surface-feeders, as their name implies, obtain all of their food from about the upper 1 m of the water column and often forage over broad areas Coastal divers can generally reach bottom and typically forage in shallow water near shore Pelagic mid-water and deep divers are capable of exploiting prey at depths of up to nearly 200 m and of foraging over large areas (Schneider and Hunt 1982, Piatt and Nettleship 1985) Most individuals of most species forage over the continental shelf during summer This is due primarily to the location of nesting areas, which are along the mainland coast and on nearshore islands, and the distribution of forage species, which in aggregate are more diverse and abundant on the shelf than off the shelf Exceptions to this generalization are the fulmars and storm-petrels, which have anatomical, behavioral, and physiological adaptations that allow them to forage at great distances from their nesting areas, giving them access to resources off the shelf (Boersma and Groom 1993, Hatch 1993), and species such as kittiwakes that typically feed over the shelf, but which can efficiently exploit prey off the shelf when those prey are within foraging range from their nesting locations (Hunt et al 1981, Springer et al 1996, Hatch unpublished data)

Therefore, as a group, seabirds sample forage populations broadly in three dimensions These characteristics, plus variations in diet between species and the sensitivity of various components of their breeding biology and population abundance to fluctuations in prey availability, make seabirds in the GOA, as elsewhere, valuable tools in the study of marine ecosystems (Cairns 1987, Aebischer et al 1990, Furness and Nettleship 1991, Springer 1991, Hatch and Sanger 1992, Montevecchi and Myers 1996, Piatt and Anderson 1996, Springer et al 1996)

Seabird populations in the North Pacific from California to Arctic Alaska are very dynamic, waxing and waning in response to changes in prey abundance,

predators, entanglement in fishing gear, and oil spills (Anderson et al 1980, Ainley and Broekelheid 1990, Paine et al 1990, Murphy et al 1991, Hatch 1993, Hatch et al 1993, Ainley et al 1994, Byrd et al 1998, Divoky 1998) Oil spilled from the *Exxon Valdez* killed an estimated 250,000 seabirds in the GOA, 185,000 of which were murres (Piatt and Ford 1996) Most murre mortality occurred downstream from PWS near the Barren Islands and Alaska

Charactenstics such as broad sampling of forage populations and sensitivity to prey availability make seabirds valuable tools in the study of manne ecosystems

Peninsula and had an unknown effect on the abundance of murres at regional colonies There is evidence that the immediate mortality and lingering effects of the spill in PWS have depressed the abundance of several other species of seabirds there throughout the 1990s (Irons et al 2000)

A strong case also has been made for a broad-scale decline in seabird abundance in the GOA during the past two to three decades beginning before the EVOS Marine birds counted at sea in summer in PWS apparently declined by some 25 percent in aggregate between 1972 and the early 1990s (Kuletz et al 1997) Many species contributed to the decline, including loons, cormorants (-95 percent), mergansers, Bonaparte's gulls, glaucous-winged gulls (-69 percent), black-legged kittiwakes (-57percent), arctic terns, pigeon guillemots (-75 percent), marbled and Kittlitz's murrelets (-68 percent), parakeet auklets, tufted puffins, and horned puffins (-65 percent) (Klosiewski and Laing 1994) Other census data further indicated that for the marbled murrelet, at-sea winter abundance declined by more than 50 percent throughout the GOA during this time (Beissinger 1995) Results from studies at several murre colonies in the GOA in summer tend to support this pattern Piatt and Anderson (1996) reviewed the abundance histories of sixteen colonies and concluded that many were in decline before the EVOS Therefore, it proved difficult to estimate the effect oil had on murre populations

It is generally thought that alterations in forage fish abundance and community structure brought on by environmental change not associated with the oil spill, such as climate change, have been primarily responsible for falling seabird populations (Oakley and Kuletz 1996, Piatt and Anderson 1996, Hayes and Kuletz 1997, Kuletz et al 1997, Anderson and Piatt 1999) For example, pigeon guillemot numbers in PWS in 1978 to 1980 averaged about 40 percent higher than in the early 1990s, and they declined further through 1996 (Oakley and Kuletz 1996) The decline in abundance was accompanied by a decline in the occurrence of sand lance in their diets, and it has been suggested that cause and effect relate the two Because sand lance has a much higher fat content than the forage species guillemots switched to, such as pollock and blennies, it is nutritionally superior (Anthony and Roby 1997, Van Pelt et al 1997) In Kachemak Bay, sand lance was particularly abundant in diets of guillemots nesting in high-density colonies in the late-1990s, and chicks fed predominantly sand lance grew faster than chicks fed lower-quality prey (Prichard 1997) Likewise, reductions in energy-dense capelin in the GOA and in diets of several species of seabird in the 1980s compared to the 1970s also have been linked to population declines (Piatt and Anderson 1996, Anderson and Platt 1999)

Additional evidence of possible climate-mediated population decline is the frequency and magnitude of large seabird die-offs in the past two decades Some of these involved huge numbers of surface-feeding species in summer, particularly kittiwakes and shearwaters in the GOA and especially the Bering Sea, during years of strong El Niño events, notably 1983 and 1997 (Nysewander and Trapp 1984, Mendenhall 1997) Others involved principally murres in the GOA in winter In 1993, on the order of 100,000 common murres starved to death, and in 1997, at least tens of thousands suffered a similar fate (Piatt and van Pelt 1993, Piatt unpublished data) Such acute mortality, when added to the normal, or perhaps elevated, attrition suffered by juvenile birds in recent years, could have significant repercussions on population size As Piatt and Anderson (Piatt and Anderson 1996) note, there was only one reported die-off of seabirds in the general region before 1983, and that was in the Bering Sea in 1970 (Bailey and Davenport 1972)

There is no evidence that seabirds in the GOA have been directly affected by commercial fisheries Most of the prey of seabirds are not targeted, for example, sand lance and capelin Adults of some prey species are fished, such as pollock, Pacific cod, and herring, but most seabirds can feed only on the small age-0 and age-1 fish of these large types and therefore do not compete with commercial fisheries for biomass Indirect effects of commercial fishing are possible if stock sizes are affected by fishing and if stock size influences the abundance of young age classes of those species or the abundance of other forage species

7 11 2 Case Studies

A lot of information has been collected on seabirds in the GOA in the past three decades, although much of the data obtained in the last ten years has not yet

been published or even presented Therefore, the integration of all results into a composite picture of seabird ecology is not currently possible Nevertheless, good information is available for some aspects of the biology of certain species at certain sites, and these examples can be used to give a general idea of the status of seabirds and their sensitivity to change in the environment Prominent species are the black-legged

The black-legged kittiwake and common murre are the most abundant, most widely distributed, and best known bird species in the GOA

kittiwake and common murre They are among the most abundant and widely distributed seabirds, nesting at hundreds of colonies from Southeastern Alaska to Unimak Pass These attributes and their ease of study have made them the best known of all species in the GOA Information on trends in abundance, productivity, and diets of kittiwakes and murres at several locations spans periods of one to more than four decades Information on other species, notably fulmars and puffins, at some colonies provides additional context

7.11.2.1 Middleton Island

The longest time series of reliable abundance estimates for seabirds in the GOA comes from Middleton Island, where the first count was made in 1956 (Rausch 1958) Between 1956 and 1974, the number of kittiwakes increased by an order of magnitude, from about 14,000 to 144,000 birds (Baird and Gould 1986) That increase is thought to have been made possible by the 1964 earthquake, which uplifted large sections of Middleton Island and created extensive new nesting habitat Numbers of kittiwakes remained high there throughout the 1970s, but began to decline steadily in the early 1980s from a peak of about 166,000 birds to about 16,000 today (Hatch et al 1993, Hatch unpublished data)

The decline in abundance has been accompanied by generally low productivity since the early 1980s, averaging just 0 06 chicks per pair between 1983 and 1999 (Table 7 5) Supplemental feeding of kittiwakes in recent years altered a variety of adult breeding parameters sensitive to food supply and increased survival of chicks, strongly supporting the notion that food limitation has been the cause of

Colony(s)	Population Trajectory	Average Production, 1983-2000	Number of Colonies	Colony years
Increasing				
Gull Island ¹	Up	0 39	1	15
Prince William Sound ²	Up	0 30	4	67
Barren Island ³	Up	0 40	1	7
Stable				
Prince William Sound– Overall ²	Level	0 18	22	372
Prince William Sound ²	Up-Down	0 14	5	94
Prince William Sound ²	Level	0 15	2	34
Chiniak Bay ²	Level	0 19	1	16
Declining				
Semıdı Islands ³⁴	Down	0 05	1	11
Chisik Island ¹	Down	0 06	1	9
Prince William Sound ²	Down	0 04	11	177
Middleton Island ⁴	Down	0 06	1	?

Table 7 5 Trends in Kittiwake Abundance and Productivity at Colonies in the Gulf of Alaska

Colonies in PWS are divided into groups of increasing, stable and declining abundance, overall kittiwake abundance is stable in PWS

¹From J Platt (unpublished data)

²From D Irons (unpublished data)

³From USFWS (unpublished data)

⁴From S Hatch (unpublished data)

poor productivity and population decline (Gill 1999, Gill and Hatch unpublished data)

The longest time series of abundance data for murres also comes from Middleton Island As with kittiwakes, the murre population increased by about an order of magnitude following the 1964 earthquake, numbering 6,000 to 7,000 individuals by the mid-1970s Also like kittiwakes, murre abundance at Middleton Island was in decline by the end of the decade, falling to about 4,000 individuals by 1985 The population abruptly increased the following year to nearly 8,000 birds, where it remained through 1988, rapidly declined again to about 2000 by 1992, and has been more or less stable since (Hatch unpublished data) The cause of the decline is thought to have been driven in part by the growth of vegetation that hampers access of chicks to the sea once they leave the nest (Hatch unpublished data), but the sharp increases and decreases during the course of the overall decline argues for other controlling factors

Glaucous-winged gulls also probably nested in comparatively small numbers on Middleton Island before 1964, although no counts were made in the early years By 1973 there were fewer than 1,000 individuals and fewer than 2,000 a decade later However, in contrast to findings for murres and kittiwakes, the population ballooned to more than 12,000 birds between 1984 and 1993, and now totals about 11,000 (Hatch unpublished data) Predation by gulls on kittiwake and murre eggs and chicks may have contributed to the declines of those species (2001)

The abundance of rhinoceros auklets on Middleton Island more than doubled from about 1,800 to 4,100 burrows between 1978 and 1998 (Hatch unpublished data) Although there are no hard data, it seems likely that few or no rhinoceros auklets nested there before the earthquake because of a lack of habitat (Hatch unpublished data) Therefore, the increase in rhinoceros auklet abundance might be just the result of an increase in the extent of nesting habitat as vegetation covered uplifted soils At St Lazaria Island in Southeast Alaska, however, rhinoceros auklet numbers nearly doubled during the 1990s (Byrd et al 1999), indicating that other factors are possibly involved

A lack of adequate data precludes firm conclusions about trends in abundance of tufted puffins, but it is thought that they are increasing in abundance on Middleton Island as well (Hatch unpublished data)

Pelagic cormorants are known to move between nesting areas within colonies between years, therefore, census data are not necessarily as accurate for them as for other cliff-nesting species of seabirds The data show that numbers of nesting pairs were comparatively stable at about 2,000 to 2,800 between the mid-1970s and mid-1980s The number of pairs was extremely volatile from 1985 to 1993, however, rising and falling by as much as 700 percent between consecutive years In 1993, pelagic cormorants numbered about 800 pairs, and have increased steadily since then to about 1,600 pairs (Hatch unpublished data)

Seabirds at Middleton Island feed on a variety of forage species common throughout the GOA (Hatch 1984, Hatch and Gill unpublished data) Early in the nesting season kittiwakes typically prey on extremely energy-dense myctophids, which are generally restricted in their distribution to deep-water regions off continental shelves (Willis et al 1988, Sobolevsky et al 1996) Later they switch to other, likely more accessible, prey and feed chicks primarily on sand lance, although capelin and sablefish are also important in some years (Hatch and Gill unpublished data)

Rhinoceros auklets feed on numerous species of fishes, but seem to be sand lance specialists (Hatch 1984, Vermeer and Westrheim 1984, Vermeer et al 1987) At Middleton Island, sand lance contributed on average 62 percent of the biomass fed to chicks in eleven years between 1978 and 2000 (Hatch unpublished data) In years of apparent low abundance during the first half of the 1990s, pink salmon, capelin, greenlings, and sablefish replaced sand lance

Tufted puffins at Middleton Island feed their chicks predominantly sand lance in years when sand lance are most abundant sand lance make up as much as 90 percent of biomass in peak years Tufted puffins apparently switch to other prey sooner than rhinoceros auklets when sand lance is scarce Alternative prey of tufted puffins consists mainly of pollock and prowfish, with somewhat lesser amounts of sablefish (Hatch unpublished data)

7.11.2.2 Prince William Sound

Twenty-three kittiwake colonies in PWS were first counted in 1972, but were not counted again until 1984 These and an additional six colonies have been visited nearly each year since (Irons 1996, Irons unpublished data) During this time, long-term increases and decreases have been noted at various colonies, but no obvious geographic pattern to the changes was found Instead, four colonies have grown to large size, and eleven smaller colonies have declined, with some disappearing completely Five other colonies first increased, then decreased, and two have not changed appreciably At least some of these changes likely resulted from movements of adults between sites (Irons unpublished data) For example, as the Icy Bay colony declined from about 2,400 birds in 1972 to fewer than 100 by 2000, the nearby North Icy Bay colony grew from about 500 birds in 1972 to about 2,000 by the late 1990s Overall, the total abundance of kittiwakes in PWS has remained stable, or perhaps increased slightly, despite substantial interannual variability, for example, decreasing by 45 percent between 1991 and 1993 and increasing by 35 percent between 1999 and 2000

Overall productivity likewise has been highly variable between years, but generally has been much greater than at Middleton Island, averaging 0 18 chicks per pair since 1984 (Table 7 5) Average productivity differed considerably between colonies with different population trajectories, however (Table 7 4) The average productivity of four colonies with increasing populations was twice that of two stable colonies and five colonies that experienced matching increases and decreases, while productivity at those was nearly four times as great as that at eleven declining colonies

7.11.2.3 Lower Cook Inlet

Kittiwakes at Chisik Island in Lower Cook Inlet were first counted in 1971 (Snarski 1971), and the population appears to have fallen steadily since then By 1978, the number of birds was down by about 40 percent and today it is just 25 percent of the 1971 total (Piatt unpublished data) The trend in murre abundance at Chisik Island has paralleled that of kittiwakes, but the decline has been even steeper. The population fell by more than half between 1971 and 1978, and today stands at just about 10 percent of its former abundance. Kittiwake productivity has been poor in most years, averaging just 0.06 chicks per pair (Table 7.5). Less is known about productivity of murres, which has been estimated only since 1996. In that time, it has been variable and averaged 0.56 chicks per pair (Table 7.6).

In contrast, just across Cook Inlet at Gull Island in lower Kachemak Bay, numbers of kittiwakes and murres have increased substantially since counts were first made in 1976 The abundance of kittiwakes more than doubled between the mid-1970s and mid-1980s, peaked in 1988, and has averaged about 10 percent to 15 percent lower through the 1990s (Piatt unpublished data) The growth in numbers of murres was somewhat less abrupt, but more enduring, with steady, exponential growth of about 300 percent through 1999 Productivity of kittiwakes at Gull Island has been much higher than at Chisik Island, and has been among the highest anywhere in the GOA with comparable data (Table 7 5) Productivity of murres at Gull Island has been less variable than at Chisik Island, but has averaged essentially the same, 0 52 chick per adult (Table 7 6)

Colony	Population Trajectory	Average Production, 1989-2000	Range	Colony Years
Gull Island ¹	Up	0 52	0 28-0 65	4
Chisik Island ¹	Down	0 56	0 18-0 74	4
Barren Island ²	Up	0 73	0 58-0 75	5
Semidi Islands ^{2 3}	Up	0 48	0 21-0 58	6

Table 7 6	Trends in Murre	Abundance	and	Productivity	at Colonies
in the Gul	f of Alaska				

¹From J Platt (unpublished data)

²From USFWS (unpublished data)

³From S Hatch (unpublished data)

Kittiwakes were first counted on the Barren Islands, at the mouth of Cook Inlet, in 1977 The next counts in 1989 to 1991 were apparently comparable Systematic counts began in 1993 and have continued since It is not known if the earlier (1977 to 1991) and later (1993 to 1999) groups are comparable Within-group data indicate that there was no apparent change in kittiwake abundance during either time period Likewise, there are two groups of counts for murres – seven counts between 1975 and 1991 and ten systematic counts between 1991 and 1999 Counts in the early part of the first interval are not comparable to later counts in that interval, therefore, it is not known whether murre numbers changed from the 1970s to the late 1980s Since 1989, however, the population has steadily grown by about 40 percent (Roseneau unpublished data) Kittiwake productivity at the Barren Islands in the 1990s was as high as at Gull Island (Table 7 5) Murre productivity since 1995 has averaged 0 73 chick per pair, which is higher than at either of the other colonies in Lower Cook Inlet

Kittiwakes and murres at all three locations prey on a similar suite of forage fishes, but the proportion of each species in diets varies depending on their relative abundance Sand lance, capelin, and cods are the three most important taxa of prey (Piatt unpublished data, Roseneau unpublished data) Among the cods, the proportions of pollock, Pacific cod, and saffron cod vary by location A variety of evidence from the Lower Cook Inlet region indicates that population trends of kittiwakes and murres at the three colonies are directly related to the abundance of prey available to the birds (Kitaysky et al 1999, Robards et al 1999, Piatt unpublished data, Roseneau unpublished data)

7.11.2.4 Kodiak Island

Of numerous seabird colonies on Kodiak Island, only the one at Chiniak Bay has received much attention Kittiwakes were first counted there in 1975 to 1977 and numbers were stable They were next counted in 1984, by which time the population had more than doubled Numbers have since been variable, but showed no significant changes until 1999, when they were about twice as great as in 1997 to 1998 Kittiwake productivity at Chiniak Bay was very high for at least two years in the mid-1970s (about one chick per nest), but was poor in the 1980s, averaging just 0 11 chick per nest between 1983 and 1989 Productivity improved in the 1990s, averaging 0 24 chick per nest, and has averaged 0 19 chick per nest overall since 1983 (Table 7 5)

Kittiwakes at Chiniak Bay preyed primarily on sand lance and capelin in the 1970s Variations in diet between years were correlated with variations in productivity (Baird 1990)

7.11.2.5 Semidi Islands

Approximately 2,500,000 seabirds, or about a third of all the seabirds nesting in the GOA, are found on the Semidi Islands, including about 10 percent of the kittiwakes, half of the murres and horned puffins, and nearly all of the northern fulmars (Hatch and Hatch 1983) Seabird studies on the Semidi Islands began in 1976 and have continued in most years since Most work has occurred at Chowiet Island, which hosts on the order of 400,000 birds of at least fifteen species, with the cliff-nesting species–kittiwakes, murres, and fulmars–receiving the greatest attention

The number of kittiwakes at Chowiet Island varied little through 1981, although the number of nests grew by 60 percent No counts were made in 1982 to 1988 Kittiwake abundance in 1989 and 1990 had not changed, but it declined abruptly in 1991, and has averaged about 30 percent lower since The number of kittiwake nests in 1989 had fallen back to the late 1970s level, where it has tended to remain (USFWS unpublished data) Productivity of kittiwakes at Chowiet Island was generally high between 1976 and 1981, averaging 0 43 chick per nest, with the highest level (about 1 chick per nest) in 1981 Kittiwakes began failing to produce chicks at least by 1983 (no data were obtained in 1982), however, and in eleven years between then and 1998, the average productivity has been just 0 05 chick per nest (Table 7 5) Accompanying the decline in abundance and collapse of productivity was a delay of nine days in the mean laying date in the 1990s compared to the 1970s and early 1980s Poor productivity and delayed laying are both symptomatic of food stress

Murre abundance on Chowiet Island was stable between 1977 and 1981 Abundance was the same in 1989 when counts were next made, but in contrast to findings for kittiwakes, the population has grown steadily since, standing 30 percent higher by 1998 As for kittiwakes, the mean laying date of murres was about ten days later in the 1990s than in the 1970s Productivity has not varied appreciably between years, except in 1998 when it was very low The average productivity since 1989 was 0 48 chick per pair, or about the same as at Chisik and Gull islands (Table 7 5)

Trends in fulmar abundance, productivity, and phenology through time exhibited patterns similar to those of kittiwakes and murres As with murres, abundance has increased numbers of fulmars grew steadily between 1976 and 1981, and generally continued that trajectory at least through the mid-1990s An exceptionally low number recorded in 1998, the last year they were counted and the only year since 1995, may be an artifact and not representative of the long-term trend, or it may represent a real decline As with kittiwakes, productivity of fulmars was lower in the 1980s and 1990s, averaging just 0 24 chick per nest from 1983 through 1998, compared to an average of 0 52 chick per nest from 1976 through 1981 In addition, as found for both kittiwakes and murres, the nesting phenology of fulmars was conspicuously later in the 1990s than in the 1970s

Little is directly known about diets of kittiwakes and murres at the Semidi Islands, but based on diets of rhinoceros auklets and tufted and horned puffins there (Hatch 1984, Hatch and Sanger 1992), it can be assumed that the usual food sources-sand lance, capelin, and pollock-are most important. These prey also are significant for fulmars. In general, the diets of fulmars overlap extensively with those of kittiwakes and murres, although overall fulmar diets are much more varied (Sanger 1987, Hatch 1993). For example, fulmars are noted for eating large amounts of jellyfish and offal and for feeding jellyfish to chicks.

7 11 3 Conclusions

1

Seabird populations at colonies in the GOA are very dynamic, with numerous examples of growth and decline during the past three decades

In spite of considerable uncertainty about the magnitude, a widespread decline in the abundance of murres in the GOA may have occurred since the 1970s Numbers are clearly down in such diverse habitats as Middleton Island, which lies near the edge of the continental shelf and is the most oceanic of all colonies in the GOA, at Chisik Island, which is arguably the most neritic (nearshore) colony, and apparently at several colonies along the south side of the Alaska Peninsula Murre numbers are not uniformly down, however, they have increased dramatically at Gull Island during the past fifteen years and at the Barren Islands and the Semidi Islands during the past ten years. Although comparatively little is known about murre productivity, it has been essentially the same in recent years at the declining colony on Chisik Island, the rate of decline of the population equals the estimated adult mortality-productivity seems to be sufficient to maintain numbers <u>if</u> those birds were recruiting to the population. Therefore, recruitment appears to have been lacking, which could be explained by poor survival of birds raised there or by
emigration to other colonies (Piatt personal communication) At Gull Island, productivity and recruitment can account for only about half the rate of population growth, with immigration required to explain the other half

In most cases, local trends in the abundance of murres and kittiwakes, likely reflect mesoscale or regional processes affecting prey availability For example, differences in population trends of both species at Chisik Island and Gull Island, and differences in productivity of kittiwakes between the islands, are related to regional variations in the abundance of forage fishes (Piatt unpublished data) The similarity in murre productivity between colonies is likely explained by flexible time budgets, which buffers them against fluctuations in prey (Burger and Piatt 1990, Zador and Piatt 1999)

There is not enough information to determine whether total kittiwake abundance in the GOA has changed one way or another Many examples of growth, decline, and stasis in individual colonies are available, but there is no apparent broad geographic pattern to the trends At the few colonies where both kittiwakes and murres have been monitored, abundances of the two species tend to track each other through time Kittiwakes, along with murres, have declined at Middleton Island and Chisik Island, and apparently increased, with murres, at Gull Island The one exception is at Chowiet Island in the Semidi Islands, where kittiwakes decreased and murres increased Elsewhere, kittiwakes have increased at Chiniak Bay on Kodiak Island and remained stable overall in PWS

There is a strong correlation between population trajectory and long-term average productivity of kittiwakes at many colonies Those colonies that are increasing in size have the highest productivity, those that are declining have the lowest Colonies that show no change have intermediate levels. There are various interpretations of such a relationship. One is that productivity and subsequent recruitment of young determines abundance. Another is that kittiwake abundance and productivity simply track changes in prey, that is, in years of high prey abundance, more adults attend colonies and produce greater numbers of chicks than in years of low prey abundance. There would not necessarily have to be any other relationship between the two

There are conspicuous temporal patterns of kittiwake productivity at many colonies during the past seventeen years Productivity at colonies in PWS and at Gull Island has varied in tandem, with peaks and valleys at about 5-year intervals high productivity in the mid- to late 1980s, low in the early 1990s, and higher again after 1995 For most of the record, from the early 1980s through the mid-1990s, this pattern was opposite that at Chiniak Bay on Kodiak Island, where productivity peaked in the early 1990s while it bottomed-out in PWS and at Gull Island Productivity at the three locations tended to track together during the latter half of the 1990s

Kittiwake productivity and population trends in PWS are well-correlated before 1991 and since 1991, but the sign (positive or negative) of the relationship

differs Before 1991, high productivity was associated with low numbers of birds at the colonies, but since 1991, the relationship has been opposite. A similar switch occurred at about the same time in the relationship between kittiwake productivity in PWS and the abundance of age-1 herring. Such differences in sign and behavior of relationships before and after the 1989-to-1990 regime shift have been pointed out for kittiwakes in the Bering Sea and for various other ecosystem components of the North Pacific. It has been suggested that the differences reflect fundamental changes in ecosystem processes (Springer 1998, Welch et al. 1998, Hare and Mantua 2000)

The peaks and valleys in kittiwake productivity in PWS have punctuated a general declining trend during the longer term If productivity depends more on prey abundance than on predation, then it seems as though prey have tended to decline throughout PWS in the past seventeen years, notwithstanding apparent oscillations

7114 Future Directions

Seabirds in the GOA are sensitive indicators of variability in the abundance of forage fishes through time and space. How well information from particular species at particular colonies reflects broad patterns of ecosystem behavior in the GOA remains to be seen. The problem is that nearly all of the colonies are situated in habitats with distinct mesoscale or regional properties. PWS is a prime example, where colonies are located at the heads of fjords with and without glaciers, in bays and on islands around the perimeter of the main body of the sound, and on islands in the center of the sound. The Barren Islands and Gull Island are strongly influenced by intense upwelling in Kennedy Entrance that greatly modifies local physical conditions and productive. Chisik Island lies in the path of the outflow of warm, nutrient-poor water from Cook Inlet. The Semidi Islands lie at the downstream end of Shelikof Strait and the center of distribution of spawning pollock in the GOA.

Thus, there are various trends in abundance of kittiwakes at the numerous colonies in PWS Trends in abundance of kittiwakes and murres at the Barren Islands and Gull Island are opposite those at neighboring Chisik Island, and patterns of kittiwake productivity at Gull Island and Chiniak Bay are opposite of each other Only Middleton Island, which sits isolated near the edge of the continental shelf and the Alaska Stream, and sites on or near the coast of the Alaska Peninsula west of Kodiak Island, which lie in the flow of the Alaska Coastal Current, seem to have the potential to represent gulf-wide variability unencumbered by possibly confusing smaller-scale features

On the other hand, there is reason for optimism that broad-scale variability is indeed expressed in seabird biology In spite of a wide variety of local habitat characteristics and population trends of kittiwakes at the many colonies in PWS, and large differences in average long-term productivity among colonies with differing abundance trends, a common temporal pattern of productivity has been shared by almost all colonies Concordant, clearly defined peaks and valleys have been observed at about five-year intervals A sound-wide environmental signal has propagated through the kittiwakes regardless of their location or status

Moreover, the signal captured by kittiwakes in PWS and expressed in patterns of productivity was also captured by kittiwakes at Gull Island, implying that they may not be as ecologically separated as one might assume considering their geographic distance and characteristics of their environments And further expanding the spatial dimension, the temporal pattern of sand lance abundance in the vicinity of Middleton Island during the past fifteen years, as revealed by its occurrence in diets of rhinoceros auklets and tufted puffins there, matches closely the patterns of kittiwake productivity in PWS and at Gull Island Although a long geographical stretch, it might not be such a long ecological stretch when viewed broadly, at the GOA scale, rather than in a regional geographic and ecological context And finally, the kittiwakes at Chiniak Bay also seemed to be attuned to this same signal, notwithstanding the fact that it apparently led to opposite behavior in the local system for some of the time One thing that is fairly certain of is that the temporal and spatial patterns in various components of seabird biology exhibited in the GOA do reflect underlying patterns in food-web production and ecosystem processes Because of the range of oceanographic situations surrounding the various colonies, detailed information from them should prove valuable in building a composite view of ecosystem behavior in the GOA

A variety of approaches to developing a long-term monitoring program in the GOA might work, but the framework that has evolved over the past three decades already has proved useful In-depth work is occurring or has occurred in many years since the 1970s at well-placed locations throughout the GOA These locations include St Lazaria Island and Forrester Island in Southeast Alaska, Middleton Island, many colonies in PWS, Chisik Island, Gull Island, and the Barren Islands in Lower Cook Inlet, Kodiak Island, the Semidi Islands, and Aiktak Island on the south side of Unimak Pass Colonies at these locations share several well-known, tractable species that provide complementary views of the ecosystem, particularly if they are systematically exploited for their contributions Just as information from each of these colonies will help build a composite broad view of the GOA, information from several species of seabirds at each colony will help build a composite regional view of ecosystem behavior

Therefore, the most popular species should continue to be the main focus These are kittiwakes and murres, the species in the GOA with the highest combined score of abundance, distribution, and ease of study Elements of their biology are sensitive to variability in prey, as seen in the GOA and numerous places elsewhere in the North Pacific and North Atlantic

Kittiwakes and murres do not do some things as well as second-tier species, namely the puffins Comparatively little is known about population trends of puffins, despite the fact that they are among the most abundant and widespread of the seabirds in the GOA This lack of knowledge results because they nest underground However, puffins have been used to monitor trends in forage fish abundance at numerous colonies throughout the GOA, Aleutian Islands, and British Columbia (Hatch 1984, Vermeer and Westrheim 1984, Hatch and Sanger 1992, Hatch unpublished data, Piatt unpublished data) Diets of the three species of puffins overlap extensively, but each samples the environment somewhat differently variability in diets among the puffins, locations, and time reveals geographic patterns of forage fish community structure and fluctuations in the abundances of individual species Puffins return whole, fresh prey to their chucks, a behavior that provides an economical, efficient means of measuring various attributes of forage fish populations, such as individual growth rates within and between years and relative year-class strength

Third-tier species, the cormorants, guillemots, and storm-petrels, also have attributes that can provide additional useful information. Cormorant and guillemot diets overlap extensively with those of kittiwakes, murres, and puffins, but the cormorants and guillemots sample prey much nearer to colonies and sample additional species not used by the others. Storm-petrels, in contrast, range widely and sample oceanic prey not commonly consumed by any other species. In combination, the diets, abundance, and productivity of the various species of seabirds provide information on prey at multiple spatial scales around colonies. In situations when this information can be easily obtained, it should not be overlooked

A successful strategy for seabird monitoring will balance breadth (geographic and ecological) with intensity (how much is done at each site) On the one hand, it is important to select a sufficient number of sites to adequately represent a range of environmental conditions in mesoscale and macroscale dimensions On the other hand, studies must be thorough at each colony Simply comparing population trends of one or two species may give uncertain, possibly misleading information on underlying conditions of the environment Without additional information on such things as survival, emigration, recruitment, diet, and physiological condition of the birds, conclusions about causes of population change, or about what population change is saying about the environment versus what productivity is saying, are elusive

Another need for a long-term monitoring plan is knowledge about when reliable time series begin For example, several estimates of murre abundance at colonies in the GOA from the 1970s are likely not comparable to more recent systematic counts (Erikson 1995, Roseneau unpublished data) Inappropriate comparisons could result in erroneous conclusions about population changes that might further lead to unsupported speculation concerning broader trends in ecosystem change The consequences of inappropriate comparisons are nicely illustrated by census data from the western Alaska Peninsula If taken at face value, the information indicates that declines in the abundance of murres have been particularly severe at colonies from the Shumagin Islands westward to Unimak Pass However, the trend data for two of the colonies, Bird Island and Unga Island, consist of single counts made in each of two years at both colonies The first counts in 1973 were made in mid-June, which is early in the nesting season when murre numbers are unstable at colonies and often much higher than later during the census period (Hatch and Hatch 1989) At another of the colonies, Aiktak Island, the evidence of decline is based on a single count of nearly 13,000 birds in 1980, the first year a census of the colony was performed (Byrd et al 1999) Single counts in 1982, 1989, and 1990 ranged between 175 and about 8,000 birds And, the lower boundary of the 90 percent confidence interval about the mean of multiple counts in 1998 was less than zero, and the upper boundary was nearly as great as the first count in 1980 One must therefore ask if the murre population has indeed changed at all over the long term at Aiktak Island, or at the other colonies in the region where similar uncertainty exists, and if so how much

In spite of such caveats, information gained from seabirds in the past three decades reveals a great deal about the nature of variability in the GOA We can be certain that the perpetuation and refinement of seabird studies will continue to provide insights and hypotheses useful to the broader goal of understanding the GOA ecosystem

7.12 Fish and Shellfish

7 12 1 Introduction

The GOA is well known for its fish and shellfish because of its long-standing and highly valuable commercial and recreational fisheries Less well known are the non-commercial fish and invertebrate species that compose the bulk of the animal biomass in the GOA As a rule, the economically important species are fairly well known from trawl, trap, and hook catches made by research and commercial vessels (Cooney 1986a, Martin 1997a, Witherell 1999a, Kruse et al 2000a) By the same rule, the majority of fish and shellfish species are less well known, having been sampled during research investigations of limited duration (Feder and Jewett 1986, Rogers et al 1986, Highsmith et al 1994, Purcell et al 2000, Rooper and Haldorson 2000) Species not commercially harvested are less well studied than commercially harvested species, such as Tanner crab For example, because no commercial fisheries are allowed for such forage fishes as eulachon, sand lance, capelin, and lantern fish, the fluctuations of their populations are not well documented More detailed consideration of some of the less economically important, but more ecologically prominent forage species is found in Section 7 10, Forage Species, and some of the less common shellfish species are considered in Section 79, Nearshore Benthic Communities

The marine fish and shellfish of the GOA fall into two major groups (Feder and Jewett 1986, Rogers et al 1986, Cooney 1986a, Cooney 1986a, Martin 1997b)

- 1 Fish-bony fish, sharks, skates, and rays, and
- 2 Shellfish-the mollusks (bivalves including scallops, squid and octopus), and Crustaceans-crabs and shrimp

Note that three other ecologically important groups, the pelagic jellyfish (Crudaria), the bottom dwelling starfish and urchins (Echinodermata), and the segmented worms (Annelida) are not included in the category of the fish and shellfish A list of all the scientific names and many common names of the species accessible to trawl gear on the continental shelf and shelf break of the GOA is found in Appendix G (see survey area map, Figure 7 10)

As would be expected with high marine productivity, the fish and shellfish fisheries of the GOA have been among the world's richest in the second half of the 20th century Major fisheries include, or have included, halibut, groundfish (Pacific cod, pollock, sablefish, Pacific ocean perch and other rockfish, flatfish such as soles and flounders), Pacific herring, multiple species of Pandalid shrimp and red king crab, five species of Pacific salmon, scallops, and other invertebrates (Kruse et al 2000a, Witherell and Kimball 2000, Cooney 1986a) The status of major fisheries and stocks of interest are addressed in the subsections below

7 12 2 Overview of Fish

Most of the approximately 287 known GOA fish species are bony fish, and the largest number of species is in the sculpin family (Cottidae), followed in order of number of species by the snailfish family (Cyclopteridae), the rockfish family (Scorpaenidae) and the flatfish family (Pleuronectidae) (Tables 77 and 78) The bony fish dominate the number of species in the GOA, with less than 10 percent of species being cartilaginous fishes (Petromyzontidae to Acipenseridae, Table 77) Species diversity in the fish depends on the type of gear used to sample (Table 77) It is important to keep in mind that trawl gear surveys are not designed or intended. to estimate species diversity A comparison of the known fish species composition (Table 77, left two columns) to the species composition in the predominant types of trawl gear surveys (Table 77, right two columns) shows that trawl gear samples underestimate the fish species diversity of the GOA (Cooney 1986b) The longest standing trawl gear surveys for the GOA are limited to the continental shelf and the shelf break (to 500 m before 1999 and to 1,000 m thereafter) The NMFS has measured relative abundance and distribution of the principal groundfish and commercially important invertebrate species (Martin 1997b), and before 1980, the International Pacific Halibut Commission (IPHC) collected information on the abundance, distribution and age structure of halibut (see Figure 7 10 in Section 761) Hook and line surveys for Pacific halibut, sablefish, rockfish, and Pacific cod on the continental shelf in the GOA have been conducted by the IPHC since 1962 (Clark et al 1999)

_	Quast and Hall ¹		Miscellaneous Surveys ²		
Family	Number of Genera	Number of Species	Number of Genera	Number of Species	
Petromyzontidae	2	3	-	-	
Hexanchidae	1	1	-	-	
Lamnidae	2	2	1	1	
Carcharhınıdae	1	1	-	-	
Squalidae	2	2	1	1	
Rajidae	1	7	1	4	
Acipenseridae	1	2	-	-	
Clupeidae	2	2	1	1	
Salmonidae	6	12	1	3	
Osmeridae	5	6	5	6	
Bathylagıdae	1	4	-	-	
Opisthoproctidae	1	1	-	-	
Gonostomatidae	2	4	-	-	
Melanostomiidae	1	1	-	-	
Chauliodontidae	1	1	1	1	
Alepocephalidae	1	1	-	-	
Anotopteridae	1	1	-	-	
Scopelarchidae	1	1	-	-	
Myctophidae	7	10	1	1	
Oneırodıdae	1	3	-	-	
Moridae	1	1	-	-	
Gadıdae	5	5	5	5	
Ophidiidae	2	2	-	-	
Zoarcidae	6 ,	11	4	7	
Macrouridae	1	3	1	1	
Scomberesocidae	1	1	1	1	
Melamphaıdae	3	3	-	-	
Zeidae	1	1	-	-	
Lampridae	1	1	-	-	
Trachipteridae	1	1	-	-	
Gasterosteidae	2	2	-	-	
Scorpaenidae	2	22	2	30	
Hexagrammidae	3	6	3	5	
Anoplopomatidae	2	2	1	1	
Cottidae	30	54	15	24	
Psychrolutidae	1	1	-	-	
Agonidae	8	12	8	9	

Table 7 7Fish Families and the Approximate Number of Genera and SpeciesReported from the Gulf of Alaska

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	Quast a	and Hall ¹	Miscellaneo	ous Surveys ²
Family	Number of Genera	Number of Species	Number of Genera	Number of Species
Cyclopteridae	12	38	5	7
Bramidae	1	1	-	-
Pentacerotidae	1	1	-	-
Sphyracnidae	1	1	-	-
Trichodontidae	2	2	1	1
Bathymasteridae	2	4	2	2
Anarhichadidae	1	1	1	1
Stichaeidae	10	15	4	6
Ptılıchthyıdae	1	1	-	-
Pholididae	2	4	-	-
Scytalınıdae	1	1	-	-
Zaproridae	1	1	1	1
Ammodytıdae	1	1	1	1
Scombridae	2	2	-	-
Centrolophidae	1	1	-	-
Bothidae	1	1	-	-
Pleuronectidae	15	17	15	16
Cryptacanthodidae ³	2	2	2	2
Totals	167	287	84	138

Table 7 7Fish Families and the Approximate Number of Genera and SpeciesReported from the Gulf of Alaska

Sources Hood and Zimmerman 1986 (after Ronholt et al 1978)

¹After Quast and Hall (1972)

²Gulf of Alaska exploratory, BCF, IPHC, and NNIFS trawl survey data

³Quast and Hall (1972) include these genera and species in the family Stichaeidae while Hart (1973) recognizes a separate family

Family ¹	Percentage of Total Fish Species	Family ²	Percentage of Total Fish Species
Cottidae	19	Scorpaenidae	10
Cyclopteridae	13	Cottidae	8
Scorpaenidae	8	Pleuronectidae	6
Pleuronectidae	6	Agonidae	3
Stichaeidae	5	Zoarcidae	2
Salmonidae	4	Cyclopteridae	2
Agonidae	4	Stichaeidae	2
Zoaricidae	4	Osmeridae	2
Myctophidae	3	Gadıdae	2
Rajidae	2	Hexagrammıdae	2
Total	68		39

 Table 7 8
 Proportion of the Total Species Composition of Gulf of Alaska Fish

 Fauna Contributed by the 10 Dominant Fish Families in Two Different Surveys

Source (Hood and Zimmerman 1986)

¹From Quast and Hall (1972)

²From GOA exploratory cruises and resource assessment surveys

On the basis of the biomass available to trawl gear on the continental shelf and shelf break, flatfish and rockfish dominate the fish fauna in most areas of the GOA As of 1996, a flatfish species, arrowtooth flounder, dominated the overall trawl survey of the fish biomass in the GOA, followed by Pacific ocean perch (rockfish), walleye pollock (gadid), Pacific halibut (flatfish), and Pacific cod (gadid) (Martin 1997a) Biomass of the arrowtooth flounder is approaching two million mt, and its biomass has been steadily increasing since 1977 (Witherell 1999a) Of the next fifteen largest biomasses of species in the 1996 NMFS survey, six were flatfish and five were rockfish

Geographic distributions of GOA fish biomass in the NMFS trawl surveys are different from the overall total In the western GOA, Atka mackeral (Hexagrammid) had the highest biomass in the Shumagin Islands, but this species was not among the twenty largest biomasses of species in the four other INPFC areas of the GOA Arrowtooth flounder dominate the trawl survey biomass throughout the GOA They are the most or second most abundant in all five areas Flatfish and especially soles comprise a large number of high-biomass species in the western and northwestern GOA (Shumagin Islands, Chirikof, and Kodiak), and rockfish have a large number of high-biomass species in the northeastern and eastern GOA (Yakutat and Southeast) Pollock and cod are a dominant part of the biomass in the western GOA, but less so in the east Pacific sleeper sharks are among the twenty largest biomasses of species in the north (Chirikof, Kodiak, and Yakutat), but not in the south (Shumagin Islands and Southeast) The only anadromous species, the eulachon, occurs among the twenty largest biomasses in the north, but not in the south With the use of a variety of gear types, including trawl net, try net, trammel net, beach seine, and tow net in waters less than 100 m, Rogers et al (1986) provided a detailed image of the distribution of fish species and biomass with depth and by region As was the case for the 1996 NMFS trawl surveys, species composition and relative biomass of fish species in multi-gear surveys change substantially in moving from the nearshore toward offshore areas in the GOA, as well as from one region to the next The findings of the multiple gear surveys were consistent with the trawl survey observations in that shallow (smaller than 100 m) fish assemblages were more diverse in the north and west of the GOA than in the northeast and east (Table 7 9 in comparison to Table 7 7)

Location	Number of Families	Number of Species
Kodiak	22	101
Lower Cook Inlet	25	105
Prince William Sound	18	72
Southeast Alaska	NA	[,] 51

 Table 7 9
 Comparison of the Number of Fish Families and Species Found

 at less than 100 m in Different Regions of the Gulf of Alaska

Information summarized from Rogers et al (1986)

NA = not available

Other trends in distribution correspond to reproduction and seasonal changes in shallow waters in some species of nearshore fishes Estuarine bays in the Kodiak archipelago are nursery areas, with larvae and juveniles being found in nearshore and pelagic habitats within bays (Rogers et al 1986) Blackburn (1979 in [Rogers et al 1986]) found a trend of larger fish with increasing depth in studies of Ugak Bay and Alitak Bay on Kodiak Island Most species of nearshore fish apparently move to deeper water in the winter In Lower Cook Inlet and Southeast Alaska, juveniles and other smaller size classes of the species of local fish assemblages are found close to shore, water temperatures permitting, and larger size classes are found farther offshore at depths greater than 30 m at all times of the year

Nearshore areas of the GOA provide rearing environments for the juveniles of many fish species Important nursery grounds for juvenile flatfishes, such as soles and Pacific halibut, are found in waters of Kachemak Bay and other waters of Lower Cook Inlet, as well as in Chiniak Bay on Kodiak Island (Norcross 1998) In Kachemak Bay, summer habitats of some juvenile flatfishes are shallower than winter habitats Juvenile flatfish distributions in coastal waters are defined by substrate type, typically mud and mud-sand, and by depth, typically 10 to 80 m, and in the case of Chiniak Bay, by temperature Deep-water and shallow-water assemblages were identified for the groundfish communities in both Kachemak and Chiniak bays, however, the limiting depths were different for the se two localities (Norcross 1998, Mueter and Norcross 1999)

Both salmon and groundfish populations in the northeastern Pacific appear to vary annually in concert with features of climate, but the responses appear to be different (Francis et al 1998) Annual groundfish recruitments follow a cycle with a roughly 10-year period that may be related to the ENSO (Hollowed and Wooster 1992), whereas salmon abundance changes sharply at intervals of twenty to twentyfive years in concert with the PDO (Brodeur et al 1996) The ENSO and the PDO were shown to be independent of one another (Mantua et al 1997) The opposite responses of groundfish and salmon (positive) and crab (negative) recruitment to intensified Aleutian Lows may be because different species-specific mechanisms are invoked by the same weather pattern Because the groundfish species described by Hollowed and Wooster (1992, 1995) were mostly winter spawners, Zheng and Kruse (2000b) hypothesize that strengthened Aleutian Lows increase advection of eggs and larvae of groundfish toward onshore nursery areas, improving survival Salmon, on the other hand, benefit from increased production of prey items under intense lows The possible links between Aleutian Lows, PDOs, and ENSO and populations of fish and other animals are discussed further below and in a recent review paper (Francis et al 1998)

7.12.2.1 Salmon

The GOA is the crossroads of the world for Pacific salmon Salmon from Japan, Russia, all of Alaska, British Columbia, and the Pacific Northwest spend part of each life cycle in the GOA (Myers et al 2000) Five species of salmon–pink, chum, sockeye, coho and Chinook–are very common in the GOA These species appear in the GOA as early as the first year of life (all pink, chum, and ocean type chinook and some sockeye), however, others may appear during the second (all coho and stream-type Chinook and most sockeye) and rarely during the third or later years (some sockeye) (see Groot and Margolis 1991) Ecologically, the salmon species may be divided into two broad groups, marine planktivores (pink, chum, and sockeye) and marine piscivores (coho and Chinook) Further ecological differentiation is apparent within planktivores. For example, the size groups of plankton consumed by chum and sockeye are inferred to be quite different, because chum use short stubby gill rakers to separate food from water, and sockeye have long feathery gill rakers as filters

Distribution within the GOA changes with time after marine entry (Nagasawa 2000), as salmon disperse among coastal feeding grounds according to species and stock, age, size, feeding behavior, food preferences, and other factors (Myers et al 2000) During the first year of marine life, salmon are located in estuaries, bays, and coastal areas within the ACC and continental shelf (Myers et al 2000) With time and growth, first-year salmon move farther away from their river of origin and father offshore First-year salmon move out of the ACC into colder waters in fall and winter of their first year at sea

Salmon of all ages are thought to exhibit seasonal migrations in spring and fall between onshore and offshore marine areas In the fall, salmon of all ages move offshore to spend the winter in waters between 4° C and 8° C that are relatively

poor in food, perhaps as an energy conservation strategy for surviving the winter (Nagasawa 2000) In the spring, salmon move onshore into waters that may reach 15° C where food sources are relatively abundant

Salmon populations overall are at very high levels in Alaska, with the notable exceptions of western Alaska chum and Chinook populations originating in drainages between Norton Sound in the north and the Kuskokwim River, west of Bristol Bay (ADF&G 1998) On Norton Sound, the chum salmon populations of the Penny and Cripple rivers have exhibited very low to zero spawning stocks in the past 5 years Another notable exception to the record high levels of Alaska salmon production are the Kvichak River sockeye populations of Bristol Bay, which have faltered Some "off-peak cycle" brood years have recently failed to produce as expected (Kruse et al 2000b)

The situation in Western Alaska notwithstanding, the 1999 commercial harvest of 404,000 mt of salmon in Alaska was the second largest in recorded history behind 1995 (451,000 mt) (Kruse et al 2000b) A large portion of the record harvests in 1999 was pink salmon from areas adjacent to the GOA, such as PWS, and Southeast Alaska The status of salmon populations and fisheries in the following areas were recently evaluated in terms of levels of harvest and spawning escapements areas coincident with habitats in the north central GOA of the Stellar sea lion, which is listed as an endangered species under the Endangered Species Act of 1973 (ESA), Kodiak, the Alaska Peninsula, and Bristol Bay All major commercial salmon stocks were judged to be healthy, with the exception of the Kvichak River off-cycle brood years (Kruse et al 2000b)

Given that marine migration patterns of each stock are thought to be characteristic and somewhat unique (Myers et al 2000), the contrast in the status of salmon stocks between Western and Southcentral and Southeast Alaska offers some intriguing research questions about the role of marine processes in salmon production (Cooney 1984) Understanding the processes that connect salmon production to climate, marine food production, and fishing requires understanding of the marine pathways of the salmon through time (Beamish et al 1999) Therefore, research approaches to understanding changes in salmon abundance on annual and decadal scales need to encompass localities that are representative of the full life cycle of the salmon and, in particular, in estuarine and marine environments Scientific information on freshwater localities is far more common than that available for estuarine and marine areas Given the current state of information on both hatchery and wild salmon, it is highly desirable to focus current and future efforts on estuaries and marine areas for understanding migratory pathways and other habitats, physiological indicators of individual health, trophic dynamics, and the forcing effects of weather and oceanographic processes (Brodeur et al 2000)

7.12 2.2 Pacific Herring

Pacific herring (herring) populations (Funk 2000) occur in the northeast GOA, with commercial concentrations in Southeast Alaska (Sitka), PWS, western Lower Cook Inlet, and occasionally around Kodiak Most of the historical information on herring in the GOA comes from coastal marine fisheries that started in Alaska in 1878 (Kruse et al 2000b), however, intensive ecological investigations at the end of the 20th century have added information on early life history (Norcross et al 1999) Herring deposit eggs onto vegetation in the intertidal and near subtidal waters in late spring, undergo a period of larval drift, and spend the first summer and winter nearshore in sheltered embayments. Transport of larvae by currents in relation to sites that are suitable summer feeding and overwintering grounds is likely an important factor affecting survival in the first year of life in PWS (Norcross et al 1999), as is the nutritional status of these age-0 herring in the fall of the year (Foy and Paul 1999). Some portion of the mature herring must migrate annually between onshore spawning grounds and offshore feeding grounds, however, the geography of the life cycle between spawning and maturation is less certain

Although the geographic scope of the herring life cycle in the Bering Sea is fairly well understood, inferences from the Bering Sea to the GOA are not direct because of apparent differences in life history strategies between the herring of the two regions (Funk 2000) Adult herring in the GOA are smaller and have shorter life spans than those in the Bering Sea Perhaps GOA herring migrate shorter distances to food sources that are not as rich as those available to Bering Sea herring, which migrate long distances from spawning to feed among the rich food sources of the continental shelf break (Funk 2000) Genetic analyses indicate that Bering Sea and GOA herring populations are reproductively isolated (Funk 2000)

Another ecologically significant characteristic of Pacific herring is the temporal change in size at age over time (Brown 2000) Annual deviations from long-term (1927 to 1998) mean length at age for Sitka Sound herring indicate a decadal-scale oscillation between positive and negative deviations. This finding is consistent with the reported coincidence of size-at-age data for Pacific herring with the PDO (Ware 1991) Herring may be affected by ENSO events. Decreased catches, recruitments, and weight-at-age of herring are at times associated with ENSO events. Seabirds in the GOA that depend on herring and other pelagic forage species showed widespread mortalities and breeding failures during the ENSO events of 1983 and 1993 (Bailey et al. 1995b). The similarities between the annual patterns of abundance and the location of weather systems (annual geographically averaged sea-level atmospheric pressure) are not as clear with herring as for other fish species, such as salmon. The difference may result because herring populations tend to be dominated by the occasional strong year class and show considerable variability in landings through the years.

The current status of herring populations may be closely related to historical fishing patterns Long-term changes associated with commercial fishing have occurred in the apparent geographic distribution and abundance of GOA herring

Herring-reduction fisheries (oil and meal) from 1878 to 1967 reached a peak harvest of 142,000 mt in 1934 That exploitation rates were high may be inferred from the fact that some locations of major herring-reduction fisheries, such as Seldovia Bay (Kenai Peninsula and Lower Cook Inlet) are now devoid of herring. It is speculated that reduction fisheries at geographic bottlenecks between herring spawning and feeding grounds, such as the entrance to Seldovia Bay and the passes of southwestern PWS, were able to apply very high exploitation rates to the adult population. Harvest management applied by the State of Alaska relies on biomass estimates, and harvests are held to a small fraction of the estimated biomass Harvest is not allowed until the population estimate rises above a minimum or "threshold" biomass level

Recent statewide herring harvests have averaged less than a third of the 1934 peak Direct comparison of past and present catch statistics is problematic, however, because current rates of harvest are thought to be substantially below those applied in 1934 (Kruse et al 2000b) Also note that recent statewide figures for herring harvests include substantial harvests from outside the GOA, and herring-reduction fisheries were located in the GOA Populations of herring were targeted for sac roe starting in the 1970s and for sac roe and roe on kelp in the 1980s Regional herring population status is variable Population levels of herring in PWS remained at low levels in 2000, and commercial harvests were not allowed in 1994, 1995, and 1996, nor since 1998 In 1999, fishing operations were halted because of low biomass and poor recruitment Disease is strongly suspected as a factor in keeping the population levels low The herring fishery of Lower Cook Inlet in Kamishak Bay closed in 1999 after a very small catch in 1998 and remains closed because of low biomass levels Catches in the Kodiak fishery for herring sac roe are declining The bait fishery in Shelikof Strait was closed in 1999 because of its possible relation to depressed Kamishak Bay herring populations

Significant questions remain about the geographic extent of the stocks to which the biomass estimates and fishing exploitation rates may apply in PWS (Norcross et al 1999) The geomorphology of PWS in relation to currents plays an important role in determining the retention of larvae in nearshore areas conducive to growth and survival The degree to which spawning aggregations of herring may represent individual stocks is a significant question, because the actual exploitation rate of herring in PWS depends on how many stocks are defined Although it is not clear how many stocks of herring occupy PWS, conditions appear to favor more than one spawning stock (Norcross et al 1999)

Water temperatures appear to play important roles in growth and survival of age-0 herring Warm summer water temperatures may be conducive to growth and survival, however, the opposite appears to be true of warm water temperatures in spring and winter Increased metabolic demands imposed by warm water on yolk-sac larvae and overwintering age-0 herring could decrease survival (Norcross et al 1999) Availability of food before winter, and perhaps during winter may be key to survival of age-0 herring Input of food from the GOA may be an important key to survival for age-0 herring at some localities Differential survival among nursery areas because of interannual variation in climate and accessibility of GOA food sources could be a key determinant of yearclass strength in PWS The sources of variability mean that geographic locality is no guarantee of any particular level of survival from year to year Sampling whole body energy content of age-0 herring at the end of the first winter among bays could provide an indicator of year class strength (Norcross et al 1999)

Questions relating to the ability of disease outbreaks to control herring populations have recently been explored Work has identified the diseases, *Viial Hemori hagic Septicemua* and a fungus as factors potentially limiting the abundance of herring in PWS (Hostettler et al 2000, Finney et al 2000)

7.12.2.3 Pollock

Pollock are an ecologically dominant and economically important cod-like fish in the GOA They appear to spawn at the same locations within the same marine areas each year, with location of spawning and migrations of adults linked to patterns of larval drift and locations of feeding grounds (Bailey et al 1999) Spawning occurs at depths of 100 to 400 m, and as a result, the distributions of eggs and larvae in some areas may have been well below the depths of historical ichthyoplankton surveys Pollock larvae feed on early developmental stages of copepods and, as juveniles, move on to feed on larger zooplankton such as euphausiids and small fishes, including pollock Although cannibalism is regarded as significant in the Bering Sea, it is not thought to be a significant factor in the GOA Pollock eggs and larvae are important sources of food for other zooplankters, and year class strength in pollock is thought to be related abundances of marine mammals and seabirds, at least in the Bering Sea

Pollock mature at about age 4 and may live as long as twenty years (Bailey et al 1999) Adult walleye pollock are distributed throughout the GOA at depths above 500 m A substantial portion (45 percent) of the total pollock biomass as well as the highest catches per unit effort (CPUEs) of the 1996 NMFS survey were found at less than 200 m in the area between Kodiak and Chirikof Islands (Martin 1997) In the western GOA, the highest pollock catches and CPUEs of the 1996 NMFS trawl survey were found at less than 200 m, whereas in Yakutat and Southeast Alaska the substantial availability of pollock to trawl gear persists above 300 m Pollock larger than 30 cm were rarely found above 200 m in the eastern GOA in 1996 (Yakutat and Southeast), although pollock of all sizes (about 10 to 70 cm) were found at all depths down to 500 m in the western GOA (Martin 1997) Although pollock are commonly found in the outer continental shelf and slope, they may also be found in nearshore areas where they may be important predators and prey, for example, in PWS (Willette et al 2001)

Populations of pollock in the GOA are considered to be separate from those in the Bering Sea (Bailey et al 1999) Among the most commercially important of the GOA groundfish species, exploitable biomasses of pollock populations in 1999 were estimated at 738,000 mt, down from a peak of about three million mt in 1982 (Witherell 1999) Annual numbers of 2-year-old pollock entering the fishable population (recruitment) from 198 to 1987 were erratic and usually lower than recruitments estimated in 1977 to 1980

Following the climatic regime shift in 1978, pollock and other cod-like fish have dramatically increased, replacing shrimp in nearshore waters as the dominant group of organisms caught in mid-water trawls on the shelf (Piatt and Anderson 1996) Recruitment in pollock is heavily influenced by oceanographic conditions experienced by the eggs and larvae Good conditions for juveniles of the 1976 and 1978 year class contributed to the 1982 peak in pollock biomass in the GOA (Bailey et al 1999) Populations have gradually declined since then (Witherell 1999) Increasing mortality schedules in 1986 to 1991 may indicate increasing predation and deteriorating physical conditions for both juveniles and adults in the GOA (Bailey et al 99) The larger-than-average year class for GOA pollock in 1988 may be related to high rates of juvenile growth coincident with warm water temperatures, lack of winds, low predator abundance, and low larval mortality rates (Bailey et al 1996) As has been shown to be the case with other groundfish species, GOA pollock recruitments are positively correlated with ENSO events (Bailey et al 1995b)

Issues in the management of pollock that currently remain unresolved include the geographic boundaries of stocks, their extent of migration, the effects of fishing in one geographic locale on the populations of pollock and predators in other geographic locales, and what controls the annual recruitment of young pollock to the fishable populations (Bailey et al 1999) In relation to stock structure, spawning aggregations in PWS, the Shumagin Islands (southwest Kodiak), and Shelikof Strait (separating Kodiak from the Alaska Peninsula) may represent separate stocks Conditions of weather and changing ocean currents and eddies in the Shelikof Strait have the capacity to alter survival of pollock larvae from year to year (Bailey et al 1995a) In particular, the effects of shifts in the strength of the ACC on larval transport pose important questions for how year class strength is determined. In 1996, anomalous relaxation of winds resulted in a dramatic increase in larval retention in the Shelikof basin Increased larval retention may be favorable to survival of pollock larvae in this area, with some exceptions (Bailey et al 1999)

7.12.2.4 Pacific Cod

Pacific cod is a groundfish with demersal eggs and larvae found throughout the GOA on the continental shelf and shelf break Pacific cod of the GOA are also an economically and ecologically important species Pacific cod had an estimated fishable population of 648,000 mt in 1999, which is on the low end of the range of 600,000 to 950,000 mt estimated for 1978 to 1999 Annual recruitments of GOA Pacific cod have been relatively stable since 1978, with exceptionally large numbers of 3-year-old recruits appearing in 1980 and 1998 Biomass of the dominant flatfish in the GOA, the arrowtooth flounder, is approaching two million mt Arrowtooth

flounder is not heavily harvested, and their biomass has been steadily increasing since 1977

Pacific cod are found throughout the GOA at depths less than 500 m They are most abundant in the western GOA (Kodiak, Chirikof and Shumagin Islands) where Pacific cod larger than 30 cm are found at all depths above 300 m, but smaller individuals are rarely found at depths less than 100 m (Martin 1997)

7.12.2.5 Halıbut

Pacific halibut are common throughout the GOA at depths less than 400 m, and halibut are available to trawl gear at depths of 500 m (Martin 1997) In the 1996 NMFS trawl survey, the largest catches and the highest CPUE were found at depths of less than 100 m east southeast of Kodiak on the Albatross Banks (Figure 7 10) In most areas of the GOA, the average weight and length of halibut caught in trawl gear increases with depth, even though the CPUE declines with depth, particularly in the western GOA (Shumagin Islands, Chirikof, and Kodiak) (Martin 1997)

The exploitable biomass of another flatfish, the highly prized Pacific halibut, in 1999 was estimated at 258,000 mt, which is above average for 1974 to 1999 (Witherell 1999) Exploitable biomass of Pacific halibut was also increasing from 1974 to 1988, after which it declined slightly

Pacific halibut appear to undergo decadal-scale changes in recruitment, which have been correlated with both the 18 6-year cycle for lunar nodal tide (Parker et al 1995) and the PDO

7 12 3 Overview of Shellfish and Benthic Invertebrates

Shellfish are commonly found on or near the surface of the sea floor, they are epibenthic, as adults, and in the water column, pelagic, for varying lengths of time as pre-adults Exceptions to this rule abound, particularly among mollusks such as squid, which live free of the bottom as adults Beyond the nearshore environment (at depths greater than 25 m), the shellfish and other invertebrates dominate the number of species and the biomass of the bottom, just as other assemblages of invertebrates dominate the nearshore (see Section 79) Among the shellfish, the arthropods and mollusks often have the largest number of species For example, of 287 species of bottom fauna identified in waters deeper than 25 m in Lower Cook Inlet, more than 67 percent were arthropods and mollusks (Feder and Jewett 1986) Many of the commercially important species of the GOA are dependent for food to a greater or lesser extent on benthic invertebrates discussed here (Commercially important crabs and shrimp are discussed below) Commercial crabs and shrimps, and scallops, join the fish species of Pacific cod, walleye pollock, halibut, and Pacific Ocean perch as members of the subtidal benthic food web for part of each life cycle Detritus, bacteria, and microalgae form the base for the benthic invertebrates of the GOA continental shelf, which are predominantly filter feeders (60 percent), and detritus eaters (33 percent) (Semenov 1965 in Feder, H M and S C Jewett 1986) Small mollusks, small crustaceans, polychaete annelids, and other

worm-like invertebrates make up the filter-feeding and detrivore component of this food web

Regional differences are pronounced in the benthic food webs of the GOA The eastern GOA has few filter feeders and lower average biomass relative to the northern and western GOA, in large part because of the nature of substrates and currents In particular the benthic species composition and productivity in the GOA is determined in part by the ACC, particularly in the embayments and fjords (Feder and Jewett 1986) The ACC brings freshwater to the environments containing the pelagic shellfish larvae and heavy sediment loads that define the bottom habitats of the later stages of the life cycle Biomass of filter feeders on the continental shelf in the western Gulf (138 grams per square meter $[g/m^2]$) is far higher than that found in the northeastern or eastern GOA combined $(33 \ 2 \ g/m^2)$ Biomasses of detritus feeders in the western (31 g/m^2) and eastern (12 g/m^2) GOA are lower than those found in the northeastern GOA (43 g/m^2) Biomasses of all trophic groups on the shelf break are lower than those of the adjacent shelf The distribution of benthic invertebrates in the GOA attests to the validity of the hypothesis that the type of bottom sediment, as influenced by proximity to alluvial inputs and currents, determines the species composition, production, and productivities of benthic communities (Semenov 1965 in (Feder and Jewett 1986)) Sedument size is dominant among the factors controlling the distribution of benthic species (Feder and Jewett 1986)

7.12.3.1 Crab

The principal commercial crab species in the GOA are the king crabs (*Paralithodes* spp), the tanner crab (*Chionoecetes ban di*), and the Dungeness crab (*Cancer magister*) All species have benthic adults and pelagic larvae, although the life history strategies vary substantially within and among species. For example, the pelagic stages of the red king crab are herbivorous, those of the tanner crab are carnivorous, and those of the golden king crab do not feed until they metamorphose into the benthic stages. The benthic stages of all crab species feed to a large extent on the less well known invertebrates of the benthic environments (Feder and Paul 1980, Jewett and Feder 1983, Feder and Jewett 1986) discussed briefly above under the shellfish overview

The status of crab populations is relatively poor in comparison to the groundfish populations (Kruse et al 2000a) Crab catches in the GOA have shown sharp changes with time, perhaps indicative of sensitivity to climatic forcing in some species, to fishing, or a to combination of factors (Zheng and Kruse 2000b) The red king crab stock of the GOA collapsed in the early 1980s and currently shows no signs of recovery The tanner crab populations in PWS, Cook Inlet, Kodiak, and the Alaska Peninsula have declined to low levels in the early 1990s, and harvest levels have been sharply reduced (Kruse et al 2000b)

In a study of time-series data on recruitment for fifteen crab stocks in the Bering Sea, Aleutian Islands, and GOA, time trends in seven of fifteen crab stocks are significantly correlated with time series of the strength of Aleutian Low climate regimes (Zheng and Kruse 2000a) Time trends in recruitments among some king crab stocks were correlated over broad geographic regions, suggesting a significant role of environmental forcing in regulation of population numbers for these species. The increased ocean productivity associated with the intense Aleutian Low and warmer temperatures was inversely related to recruitment for seven of the fifteen crab stocks. The seven significantly negative correlations between ocean productivity and crab recruitment were from Bristol Bay, Cook Inlet ,and the GOA Crab stocks declined as the Aleutian Low intensified. A significant inverse relation between the brood strength of red king crab and Aleutian Low intensity was reported earlier for one of the stocks in this study, red king crab from Bristol Bay (Tyler and Kruse 1996)

Tyler and Kruse (1996, 1997) and (Zheng and Kruse 2000a) have articulated an explicit series of hypotheses linking features of physical and geological [^] oceanography to the reproductive and developmental biology of red king and tanner crab The hypotheses explain observed relations between climate and recruitment Tanner and red king crab in the Bering Sea are thought to respond differently to the physical factors associated with the Aleutian Low because of the distribution of the different types of sea bottom required by the post-planktonic stage of each species Suitable bottom habitat for red king crabs in the Bering Sea is more generally nearshore, whereas suitable bottom habitat for tanner crab is offshore Intense Aleutian Low conditions favor surface currents that carry or hold planktonic crab larvae onshore, whereas weak Aleutian Low conditions favor surface currents that move larvae offshore The process may not be species specific, but stock specific, depending on the location of suitable settling habitat in relation to the prevailing currents In the case of red king crab, Zheng and Kruse (2000b) explain the apparent paradox of lowered recruitment for red king crab during periods of increased primary productivity Red king crab eat diatoms, but show a preference for diatoms similar to *Thalassiosii a* spp, which dominate in years of weak lows and stable water columns Strong lows contribute to well-mixed water columns and a diverse assemblage of primary producers, which may be unfavorable for red king crab larvae, but favorable for tanner crab larvae Tanner crab larvae eat copepods, which are favored by the higher temperatures associated with intense lows

Recently completed modeling studies (Rosenkranz 1999) support climatic variables as determinants of recruitment success in tanner crab Predominant wind direction and temperature of bottom water were strongly related to strength of tanner crab year classes in the Bering Sea Northeast winds are thought to set up ocean transport processes that promote year-class strength by carrying the larvae toward suitable habitat Elevated bottom-water temperatures were expected to augment the effect of northeast wind by increasing survival of newly hatched larvae (Rosenkranz, G 1999)

7.12.3.2 Shrimp

The shrimp were once among the dominant benthic epifauna in Lower Cook Inlet and Kodiak and along the Alaska Peninsula (Anderson and Piatt 1999, Feder and Jewett 1986) and of substantial commercial importance in the GOA Five species of Pandalid shrimp dominated the commercial catches, which occurred west of 144° W longitude in PWS, Cook Inlet, Kodiak and along the Alaska Peninsula (Kruse et al 2000b) Shrimp fisheries in the GOA peaked at 67,000 mt in 1973, reached 59,000 mt in 1977, and declined thereafter to the point where shrimp fishing is virtually nonexistent in the GOA today

Regional fisheries follow the pattern seen for the GOA as a whole The trawl fishery for northern shrimp (*Pandalus borealis*) in Lower Cook Inlet peaked at 2,800 mt in 1980 to 1981 and was closed in 1987 to 1988 The fishery for northern and sidestriped shrimp (*P dispar*) along the outer Kenai Peninsula peaked at 888 mt in 1984 to 1985 and closed in 1997 to 1998 The pot fishery for spot (*P platyceros*) and coonstriped shrimp (*P hypsinotus*) in PWS increased rapidly after 1978 to its peak harvest of 132 mt in 1986 This pot fishery then declined to its low of eight mt in 1991 and has been closed since 1992 The trawl shrimp fishery for northern shrimp in PWS peaked at 586 mt in 1984 and switched to sidestriped shrimp in 1987 The PWS trawl fishery for sidestriped shrimp peaked at 89 mt in 1992, and the northern shrimp in 1999 was 29 mt and falling The Kodiak trawl fishery for northere mt in 1997 to 1998 In the Aleutian Islands, shrimp catches after the 1978 season declined precipitously, and the fishery has not rebounded since

7.13 Marine Mammals

7 13 1 General Characteristics of the GOA Marine Mammal Fauna

The GOA has a mostly temperate marine mammal fauna Calkins (1986) provided the only previously published review of GOA marine mammals, and listed 26 species as occurring in the region Five of those (pilot whale, Risso's dolphin, right whale dolphin, white sided dolphin, and California sea lion) are primarily southern species that occur occasionally in Southeast Alaska but rarely, if at all, in the EVOS region He also listed the Pacific walrus, which is a subarctic species that occurs in the GOA only as occasional wanderers

Table 7 10 provides a summary of the general characteristics of twenty marine mammal species that occur regularly in the GEM region, including seven baleen whales, eight toothed whales and porpoises, four pinnipeds, and the sea otter Useful reviews of information on these species can be found in Lentfer (1988), Calkins (1986), Perry et al (1999), Forney et al (2000), and Ferrero et al (2000) Various aspects of marine mammal biology are described in detail in Reynolds and Rommel (1999)

Most of the marine mammal species shown in Table 7 10 are widely distributed in the North Pacific Ocean, and the animals that inhabit the GEM region represent only part of the total population Application of modern molecular genetics techniques, however, has provided much new information on population structures (Dizon et al 1997) Researchers have found that for species such as killer whales (Hoelzel et al 1998), beluga whales (O'Corry-Crowe and Lowry 1997), (Bickham et al 1996), harbor seals (Westlake and O'Corry-Crowe 1997), and sea otters (Scribner et al 1997), genetic exchange among adjacent and sometimes overlapping groups of animals is so low that they need to be managed as separate stocks

Taxonomically the GOA marine mammal fauna can be broken down into four major groups

- Mysticete cetaceans --- baleen whales,
- Odontocete cetaceans toothed whales,
- Pinnipeds -- seals, sea lions, and fur seals, and
- Mustelids sea otters

The baleen whales are primarily summer seasonal visitors to the GOA that come to the continental shelf and offshore waters to feed on zooplankton and small schooling fishes (Calkins 1986, Perry et al 1999) Breeding and calving occur in more southerly, warmer, regions The GOA is primarily a migration route for the gray whale, which breeds and calves in Baja California, Mexico, and has its primary feeding grounds in the northern Bering and Chukchi seas (Jones et al 1984)

The large species of baleen whales were all greatly reduced by commercial over-exploitation (Perry et al 1999) Historical information on stock structure and abundance is very limited, and, partly because of their broad distributions, accurately assessing current abundance and population trend is generally difficult (Ferrero et al 2000) Humpback whales and gray whales are exceptions to that generalization For humpbacks, estimates of population size based on individual identifications from fluke photos (Calambokidis et al. 1997) suggest that the central North Pacific stock is increasing (Ferrero et al 2000) For many years, systematic counts have been made of gray whales migrating along the California coast, and results indicate that since the 1960s the population has been increasing by 2.5 percent per year (Breiwick 1999)

The situation with sperm whales is much like that of the large baleen whales Many features of their basic biology, such as stock structure, distribution, migratory patterns, and feeding ecology, are poorly known They occur throughout the North Pacific, mostly in deep water south of 50° N latitude, but Table 7 10 Summary of Characteristics of Marine Mammal Species That Occur Regularly in the Gulf of Alaska Exxon Valdez Oil Spill Area

	Use of C	Bulf of Alaska	by Species	Populat	tion Status	Mai	nagement Cla	ssification
Species	Residence	Habıtats ¹	Activities ²	Abundance ³	Trend	EVOS	MMPA	ESA
Mysticetes								
Blue whale	seasonal	SD	F	smail?	unknown		depleted	endangered
Fın whale	seasonal	S, D	F	medium?	unknown		depleted	endangered
Seı whale	seasonal	S, D	F	medium?	unknown		depleted	endangered
Humpback whale	seasonal	C, S, D	F	medium	increasing		depleted	endangered
Gray whale	seasonal	CS	M F?	large	increasing			
Right whale	seasonal	S	F	small	unknown		depleted	endangered
Minke whale	resident?	C, S	FCB?	medium?	unknown			
Odontocetes								
Sperm whale	seasonal?	S O	F	large?	unknown		depleted	endangered
Kıller whale	resident	C, S, D	F, C, B	small	unknown	damaged		
Beluga whale	resident	C, S	F, C, B	small	declining?		depleted	
Beaked whale ⁴	resident?	S, D	FCB	unknown	unknown			
Dail's porpoise	resident	S, D	FC,B	large	unknown			
Harbor porpoise	resident	C, S	F, C B	large	unknown			
Pinnipeds	· · · · · · · ·							
Steller sea lion	resident	T, C, S, D	F, C, B	large	declining		depleted	endangered
Northern fur seal	seasonal	SD	MF	large	stable		depleted	
Harbor seal	resident	T, C, S	F, C, B	large	declining	damaged		
Elephant seal	seasonal	SD	F	large	increasing			
Mustelids	·							
Sea otter	resident	T.C.S	F. C. B	large	unknown	damaged		

Species shown in bold are those that have been selected as focal species for GEM

¹T = terrestrial, C = coastal, S = continental shelf, D = deep water
 ²F = feeding, M = migrating, C = calving/pupping, B = breeding
 ³small = <1 000, medium = 1,000-10 000 large = >10 000
 ⁴ Probably includes at least 3 species Baird's beaked whale, Cuvier's beaked whale, and Bering Sea beaked whale

some are seen in the northern GOA at least in summer (Calkins 1986, Perry et al 1999) From what is known of their diet, sperm whales eat mostly deep-water fishes and squids North Pacific sperm whales were intensely harvested, with more than 250,000 killed during 1947 to 1987 (Perry et al 1999) Current abundance and population trends are complete unknowns

In contrast to the baleen whales and sperm whale, the smaller toothed whales are primarily resident in the GOA Very little is known about the biology of beaked whales, but the other species have been relatively well studied Two species, killer whales and beluga whales, have been selected as focal species for GEM and are discussed in detail in later sections Harbor porpoises and Dall's porpoises both have relatively large populations, and with the exception of incidental take in commercial fisheries, they are unlikely to have been significantly impacted by human activities (Ferrero et al 2000) Both species feed on small fishes and squids, with Dall's porpoises using mostly continental shelf and slope areas and harbor porpoises most common in coastal and continental shelf waters (Calkins 1986)

The two resident pinniped species, Steller sea lions and harbor seals, are both focal species for GEM and will be discussed later in this section Northern fur seals pup and breed on islands in the Bering Sea (Pribilof Islands and Bogoslof Island) A portion of the population migrates through the GEM region on its way to and from their rookeries Adult fur seals may feed in the GOA during migration and winter months, and non-breeding animals may feed in the area year-round Small fishes and squids are the primary foods of fur seals (Calkins 1986) Historically, northern fur seals were depleted by commercial harvests, but the population is now large, numbering about one million animals, and currently stable (Ferrero et al 2000) Northern elephant seals pup and breed at rookeries in California and Mexico After breeding, adult males go to the GOA to feed on deep-water fishes and cephalopods (Stewart 1997) The northern elephant seal population was greatly depleted by harvesting, but it is currently large and growing (Forney et al 2000)

The sea otter 1s a focal species for GEM and 1s discussed later in this section

As a group, marine mammals are managed and protected by domestic legislation and international treaties that generally do not apply to other marine species (Baur et al 1999) (see Table 7 10) Early protective efforts were in response to the need to limit commercial harvests and to reduce their impacts on declining and depleted populations The North Pacific Fur Seal Convention, agreed to in 1911, provided protection to both fur seals and sea otters In 1946, the International Convention for the Regulation of Whaling began to manage harvests of large whales, and it provided progressive protection to stocks as they became overexploited The ESA provides protection to marine mammals (and other species) that may be in danger of extinction because of human activities The SEA also allows protection of "critical habitat" needed by those species All species of marine mammals are covered by the Marine Mammal Protection Act (MMPA), which became federal law in 1972 Primary objectives of the MMPA are to "maintain the health and stability of the marine ecosystem," and for each marine mammal species to "obtain an optimum sustainable population keeping in mind the carrying capacity of the habitat" Provisions of the MMPA put a moratorium on all "taking" of marine mammals, with exceptions allowed for subsistence hunting by Alaska Natives, scientific research, public display, commercial fishing, and certain other human activities, subject to restrictions and permitting Species determined to be below their "optimum sustainable population" level, and those listed as threatened or endangered under provisions of the ESA, are listed as depleted under the MMPA and may be given additional protection Certain species of marine mammals were determined to have been damaged by the EVOS, and therefore have been subjects of EVOS restoration activities

Another unique aspect of marine mammal management is the strong involvement of Alaska Natives in the process Alaska Natives have formed a number of groups that represent their interests in research, management, conservation, and traditional subsistence uses of marine mammals Groups especially relevant to the EVOS GOA region include the Alaska Native Harbor Seal Commission (ANHSC), the Alaska Sea Otter and Steller Sea Lion Commission, and the Cook Inlet Marine Mammal Council The ANHSC has been particularly active in the EVOS region, and has received funds from the Trustee Council to conduct a biosampling program in PWS and the GOA, and to contribute information about the distribution, abundance, and health of seals Congress has recognized the benefits of involving Alaska Natives in marine mammal management, and has included provisions for co-management programs (Alaska Native organizations working as partners with federal management agencies) in the 1994 amendments to the MMPA

As will be discussed in detail in the following sections, some marine mammal populations have declined in the GOA (and elsewhere in Alaska) in recent years In general, the causes of those declines are unclear, but there has been speculation that they may be in some way related to the climactic regime shift that occurred in the region. The evidence supporting such a connection is the temporal coincidence of the shift to a warmer regime, which happened in the mid-1970s, and the decline of harbor seals and Steller sea lions that has occurred in the 1970s through the 1990s

The National Research Council (NRC) reviewed evidence for a linkage between climate and marine mammal declines as part of their effort to explain changes that have occurred in recent years in the Bering Sea (NRC 1996) They found data that showed some likely negative effects of cold weather on northern fur seal pups (Trites 1990) and a strong influence of warm El Niño conditions on California sea lions (Trillmich and Ono 1991) Because most GOA marine mammals have broad ranges that include waters much warmer than the GOA, it is unlikely that a warmer regime has had any direct negative effect on their reproduction or survival The warmer conditions, however, have resulted in changes in fish and invertebrate populations (Anderson et al 1997) that may in turn have affected the nutrition of harbor seals and Steller sea lions (Alaska Sea Grant College Program 1993) The NRC concluded that food limitation was likely a factor in Bering Sea pinniped population declines, but that this was due to a complex suite of biological and physical interactions and not simply the regime shift (NRC 1996)

7 13 2 Focal Marine Mammal Species for the GEM Program

7.13.2.1 Killer Whale

Killer whales are medium-sized, toothed whales They are a cosmopolitan species generally found throughout the world's oceans, but most common in colder nearshore waters (Heyning and Dahlheim 1988) Sightings in Alaska show a wide distribution, mostly on the continental shelf, but also offshore (Braham and Dahlheim 1982) Because there has been no real effort to track individual killer whales, the understanding of movements is based primarily on sightings of animals that can be identified by marks and pigmentation patterns (Bigg et al 1987) The general pattern seems to be that some killer whales may stay in areas for several months while feeding on seasonally abundant prey, but long-distance movements are not uncommon (Ferrero et al 2000)

In the GOA, killer whales are seen frequently in Southeast Alaska and the area between PWS and Kodiak (Matkin and Saulitis 1994) Within the EVOS GOA region, whales are seen most commonly in southwestern PWS, Kenai Fiords, and southern Resurrection Bay (Matkin et al 2000) Whales move back and forth between these areas as well as to and from Southeast Alaska (Matkin et al 1997) Sightings from the area around Kodiak suggest that killer whales are common, but there has been little study effort devoted to that region (Matkin and Saulitis 1994)

Killer whales have been studied in detail in easily accessible areas such as Washington state, British Columbia, Southeast Alaska, and PWS Researchers have found that killer whales have a very complex social system and population structure Studies of association patterns (Matkin et al 1998), vocalizations (Ford 1991, Saulitis 1993), feeding behavior (Ford et al 1998), and molecular genetics (Hoelzel et al 1998, Barrett-Lennard et al in press) have shown that there are two primary types of killer whales The types are termed "transient" and "resident " A primary ecological difference between the two types is that residents eat fish, while transients mostly prey on other marine mammals (Ford et al 1998) Within each of these general types, killer whales are divided into pods that may be composed of one or more matrilineal groups In resident whales, the pods are very stable through time, with virtually no permanent exchange of individuals between pods, but new pods may be formed by splitting off of a maternal group A third killer whale type called "offshore" has been encountered, but little is known about them (Ford et al 1994)

What is known of the life history and biology of killer whales in Alaska was compiled in Matkin and Saulitis (1994) Both females and males are thought to become sexually mature at about fifteen years of age Females may produce calves until they are about forty, at intervals of two to twelve years Mating occurs mostly during May through October, and most births happen between fall and spring Maximum longevity has been estimated to be 80 to 90 years for females and 50 to 60 years for males Killer whales have no natural enemies, but in some areas, local abundance and pod structure have been affected by human activities, including live captures for public display, interactions with commercial fisheries, and the EVOS (Olesiuk et al 1990, Dahlheim and Matkin 1994, Matkin et al 1994, Ferrero et al 2000, Forney et al 2000) Normal birth and death rates for resident killer whales are about 2 percent per year (Olesiuk et al 1990)

Surface observations and examination of stomach contents from stranded animals have shown that as a group killer whales can and do eat a wide array of prey, including fishes, birds, and mammals (Matkin and Saulitis 1994) More detailed studies have documented considerable prey specialization in certain pods and individuals Resident killer whales in the PWS feed mostly on coho salmon during the summer (Matkin et al 1997) and on Chinook salmon in winter and spring (Matkin 2000) Transient whales in the same area eat mostly harbor seals, Dall's porpoise, and harbor porpoise (Saulitis 1993, Matkin and Saulitis 1994) Some GOA transient killer whales occasionally eat Steller sea lions (Barrett-Lennard et al 1995)

It is difficult to come up with meaningful population estimates for killer whales, partly because they may move over great distances and partly because some groups (such as the offshore type) and areas (such as the GOA west of Resurrection Bay) have been poorly studied Ferrero et al (2000) gave a minimum estimate of 717 whales in the northern resident stock of the eastern North Pacific, and Forney et al (2000) gave a minimum number of 376 for the transient stock of the eastern North Pacific Reliable data on trend in abundance are not available for either stock The most recent census (1999) indicates that there are 135 killer whales in the eight pods that regularly use the Kenai Fiords-PWS region (Matkin 2000)

Studies of killer whales in the PWS area began in the late 1970s (von Ziegesar et al 1986, Leatherwood et al 1990) Because killer whales were determined to have been damaged by the EVOS, killer whale studies were intensified during 1989 to 2000 (Matkin et al 1994, 2000) Those long-term studies allow accurate determination of numbers, because all individuals in each pod are photoidentified nearly every year Births and deaths of individual animals are monitored, which allows the calculation of reproductive and survival rates for each pod (Matkin and Saulitis 1994, Matkin et al 2000)

Matkin et al (1999) used association and genealogical data to organize the resident killer whales in the EVOS GOA area into nine pods Data on the number of whales in each of those pods for the period from 1984 to 2000 are shown in Table 7 10 All resident pods with the exception of AB pod have either increased or stayed the same since 1984 The number of whales in AB pod decreased by 36 percent from 1988 to 1990 and has stayed about the same since Since 1990, the

recruitment rate for AB pod has been similar to other resident pods, but the mortality rate has been more than twice as high (Matkin et al 2000)

Less is known about transient killer whales, and their stock structure within the eastern North Pacific is less clear Stock assessment reports have dealt with all transient whales that occur from Alaska to California as a single stock (Forney et al 2000) Studies have shown, however, that two groups of whales that occur in the EVOS GOA region, called AT1 transients and GOA transients, are genetically and acoustically distinct from one another and from other west coast transients (Saulitis, E L 1993, Barrett-Lennard et al in press) GOA transients range widely, but are seen only occasionally in the PWS-Kenai Fiords area The AT1 pod occurs in the PWS-Kenai Fiords area year-round (Saulitis 1993, Matkin et al 2000) The number of whales in the AT1 pod has declined by more than 50 percent since 1988, with only ten individuals remaining in 2000 (Table 7 11)

Pod Identifier	1984	1988	1990	2000
Resident Pods				
AB	35	36	23	25
AD05	13	11	12	13
AD16	6	5	5	6
AE	13	12	13	18
Al	6	6	6	6
AJ	25	26	28	36
AK	7	8	9	11
AN10	12	13	13	20
AN20	23	26	29	1
Transient Groups				
AT1	22	22	13	10

Table 7 11 Number of Whales Photographically Identified in Killer Whale Pods in Gulf of Alaska *Exxon Valdez* Oil Spill Area, 1984 to 2000

Source (Matkin et al 2000) and (Matkin 2000)

¹ The entire AN20 pod has not been photographed since 1991

The declines in the AB and AT1 killer whale pods are issues of major conservation concern Thirteen whales, mostly juveniles and adult females, disappeared from AB pod from March 1989 to June 1990, the highest mortality rate ever seen in a resident killer whale pod Although twelve calves have been born in AB pod since then, there is no clear trend toward recovery because an additional ten animals have died For the AT1 transients, twelve whales have died since 1988 and no calves have been recruited to the group since 1984 (Matkin 2000)

The causes of the declines in these two killer whale pods are not entirely clear Killer whales are only rarely caught incidental to commercial fishing operations (Ferrero et al 2000) In the mid-1980s, however, the AB pod was involved in a different type of interaction with the longline fisheries for sablefish and halibut (Matkin and Saulitis 1994) Whales removed hooked fish from the lines, and fishermen attempted to deter them by shooting at them and detonating explosives A number of whales were seen with gunshot wounds, and some of those later disappeared In spite of eight mortalities during the previous four years, the pod numbered thirty-six animals in 1988, one more than in 1984 (Matkin et al 1994) In March to September 1989, members of the AB pod were several times seen swimming in oil from the EVOS Although a direct cause-effect relationship cannot be shown, there is reason to believe that the population decline is in some way due to the spill (Dahlheim and Matkin 1994, Matkin et al 1994) Members of the AT1 transient group were also seen in oil in summer 1989, and many members of the group were missing the following year and have not been seen since (Matkin et al 1994, 2000) An additional concern related to the potential effects of contact with oil is the consumption of harbor seals, which AT1 transients feed on to a large extent (Saulitis 1993) Because many harbor seals were coated with oil by the spill (Lowry et al 1994), the whales may have ingested contaminated prey In addition, the harbor seal population has decreased Harbor seal numbers were declining in parts of PWS before 1989, an estimated 300 seals were killed by the spill, and the seal population has continued to decline at least through 1997 (Frost et al 1994, Frost et al 1999) Therefore, the lack of recruitment into the AT1 pod may be at least partly caused by the severe reduction of harbor seal numbers in the EVOS GOA region (Matkin et al 2000)

Other than their general status under the MMPA, Alaskan killer whales have not been afforded any special legal protection Although the AB pod is part of a larger resident population, the AT1 group is a distinct population that is demographically and genetically isolated from other killer whales For that reason, protective listing under the ESA may be warranted for the AT1 group

7.13.2.2 Beluga Whale

Belugas, also called white whales or belukhas, are medium-sized, toothed whales They have a disjunct circumpolar distribution and occur principally in arctic and subarctic waters (O'Corry-Crowe and Lowry 1997) Recent studies have shown that belugas are separated into a number of discrete genetic groups (stocks), that generally correspond to groups of animals that summer in different regions (O'Corry-Crowe et al 1997, Brown Gladden et al 1999) There are four relatively large stocks that range throughout western and northern Alaska and a small stock that occurs in Cook Inlet and the GOA (O'Corry-Crowe and Lowry 1997)

In the GOA, belugas are seen most commonly in Cook Inlet, but sightings have been made near Kodiak Island, in PWS, and in Yakutat Bay (Laidre et al in press) The fact that there have been several reports of belugas in Yakutat Bay during 1976 to 1998 suggests the possibility of a small resident group there The other sightings have most likely been of animals from the main Cook Inlet concentration Because summer surveys of belugas in Cook Inlet have been conducted at irregular intervals since the 1960s and annually since 1993, beluga distribution in that region is fairly well known (Klinkhart 1966, Calkins 1984, Rugh et al in press) Belugas may be found throughout Cook Inlet, and in mid-summer they are always most common near the mouths of large rivers in Upper Cook Inlet, especially the Beluga River, the Susitna River, and Chickaloon Bay Other areas where they have been commonly seen include Turnagain Arm, Knik Arm, Kachemak Bay, Redoubt Bay, and Trading Bay Rugh et al (in press) compared the distribution of June and July sightings made in the 1990s with earlier years They found that the proportion of sightings in Upper Cook Inlet has increased greatly in the last decade, and they conclude that the number of sightings in Lower Cook Inlet and in offshore waters has declined during the years

In February-March 1997, aerial surveys were conducted with the specific goal of gathering information on winter distribution of the Cook Inlet beluga stock (Hansen and Hubbard 1999) The area surveyed included Cook Inlet and parts of the GOA between Kodiak Island and Yakutat Bay Almost all beluga sightings (150 out of 160) were in the middle part of Cook Inlet, and the remaining sightings were in Yakutat Bay

Since 1999, the NMFS National Marine Mammal Laboratory (NMML) has gathered data on Cook Inlet beluga distribution and movements through use of satellite-linked tags In 1999, one whale that was tagged and tracked for 110 days (from May 31 to September 17) stayed in Upper Cook Inlet (Ferrero et al in press) To try to obtain information on winter distribution, two tags were attached to whales on September 13, 2000 The whales were tracked until mid-January During that time, they moved around quite a bit in Upper Cook Inlet, but did not go south of Kalgin Island (NMML unpublished data available at http://nmml.afsc.noaa.gov/CetaceanAssessment/2000_Folder/2000_beluga_whale_tagging htm, also 1999 and 2001 studies available by substituting year)

In many parts of Alaska, including Cook Inlet, belugas are most common in nearshore waters during the summer (Calkins 1986, Frost and Lowry 1990) Proposed reasons for the use of nearshore habitats include the possible advantage of warm protected waters for newborn calves (Sergeant and Brodie 1969), facilitation of the epidermal molt by fresh water and rubbing on gravel (St Aubin et al 1990, Smith et al 1992), and feeding on seasonally abundant coastal and anadromous fishes (Seaman et al 1985, Frost and Lowry 1990) Although there have been no direct studies of the diet of Cook Inlet beluga whales, at least part of the reason for their congregating nearshore and near river mouths must be to feed on abundant fishes such as salmon and eulachon (Calkins 1984, Moore et al in press)

There has been no life history information collected from Cook Inlet belugas Biological characteristics of belugas in other areas were reported by Hazard (1988) Females become sexually mature at four to seven years of age and males at seven to nine years Mature females give birth to calves every two to three years, mostly in late spring or summer The maximum life span has not been well defined, but is likely to be about forty years In the southern part of their range, belugas are preyed upon by killer whales, and in more northern areas by polar bears

Beluga whales are difficult to enumerate for a number of reasons Principal problems are that whales are easy to miss in muddy water or when whitecaps are present, and in all conditions some fraction of the population will be underwater where they cannot be seen Early survey efforts largely ignored these problems and just reported the number of animals counted, which during the 1960s to 1980s was usually a few hundred In 1994 the NMFS NMML began to produce annual estimates of population size with standardized aerial surveys of the entire Cook Inlet and a sophisticated set of methods to correct for whales that were missed by observers (Hobbs et al in press, Rugh et al in press, Hobbs 2000) For each survey, they reported the number of whales counted and an estimate of the total population size (Table 7 12) Unfortunately because of problems inherent in counting whales from the air, the annual estimates are imprecise and have a relatively large coefficient of variation Nonetheless, regression analysis shows a statistically significant population decline during the 7-year period The 2000 population is most likely at least one-third smaller than it was in 1994 The 95 percent confidence limits for the 2000 survey were 279 to 679 whales, meaning it is very likely that the true current population size is somewhere in that range

Year	Whale Count	Abundance Estimate	Coefficient of Variation
1994	281	653	0 43
1995	324	491	0 44
1996	307	594	0 28
1997	264	440	0 14
1998	193	347	0 29
1999	217	357	0 20
2000	184	435	0 23

Table 7 12	Counts and Population Estimates for Cook Inlet Beluga Whales,
1993 to 200	0

Sources (Hobbs et al in press) and (Hobbs 2000)

Available data suggest that beluga whales in Cook Inlet rarely become entangled in fishing gear (Ferrero et al 2000) The largest source of mortality in recent years has been hunting by Alaska Natives Although harvest data are imprecise, estimates of the annual number of whales killed during 1993 to 1998 ranged from 21 to 123 animals (Ferrero et al 2000, Mahoney and Shelden in press) This compares to a likely sustainable harvest of about twenty whales from a population of 500

Because of the population decline and the potential for continued overharvest, several environmental groups and one individual submitted a petition to NMFS in

March 1999 requesting that the Cook Inlet beluga whale be listed as an endangered species under the ESA Responding to the same problems, Senator Ted Stevens inserted language into federal legislation passed in May 1999 that prohibited any hunting of beluga whales by Alaska Natives, unless they had entered into a comanagement agreement with NMFS to regulate the hunt In May 2000, NMFS finalized a designation of depletion under provisions of the MMPA for the Cook Inlet beluga population, and in June 2000, the agency determined that a listing under the ESA was not warranted There was no legal harvest of Cook Inlet belugas in either 1999 or 2000 NMFS is currently working through provisions of the MMPA to allow a small, regulated take of Cook Inlet belugas to satisfy the cultural needs of Alaska Natives

Although overharvest by Alaska Natives in the 1990s appears to be sufficient to explain the population decline, concerns that this small isolated population may be vulnerable to other threats remain Areas of concern that have been identified include commercial fishing, oil and gas development, municipal discharges, noise from aircraft and ships, shipping traffic, and tourism (Moore et al in press)

7.13.2.3 Steller Sea Lion

Steller sea lions are the largest species of otariid (eared seal) They are distributed around the North Pacific rim from northern Japan, the Kuril Islands and Okhotsk Sea, through the Aleutian Islands and Bering Sea, along the southern coast of Alaska, and south to California (Kenyon and Rice 1961, Loughlin et al 1984, Loughlin et al 1992) Most large rookeries are in the GOA and Aleutian Islands The northernmost rookery, Seal Rocks, is in the EVOS region at the entrance to PWS Currently the largest rookery is on Lowrie Island, in the Forrester Island complex in southern Southeast Alaska

Steller sea lions are listed as two distinct population segments under the ESA an eastern population that includes all animals east of Cape Suckling, Alaska, and a western population that includes all animals at and west of Cape Suckling. This distinction is based mostly on results from mitochondrial DNA genetic studies that found a distinct break in the distribution of haplotypes between locations sampled in the western part of the range and eastern locations, indicating restricted gene flow between two populations (Bickham et al 1996, Bickham et al 1998a) Information on distribution, population response, and phenotypic characteristics, also support the concept of two Steller sea lion stocks (Loughlin 1997)

Most adult Steller sea lions occupy rookeries during the pupping and breeding season, which extends from late May to early July (Pitcher and Calkins 1981, Gisiner 1985) Some juveniles and non-breeding adults may summer at or near the rookeries, but most use other locations as haul-outs During fall and winter, sea lions may be at rookery and haul-out sites that are used during the summer, and they are also seen at other locations They do not make regular migrations, but do move considerable distances When they reach adulthood, females generally return to the rookeries of their birth to pup and breed (Kenyon and Rice 1961, Calkins and Pitcher 1982, Loughlin et al 1984)

Steller sea lions use a number of marine and terrestrial habitats Adults congregate for pupping and breeding on rookeries that are usually on sand, gravel, cobble, boulder, or bedrock beaches of relatively remote islands Haul-outs are sites used by adult sea lions during times other than the breeding season, and by nonbreeding adults and subadults throughout the year Haul-outs may be at sites also used as rookeries, or on other rocks, reefs, beaches, jetties, breakwaters, navigational aids, floating docks, and sea ice With the exception of sea ice, sites used for rookeries and haul-outs are traditional and the specific locations used vary little from year to year Factors that influence the suitability of a particular area are poorly understood (Gentry 1971, Sandegren 1970, Calkins and Pitcher 1982)

When not on land, Steller sea lions are seen near shore and out to the edge of the continental shelf, in the GOA, they commonly occur near the 200-m depth contour (Kajimura and Loughlin 1988) Studies with using satellite-linked telemetry have provided detailed information on at-sea movements (Merrick and Loughlin 1997) Adult females tagged at rookeries in the central GOA and Aleutian Islands in summer made short trips to sea and generally stayed on the continental shelf. In winter, adult females ranged more widely with some moving to seamounts far offshore. Pups tracked during the winter made relatively short trips to sea, but one moved 320 km from the eastern Aleutians to the Pribilof Islands.

Female Steller sea lions reach sexual maturity at three to six years of age and most breed annually during June and July (Pitcher and Calkins 1981) Males reach sexual maturity at three to seven years of age and physical maturity by age ten, they establish territories on rookeries during the breeding season, and one male may breed with several females (Thorsteinson and Lensink 1962, Gentry 1971, Sandegren 1970, Gisiner 1985) Territorial males fast for long periods during the pupping and breeding season Pups are born on land, normally in late May to June, and they stay on land for about two weeks, then spend an increasing amount of time in intertidal areas and swimming near shore After giving birth, sea lion mothers attend pups constantly for about ten days, then alternate trips to sea for feeding with returns to the rookery to suckle their pup Unlike most pinnipeds, for which weaning is predictable and abrupt, Steller sea lions may continue to nurse until they are at least three years old (Gentry 1971, Sandegren 1970, Calkins and Pitcher 1982)

Steller sea lions due from a number of causes, including disease, predation, shooting by humans, and entanglement in fishing nets or debris (Merrick et al 1987) In addition, pups may due from drowning, starvation caused by separation from the mother, crushing by larger animals, and biting by females other than the mother (Orr and Poulter 1967, Edie 1977)

Steller sea lions are generalist predators that mostly eat a variety of fishes and invertebrates (Pitcher 1981) Seals, sea otters, and birds are also occasionally eaten (Gentry and Johnson 1981, Pitcher and Fay 1982, O'Daniel and Schneeweis 1992)

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Much effort has been devoted to describing the diet of sea lions in the GOA In the mid 1970s and mid 1980s, the primary food found in sea lion stomachs was walleye pollock. Octopus, squid, herring, Pacific cod, flatfishes, capelin, and sand lance also were consumed frequently (Pitcher 1981, Calkins and Goodwin 1988) In the 1970s, walleye pollock was the most important prey in all seasons, except summer, when small forage fishes (capelin, herring, and sand lance) were eaten more frequently (Merrick and Calkins 1996) Results from examination of scats collected on rookeries and haul-outs in the GOA in the 1990s confirmed that pollock has been overall the dominant prey, with Pacific cod and salmon also important in some months (Merrick et al 1997) The diet of juvenile Steller sea lions has not been studied in detail, but it is known that they eat somewhat smaller pollock than do adults (Frost and Lowry 1986, Calkins 1998) Available data suggest that the average daily food requirement for sea lions is on the order of 5 percent to 8 percent of their body weight per day (Kastelein et al 1990, Rosen and Trites 2000)

Satellite-linked tags attached to sea lions have provided information on the amount of time spent diving and diving depths (Merrick and Loughlin 1997) Adult females in winter spent the most time feeding and dove the deepest, and young of the year spent relatively little time diving to shallow depths As young of the year matured, foraging effort increased from November to May

The abundance of Steller sea lions in the western population has decreased greatly since the 1960s, to the extent that the species has been listed as endangered under the ESA From the mid-late 1970s through 2000, index counts of adults and juveniles for the western population as a whole declined by 83 percent from 109,880 to 18,193 (Crane and Galasso 1999) Declines in the eastern GOA (Seal Rocks to Outer Island) and central GOA (Sugarloaf Island to Chowiet Island) have been of a generally similar magnitude (73 percent and 87 percent), but it appears that the decline in the eastern GOA began later than in the western GOA and other regions (Sease and Loughlin 1999, Crane and Galasso 1999) (Table 7 13) Counts of pups on rookeries have shown similar declines Modeling and tagging studies have suggested that the proximate cause of the population decline is probably a reduction in survival of juvenile animals (York 1994, Chumbley et al 1997) Birth rates are also comparatively low (Calkins and Goodwin 1988), which could be a contributing factor Population viability analysis suggests that if the decline continues at its current rate some rookeries will go extinct in the next forty to fifty years, and the entire western population could be extinct within 100 to 120 years (York et al 1996)

Survey Year	Eastern GOA	Central GOA	Western Stock Total
1976	7 053	24 678	109 880 ¹
1985		19 002	
1989	7 241	8 552	
1990	5 444	7 050	30 525
1991	4 596	6 273	29 418
1992	3 738	5 721	27,286
1994	3 369	4 520	24 119
1996	2 133	3 915	22 223
1997		3 352	
1998		3 346	20 201
1999	1 952	-	
2000	1 894	3,177	18 193

Table 7 13 Index Counts of Steller Sea Lions in the Eastern Gulf of Alaska (Seal	Rocks
to Outer Island) and Western Gulf of Alaska (Sugarloaf Island to Chowiet Island)	

Sources (Sease and Loughlin 1999) and (Crane and Galasso 1999)

The multiple factors that have been suggested to affect abundance of the western Steller sea lion population in the past three to four decades (Merrick et al 1987) are represented by six related hypotheses displayed on a National Marine Fisheries Service web page on December 27, 2001

Brief Characterization of the Principle Hypotheses Surrounding the Steller Sea Lion Decline http://www.fakr.noaa.gov/omi/grants/sslri/hypothesis.htm

1 Fisheries Competition

Commercial fisheries potentially cause or contribute to nutritional stress in the western stock of Steller sea lions by reducing either the abundance of prey at scales relevant to for aging sea lions or by disturbing prey patches so as to reduce their availability. In turn, nutritional stress is manifested in the population as increased mortality or lowered reproductive output

2 Environmental Change

Environmental conditions in areas inhabited by Steller sea lions may have changed since the 1970s in ways that reduced the availability of prey for Steller sea lions and precipitated nutritional stress. The changes may have either reduced the abundance of important prey items or altered then distributions

3 Predation

Predation of Steller sea lions by killer whales and sharks has increased as a function of a) their increased population size, b) their increased per capita

consumption , or c) remained constant over time, but with increasing effects as the Steller sea hon population has diminished over time

4 Anthropogenic Effects

One or more sources of anthropogenic activity, including incidental mortality (e.g. entanglement), direct mortality (e.g. shooting), commercial harvesting, subsistence harvesting, and harassment have contributed to the decline in the Steller sea lion population. Such effects would include both those over the past decades since the decline began and those which may be ongoing

5 Disease

The Steller sea hon population is being reduced by diseases which may result in mortality or reduced reproductive output

6 Contaminants

Contaminants from either local or distant sources have had detrimental physical impacts on Steller sea hons leading to increased mortality or reduced reproductive output

Available data permit no definitive evaluation of any of these hypotheses at present There is no evidence that patterns of predation, disease, or environmental contaminants have changed sufficiently to have caused such a major decrease in abundance (Loughlin 1998) In the past, many sea lions were killed in commercial harvests, by incidental entanglement in nets, and by shooting to reduce damage to fishing gear and fish depredation (Alverson 1992) That mortality may have played some part in the early stages of the decline, but such killing has been eliminated or greatly reduced and cannot explain the widespread, continuing decline Subsistence hunting by Alaska Natives occurs at low levels and is not judged to be an important factor overall (Ferrero et al 2000) Currently the most likely explanation is that sea lions, especially juveniles, are experiencing higher than normal mortality because they are nutritionally limited (Loughlin 1998, Crane and Galasso 1999) The nutritional limitation could be caused by environmental changes that have affected sea lion prey species, competition for prey with commercial fisheries, or some combination of the two

The decline of the western population of Steller sea lions, and the need to recover the population and protect critical habitat as required by the ESA, have been a major conservation issue in recent years (Lowry et al 1989, Fritz et al 1995) Actions proposed to facilitate recovery may have substantial effects on commercial fisheries and coastal communities in the GOA and elsewhere (Crane and Galasso 1999) Major research efforts have been generously funded (\$43M FY 01, \$40M FY 02, \$60M FY 03) by the federal government

7.13.2.4 Pacific Harbor Seal

Harbor seals are medium-sized, "earless" seals that are widespread in temperate waters of both the North Atlantic and the North Pacific In the North Pacific, their distribution is nearly continuous from Baja California, Mexico, to the GOA and Bering Sea, through the Aleutian Islands, and to eastern Russia and northern Japan (Shaughnessy and Fay 1977, Hoover-Miller 1994)

Harbor seals are found primarily in the coastal zone where they feed and haul out to rest, give birth, care for their young, and molt Haul-out sites include intertidal reefs, rocky shores, mud and sand bars, gravel and sand beaches, and floating glacial ice (Hoover-Miller 1994) From the results of satellite tagging studies in PWS, most adult harbor seals are known to use the same few haul-outs for most of the year (Frost et al 1996, Frost et al 1997)

Although it is relatively easy to study harbor seals while they are on haul-outs, their distribution and movements at sea are not as well understood During 1992 to 1997, as part of EVOS restoration studies, satellite-linked depth recorders (SDRs) were attached to seals in PWS to study their at-sea behavior. Analysis of the tracking data from foorty-nine subadult and adult harbor seals indicated that most tagged seals stayed in or near PWS, but some subadults moved 300 to 500 km east and west in the GOA (Frost et al 2001, Lowry et al 2001). Virtually all relocations were on the continental shelf in water less than 200 m deep. Most feeding trips for adults went 10 km or less from haul-outs, and juveniles fed mostly within 25 km. Patterns of diving (effort and depth) varied geographically and seasonally. During 1997 to 1999, SDRs were attached to twenty-seven recently weaned harbor seal pups in PWS. Preliminary analysis of those data (Frost et al 1998, Lowry and Frost unpublished) did not show any extraordinary movement patterns.

SDRs have also been attached to harbor seals in Southeast Alaska and the Kodiak region Preliminary results from those tagging efforts have been reported in Small et al (1997, 1998) The data are currently being analyzed and prepared for publication (Small 2001)

Overall, harbor seals are relatively sedentary and they show considerable fidelity to haul-out sites (Pitcher and McAllister 1981, Frost et al 1996, Frost et al 1997) For management purposes, NMFS has delineated three harbor seal stocks in Alaska

- 1 The southeast Alaska stock, including animals east and south of Cape Suckling,
- 2 The GOA stock, including animals from Cape Suckling to Unimak Pass and westward through the Aleutian Islands, and
- 3 The Bering Sea stock including animals in Bristol Bay and the Pribilof Islands (Ferrero et al 2000)
During the past several years, an in-depth study of Alaska harbor seal genetics has been conducted by the NMFS Southwest Fisheries Science Center Preliminary analysis of those data indicate a number of relatively small population units with very limited dispersal among them (O'Corry-Crowe et al in press), in (Small et al 1999) Results suggest that within the EVOS area, there are multiple harbor seal stocks that may require individual management attention NMFS scientists are currently analyzing the molecular genetics data and preparing it for publication NMFS managers are evaluating those results with the intention of refining stock boundaries for Alaska harbor seals

Hoover-Miller (1994) summarized available information on Alaska harbor seal biology and life history Both male and female harbor seals reach sexual maturity at three to seven years old Adult females give birth to single pups once a year, on land or on glacial ice In PWS and the GOA, most pupping occurs from mid-May through June Newborn harbor seals pups are born with their eyes open, with an adult-like coat, and are immediately able to swim Pups are weaned when they are three to six weeks old Once each year in July to September, harbor seals shed their old hair and grow a new coat During this time, the seals spend more time hauled out than they do at other times For that reason, the molt period is a good time to count seals to estimate population sizes and trends

Most information about the diet of harbor seals in PWS and the GOA was collected in the mid-1970s by examination of stomach contents (Pitcher 1980) The major prey overall in both PWS and adjacent parts of the GOA was pollock Octopus, capelin, Pacific cod, and herring also are eaten frequently Stomachs of young seals contained mostly pollock, capelin, eulachon, and herring As part of EVOS restoration studies, blubber samples from PWS harbor seals have been analyzed for their fatty acid composition to examine their recent diets (Iverson et al 1997), and (Lowry and Frost unpublished) Initial results showed that herring, pollock, other fishes, and cephalopods (a class of squid and octopi) had been eaten Seals sampled at the same haul-out had similar fatty acid compositions, suggesting that they had fed locally on similar prey In contrast, seals sampled from areas as little as 80 km apart had different fatty acid compositions, indicating substantially different diets Small et al (1999) have examined scats from harbor seals collected near Kodiak and found mostly remains of sculpins, greenling, sand lance, and pollock

Known predators of harbor seals include killer whales, Steller sea lions, and sharks The impact of these predators on harbor seal populations is unknown, but may be significant In PWS alone, killer whales may eat as many as 400 harbor seals per year (Matkin 2000) The incidence of sharks caught on halibut longlines in the GOA has increased greatly in the last decade (Lowry and Frost unpublished data) The degree to which these sharks prey on harbor seals is unknown, but seal remains have been observed in their stomachs (Matkin 2000)

Before the MMPA, harbor seals were hunted commercially in Alaska, and they were also killed to reduce their predation on commercially important fishes

(Hoover-Miller 1994) Such kills, which exceeded 10,000 animals in many years, were largely stopped in 1972 The MMPA allowed fishermen to shoot seals if they were damaging their gear or catch and could not be deterred by other means A few hundred animals probably were killed annually for that reason during 1973 to 1993 In 1994, the MMPA was amended to require that fishermen use only non-lethal means to keep marine mammals away from their gear

Harbor seals have been and continue to be an important food and handicraft resource for Alaska Native subsistence hunters in PWS and the GOA The ADF&G Division of Subsistence estimated the size of the harbor seal harvest annually during 1992 to 1998 The average annual kill during that period was approximately 380 seals in PWS and 360 for Kodiak, Cook Inlet-Kenai, and the south Alaska Peninsula combined (Wolfe and Hutchinson-Scarbrough 1999) About 88 percent of the seals shot were retrieved, and 12 percent were struck and lost Although harvests at individual villages have varied from year to year, regional harvest levels have shown no clear trend

Harbor seals are sometimes entangled and killed in the gear set by several commercial fisheries that operate in the EVOS GOA region Ferrero et al (2000) estimated an average minimum annual mortality of thirty-six animals for the GOA stock This figure was an underestimate, because there have not been observer programs for several of the fisheries that are likely to interact with harbor seals

Some harbor seals were killed by the EVOS, at least in PWS (Frost et al. 1994) In August and September 1989, ADF&G flew aerual surveys of harbor seals in oiled and unoiled areas of central and eastern PWS Results of those surveys were compared to earlier surveys of the same haul-outs conducted in 1983, 1984, and 1988 Before the EVOS, counts in oiled and unoiled areas of PWS were declining at a similar rate, about 12 percent per year From 1988 to 1989, however, there was a 43 percent decline in counts of seals at oiled sites compared to 11 percent at unoiled sites Other studies conducted as part of the EVOS damage assessment program showed that seals in oiled areas became coated with oil (Lowry et al 1994) Many oiled seals acted sick and lethargic for the first few months after the spill Tests of bile and tissues showed that oiled seals were metabolizing petroleum compounds (Frost et al 1994) Microscopic examination indicated that some oiled seals had brain damage that would likely have interfered with important functions such as breathing, swimming, diving, and feeding (Spraker et al 1994) It was estimated that approximately 300 seals died because of the EVOS (Frost et al 1994) Hoover-Miller et al. (2000) disputed the mortality estimate of Frost et al. (1994), but they admit that the spill had effects on harbor seals and do not provide an alternative estimate of mortality

Harbor seals are one of the most common marine mammals in the EVOS GOA region In 1973, ADF&G estimated there were about 125,000 in this region based on harvest data, observed densities of seals, and the amount of available habitat (Pitcher 1984) The most recent population estimate for the GOA harbor seal stock, derived from intensive aerial surveys conducted by NMFS, is 29,175 (Ferrero et al

2000) Although the methods used to derive the two estimates were very different and they are not directly comparable, the difference does suggest that a large decline in harbor seal numbers has occurred in the GOA

Counts at individual haul-outs and along surveys routes established to monitor trends confirm the decline and provide some information on the temporal pattern of changes (Table 7 14) At Tugidak Island (south of Kodiak Island), average molt period counts declined by 85 percent from 1976 to 1988 (Pitcher 1990), followed by a period of stabilization before a population increase of about 5 percent per year during 1994 to 1999 (Small et al 1999) In eastern and central PWS, the number of seals at twenty-five trend index sites declined by 42 percent between 1984 and 1988 (Pitcher 1989) Trend counts at index sites have shown that the decline in that part of PWS continued at least through 1997, by which time there were 63 percent fewer seals than there were in 1984 (Frost et al 1999) Counts on the PWS trend route were fairly similar in 1994 to 1998 (Table 7 14), suggesting that the decline in that area may have stopped In the Kodiak trend area, harbor seal counts increased by 5 6 percent per year during 1993 to 1999 (Small et al 1999)

Year	Tugıdak İsland	PWS	Kodiak
1976	5 708		
1977	4 618		
1978	3 781		
1979	3 133		
1982	1,918		
1984	1 469	2 488	
1986	1,181		
1988	966	1 875	
1989		1 423	
1990	882	1 282	
1991		1 200	
1992	820	1 133	
1993	805	1 126	3 129
1994	800	981	3 478
1995	804	1 126	3 855
1996	819	962	3 322
1997	844	929	3 674
1998	880	1 053	4 247
1999	929		4 876

 Table 7 14 Counts of Harbor Seals at Index Sites in the Exxon Valdez Oil Spill

 Gulf of Alaska Area

Sources (Pitcher 1990), Frost et al 1994, Frost et al unpublished, and Small 2001) Counts have been adjusted to account for important covariates (Frost et al 1999) Mortality of harbor seals caused by people because of fishery interactions, the EVOS, and hunting has been fairly well documented Each of these causes may be a contributing factor, but it seems unlikely that they could have caused such a widespread and major population decline. Other factors that could be involved in the decline include disease, food limitation, predation, contaminants, and changes in habitat availability. No strong scientific evidence has been produced, however, to suggest that any of these factors has been a primary cause (Sease 1992, Hoover-Miller 1994). A Leslie matrix model for population projection showed that large changes in vital parameters (reproduction and survival) must have occurred to cause the declines in abundance seen in PWS during 1984 to 1989, and that changes in juvenile survival are likely to have the greatest effect on population growth (Frost et al. 1996).

The large decrease in harbor seal abundance in the GOA has been a major concern among scientists, resource managers, Alaska Natives, and the public After completion of damage assessment, the Trustee Council funded restoration studies to learn about the biology and ecology of harbor seals in the spill area, and to investigate possible causes for the decline (Frost and Lowry 1994, Frost et al 1995, Frost et al 1996, Frost et al 1997, Frost et al 1998, Frost et al 1999) At about the same time, Congress began providing funds to ADF&G to be used to investigate causes of the Alaskan harbor seal decline Those funds were used to initiate harbor seal research programs in Southeast Alaska and the Kodiak area, and to resume long-term studies on Tugidak Island (Lewis 1996, Small et al 1997, Small 1998, Small et al. 1999, Small and Pendleton 2001) A major part of all those studies has been live-capturing seals and attaching SDRs to them to learn about their movements, foraging patterns, and behavior on land and at sea As part of the field studies, researchers have weighed and measured each seal, and have taken samples for studies of blood chemistry, disease, genetics, and diet Some parts of those studies have been completed and published, some are in the analysis and reporting stage, and others are ongoing As discussed above, the results have added greatly to the understanding of harbor seals in this area and will continue to do so as more of the work is completed

Any time a wildlife population declines, it is a cause for concern For harbor seals in PWS and the GOA, however, the concern is magnified because the causes for the decline are unknown and because these seals are an important food and cultural resource of Alaska Natives In addition, the results of genetics studies are showing very limited dispersal between seals in adjacent areas, suggesting that harbor seals should be managed as a number of relatively small units So far GOA harbor seals have not been listed as depleted under the MMPA or as threatened or endangered under the ESA The listing status could change if recovery doesn't happen in some genetically discrete population units

Harbor seals may have great value as an indicator species of environmental conditions in the GEM region. They are important in the food web, both as upper level predators on commercially exploited fishes and other fishes and invertebrates, and also as a food resource for killer whales and Alaska Native hunters. Because they are non-migratory and have low dispersal rates, changes in their abundance

and behavior should be reflective of changes in local environmental conditions in the areas they inhabit Further, they are relatively easy to study, and during the past 30 years a considerable amount of baseline data has been collected on their abundance, distribution, and other aspects of their biology and ecology

7.13.2.5 Sea Otter

Sea otters are the only completely marine species of the aquatic lutrinae, or otter subfamily of the family Mustelidae They occur only in coastal waters around the North Pacific rim, from central Baja California, Mexico, to the northern Islands of Japan The northern distribution of sea otters is limited by the southern extent of winter sea ice that limits access to foraging habitat (Kenyon 1969, Riedman and Estes 1990) Southern range limits are less well understood, but are likely related to reduced productivity at lower latitudes, increasing water temperatures, and thermoregulatory constraints imposed by the sea otter's dense fur

Three subspecies of sea otters are recognized *Enhydra lutris lutris* from Asia to the Commander Islands of Russia, *E l kenyoni* from the western Aleutians to northern California, and *E l nereis*, south of the Oregon (Wilson et al 1991) The subspecific taxonomy suggested by morphological analyses is largely supported by subsequent molecular genetic data (Cronin et al 1996, Scribner et al 1997) The distribution of mitochondrial DNA haplotypes suggests little or no recent female-mediated gene flow among populations Populations separated by large geographic distances, however, share some haplotypes (for example, in the Kuril and Kodiak islands), suggestive of common ancestry and some level of historical gene flow The differences in genetic markers among contemporary sea otter populations likely reflect the following:

- Periods of habitat fragmentation and consolidation during Pleistocene glacial advance and retreat,
- Some effect of reproductive isolation over large spatial scale, and
- The recent history of harvest-related reductions and subsequent recolonization (Cronin et al 1996, Scribner et al 1997)

Sea otters occupy and use only coastal marine habitats The seaward limit of their feeding habitat, which is about the 100-m depth contour, is defined by their ability to dive to the sea floor Although sea otters may be found at the surface in deeper water, either resting or swimming, they must maintain relatively frequent access to shallower depths where they can feed In PWS, 98 percent of the sea otters are found in water with depths less than 200 m and sea otter abundance is inversely correlated with water depth, with about 80 percent of the animals observed in water less than 40 m deep (Bodkin and Udevitz 1999) Sea otters forage in diverse bottom types, from fine mud and sand to rocky reefs Although they may haul out on intertidal or supratidal shores, no aspect of their life history requires leaving the ocean. Where present, surface-canopy-forming kelps provide preferred resting habitat. In areas lacking kelp canopies, sea otters rest in groups or

alone in open water, but may select areas protected from large waves where available Sea otters generally feed alone and often rest in groups of ten or fewer, but also occur in groups numbering in the hundreds (Riedman and Estes 1990)

Relatively few data are available to describe relations between sea otter densities and habitat characteristics Maximum sea otter densities of about twelve per square kilometer (km²) have been reported from the Aleutian and Commander islands (Kenyon 1969, Bodkin et al 2000) where habitats are largely rocky Maximum densities in Orca Inlet of PWS, a shallow soft-sediment habitat, are about 16 per km² Equilibrium, or sustainable densities, likely vary among habitats, with reported values of about 5 to 8 per km² In PWS, sea otter densities vary among areas, averaging about 1 5 per km² and ranging from fewer than one to about 6 per km² (Bodkin and Udevitz 1999, USGS unpublished data)

The sea otter is the largest mustelid, with males considerably larger than females Adult males attain weights of 45 kg and total lengths of 148 cm Adult females attain weights of 36 kg and total lengths of 140 cm At birth, pups weigh about 17 to 23 kg and are about 60 cm in total length

Adult male sea otters gain access to estrous females by establishing and maintaining territories from which other males are excluded (Kenyon 1969, Garshelis et al 1984, Jameson 1989) Male territories vary in size from about 20 to 80 hectares Territories may be located in or adjacent to female resting or feeding areas or along travel corridors between those areas, and are occupied continuously or intermittently through time (Loughlin 1981, Garshelis et al 1984, Jameson 1989) Female sea otters attain sexual maturity as early as age two, and by age three most females are sexually mature Where food resources may be limiting population growth, sexual maturation may be delayed to four to five years of age

Adult female reproductive rates range from 0 80 to 0 94 (Siniff and Ralls 1991, Bodkin et al. 1993, Jameson and Johnson 1993, Riedman et al 1994, Monson and DeGange 1995, Monson et al 2000b) Among areas where sea otter reproduction has been studied, reproductive rates appear to be similar despite differences in resource availability Although copulation and subsequent pupping can take place at any time of year, there appears to be a positive relation between increasing latitude and reproductive synchrony (occurring simultaneously) In California, pupping is weakly synchronous to nearly uniform across months, in PWS, a distinct peak in pupping occurs in late spring

Reproductive output remains relatively constant across a broad range of ecological conditions, and pup survival appears to be influenced by resource availability, primarily food At Amchitka Island, a population at or near equilibrium density, dependent pup survival ranged from 22 percent to 40 percent, compared to nearly 85 percent at Kodiak Island, where food was not limiting and the population was increasing (Monson et al 2000b) Post-weaning annual survival is variable among populations and years, ranging from 18 percent to nearly 60 percent (Monson et al 2000b) Factors affecting survival of young sea otters, rather than reproductive rates, may be important in ultimately regulating sea otter population size Survival of sea otters more than two years of age is generally high, approaching 90 percent, but gradually declines through time (Bodkin and Jameson 1991, Monson et al 2000b) Most mortality, other than human related, occurs during late winter and spring (Kenyon 1969, Bodkin and Jameson 1991, Bodkin et al 2000) Maximum ages, based on tooth annuli, are about twenty-two years for females and fifteen years for males

Although the sex ratio before birth (fetal sex ratio) is one to one (Kenyon 1982, Bodkin et al 1993), sea otter populations generally consist of more females than males Age-specific survival of sea otters is generally lower among males (Kenyon 1969, Kenyon 1982, Siniff and Ralls 1991, Monson and DeGange 1995, Bodkin et al 2000), resulting in a female-biased adult population

The sea otter relies on air trapped in the fur for insulation and an elevated metabolic rate to generate internal body heat To maintain the elevated metabolic rate, energy intake must be high, requiring consumption of prey equal to about 20 percent to 33 percent of their body weight per day (Kenyon 1969, Costa 1982)

The sea otter is a generalist predator, known to consume more than 150 different prey species (Kenyon 1969, Riedman and Estes 1990, Estes and Bodkin in press) With few exceptions, their prey generally consist of sessile or slow moving benthic invertebrates such as mollusks, crustaceans, and echinoderms Preferred foraging habitat is generally in depths less than 40 m (Riedman and Estes 1990), although studies in southeast Alaska have found that some animals forage mostly at depths from 40 to 80 m. A sea otter may forage several times daily, with feeding bouts averaging about three hours, separated by periods of rest that also average about three hours. Generally, the amount of time a sea otter allocates toward foraging is positively related to sea otter density and inversely related to prey availability. Time spent foraging may be a meaningful measure of sea otter population status (Estes et al. 1982, Garshelis et al. 1986).

Although the sea otter is known to prey on a large number of species, only a few tend to predominate in the diet, depending on location, habitat type, season, and length of occupation The predominately soft-sediment habitats of Southeast Alaska, PWS, and Kodiak Island support populations of clams that are the primary prey of sea otters Throughout most of Southeast Alaska, burrowing bivalve clams (species of *Saxidomus, Protothaca, Macoma, and Mya*) predominate in the sea otter's diet (Kvitek et al 1993) They account for more than 50 percent of the identified prey, although urchins (*S droebachiensis*) and mussels (*Modiolis modiolis, Musculus* spp) can also be important In PWS and at Kodiak Island, clams account for 34 percent to 100percent of the otter's prey (Calkins 1978, Doroff and Bodkin 1994, Doroff and DeGange 1994) Mussels (*Mytilus trossulus*) apparently become more important as the length of occupation by sea otters increases, ranging from 0 percent at newly occupied sites at Kodiak to 22 percent in long-occupied areas (Doroff and DeGange 1994) Crabs (*C magister*) were once important sea otter prey in eastern PWS, but apparently have been depleted by otter foraging and are no

longer eaten in large numbers (Garshelis et al 1986) Sea urchins are minor components of the sea otter diet in PWS and the Kodiak archipelago In contrast, the sea otter diet in the Aleutian, Commander, and Kuril islands is dominated by sea urchins and a variety of fin fish (including hexagrammids, gadids, cottids, perciformes, cyclopterids, and scorpaenids) (Kenyon 1969, Estes et al 1982) Sea urchins tend to dominate the diet of low-density sea otter populations, whereas fishes are consumed in populations near equilibrium density (Estes et al 1982) For unknown reasons, sea otters in regions east of the Aleutian Islands rarely consume fish

Sea otters also exploit episodically abundant prey such as squid (*Loligo* spp) and pelagic red crabs (*Pleut oncodes planipes*) in California and smooth lumpsuckers (*Aptocyclus ventricosus*) in the Aleutian Islands On occasion, sea otters attack and consume sea birds, including teal (*Anas crecca*), scoters (*Melanita perspicillata*), loons (*Gavia immer*), gulls (*Larus spp*), grebes (*Aechmophoru soccidentalis*), and cormorants (*Phalaci ocor a* spp) (Kenyon 1969, Riedman and Estes 1990)

Sea otters are known for the effects their foraging has on the structure and function of nearshore marine communities They provide an important example of the ecological "keystone species" concept (Power et al 1996) In the absence of sea otter foraging during the 20th century, populations of several species of urchins (Strongylocentrotus spp) became extremely abundant. Grazing activities of urchins effectively limited kelp populations, resulting in deforested areas known as "urchin barrens" (Lawrence 1975, Estes and Harrold 1988) Because sea urchins are a preferred prey item, as otters recovered, they dramatically reduced the sizes and densities of urchins, as well as other prey such as mussels, *Mytilus* spp Released from the effects of urchin-related herbivory, populations of macroalgae responded, resulting in diverse and abundant populations of under-story and canopy-forming kelp forests Although other factors, both non-living (abiotic) and living (biotic), can also limit sea urchin populations (Foster and Schiel 1988, Foster 1990), the generality of the sea otter effect in reducing urchins and increasing kelp forests is widely recognized (reviewed in Estes and Duggins 1995) Further cascading effects of sea otters in coastal rocky subtidal communities may stem from the proliferation of kelp forests Following sea otter recovery, kelp forests provide food and habitat for other species, including fin fish (Simenstad et al 1978, Ebeling and Laur 1998), which provide forage for other fishes, birds, and mammals Furthermore, where present, kelps provide the primary source of organic carbon to the nearshore marine community (Duggins et al 1989)

Effects of sea otter foraging are also documented in rocky intertidal and softsediment marine communities The size-class distribution of mussels was strongly skewed toward animals with shell lengths smaller than 40 mm where otters were present, however, mussels with shell lengths larger than 40 mm comprised a large component of the population where sea otters were absent (VanBlaricom 1988) In soft-sediment coastal communities, sea otters forage on epifauna (crustaceans, echinoderms, and mollusks) and infauna (primarily clams) They generally select the largest individuals These foraging characteristics cause declines in prey abundance and reductions in size-class distributions, although the deepest burrowing clams (such as, *Tresus muttallu* and *Panopea generosa*) may attain refuge from some sea otter predation (Kvitek and Oliver 1988, Kvitek et al 1992) Community level responses to reoccupation by sea otters are much less well studied in soft-sediment habitats that dominate much of the North Pacific, and additional research is needed in this area

A century ago, sea otters were nearly extinct, having been reduced from several hundred thousand individuals, by a multi-national commercial fur harvest. They persisted largely because they became so rare that, despite exhaustive efforts, they were only seldom found (Lensink 1962). Probably less than a few dozen individuals remained in each of thirteen remote populations scattered between California and Russia (Kenyon 1969, Bodkin and Udevitz 1999). By about 1950, it was clear that several of those isolated populations were recovering. Today, more than 100,000 sea otters occur throughout much of their historic range (Table 7 15), although suitable unoccupied habitat remains in Asia and North America (Bodkin and Kenyon in press).

Subspecies	Area	Year	Number	Status
El lutris	Russia	1995-97	21 500	Stable in Kurils and Commander Islands Increasing in Kamchatka
El kenyonı	Alaska USA	1994-99	100 000	Declining in Aleutians uncertain in GOA and increasing in Southeast
	British Columbia Canada	1997	1,500	Increasing
	Washington USA	1997	500	Increasing
El nereis	Calıfornıa USA	1997	2 200	Uncertain
Total			125 700	

 Table 7 15 Recent Counts or Estimates of Sea Otter (Enhydra lutris) Abundance

 In the North Pacific

Source (Bodkin and Kenyon in press)

Trends in sea otter populations today vary widely from rapidly increasing in Canada, Washington, and Southeast Alaska, to stable or changing slightly in PWS, the Commander Islands and California, to declining rapidly throughout the entire Aleutian archipelago (Estes et al 1998, Estes and Bodkin in press) Rapidly increasing populations sizes are easily explained by abundant food and space resources, and increases are anticipated until those resources become limiting Relatively stable populations can be generally characterized by food limitation and birth rates that approximate death rates The recent large-scale declines in the Aleutian archipelago are unprecedented in recent times and demonstrate complex relations between coastal and oceanic marine ecosystems (Estes et al 1998) The magnitude and geographic extent of the Aleutian decline into the GOA are unknown, but the PWS population appears relatively stable The view of sea otter populations has been largely influenced by events in the past century when food and space where generally unlimited As food and space become limiting, however, it is likely that other mechanisms, such as predation, contamination, human take, or disease will play increasingly important roles in structuring sea otter populations

A number of predators include sea otters in their diet, most notably the white shark (*Carcharadon charcharas*) and the killer whale (*Orca orcinus*) Bald eagles (*Hahaeetus leucocephalus*) may be a significant source of very young pup mortality Terrestrial predators, including wolves (*Canis hipus*), bears (*Ursus arctos*), and wolverine (*Gulo gulo*) may kill sea otters when they come ashore, although such instances are likely rare Before the work of Estes et al (1998) predation was thought to play a minor role in regulating sea otters (Kenyon 1969)

Pathological disorders related to enteritis and pneumonia are common among beach-cast carcasses and may be related to inadequate food resources, although such mortalities generally coincide with late winter periods of inclement weather (Kenyon 1969, Bodkin and Jameson 1991, Bodkin et al 2000) Non-lethal gastrointestinal parasites are common, and lethal infestations are occasionally observed Among older animals, tooth wear can lead to abscesses and systemic infection, eventually contributing to death

Contaminants are of increasing concern in the conservation and management of sea otter populations throughout the North Pacific Concentrations of organochlorines, similar to levels causing reproductive failure in captive mink (*Mustela vison*), occurred in the Aleutian Islands and California, whereas otters from Southeast Alaska were relatively uncontaminated (Estes et al 1997, Bacon et al 1998) Elevated levels of butyltin residues and organochlorine compounds have been associated with sea otter mortality caused by infectious disease in California (Kannan et al 1998, Nakata et al 1998) Changes in stable lead isotope compositions from pre-industrial and modern sea otters in the Aleutians reflect changes in the sources of lead in coastal marine food webs In pre-industrial samples, lead was from natural deposits, in contemporary sea otters, lead is primarily from Asian and North American industrial sources (Smith et al 1990)

Susceptibility of sea otters to oil spills, largely because of the reliance on their fur for thermoregulation, has long been recognized (Kenyon 1969, Siniff et al 1982) and this was confirmed by the EVOS Accurate estimates of acute mortality resulting from the EVOS are not available, but nearly 1,000 sea otter carcasses were recovered in the months following the spill (Ballachey et al 1994) Estimates of carcass recovery rates ranged from 20 percent to 59 percent (DeGange et al 1994, Garshelis 1997), indicating mortality of up to several thousand animals (Ballachey et al 1994) Sea otter mortality in areas where oil deposition was heaviest and persistent was nearly complete, and through at least 1997, sea otter numbers had not completely recovered in those heavily oiled areas (Bodkin and Udevitz 1994,

Dean et al 2000) Long-term effects include reduced sea otter survival for at least a decade following the spill (Monson et al 2000a), likely a result of sublethal oiling in 1989, chronic exposure to residual oil in the years following the spill, and spill-related effects on invertebrate prey populations (Ballachey et al 1994, Fukuyama et al 2000, Peterson 2000) As human populations increase, exposure to acute and chronic environmental contaminants will likely increase Improved understanding of the effects of contaminants on keystone species, such as sea otters, may be valuable in understanding how and why ecosystems change

Human activities contribute to sea otter mortality throughout the Pacific Rim Incidental mortality occurs in the course of several commercial fisheries In California, an estimated annual take of eighty sea otters in gill and trammel nets, out of a population numbering about 2,000, likely contributed to a lack of population growth during the 1980s (Wendell et al 1986) Developing fisheries and changing fishing techniques continue to present potential problems to recovering sea otter populations In Alaska, sea otters are taken incidentally in gillnet, seine, and crab trap fisheries throughout the state, but total mortality has not been estimated (Rotterman and Simon-Jackson 1988) Alaska Natives are permitted to harvest sea otters for subsistence and handicraft purposes The harvest is largely unregulated and exceeded 1,200 in 1993, with most of that from a few, relatively small areas In addition, an illegal harvest of unknown magnitude continues throughout much of the geographic range of sea otters

Sea otters occupy an important, and well documented, position as an upperlevel predator in nearshore communities of the North Pacific In contrast to most marine mammals that are part of a plankton and fish trophic web, sea otters rely almost exclusively on benthic invertebrates Because both sea otters and their prey are resources

Relatively little work has been conducted in investigating relations between those physical and biological attributes that contribute to variation in productivity of nearshore marine invertebrates, such as the clams, mussels, and crabs that sea otters consume, and how that variability in productivity translates into variation in annual sea otter survival Given the observed variation in sea otter survival, and the recognized role of food in regulating sea otter populations, understanding these relations would provide some empirical measure of the relative contributions of predation and primary production as controlling factors in structuring nearshore marine communities Due to the size of their home ranges, sea otters are relatively sedentary They integrate physical and biological attributes of the ecosystem over small spatial scales Further, both sea otters and their prey occur nearshore, allowing accurate and efficient monitoring of sea otters, their prey, and physical and biological ecosystem attributes This suite of factors offers a strong foundation for understanding mechanisms, and interactions among factors that regulate longlived mammalian populations Given that many populations of large carnivorous mammals are severely depleted worldwide, such an understanding would likely be broadly applicable to conservation and management.

7.14 Introduction to the Economics of Human Uses and Activities in the Northern Gulf of Alaska

Human uses have likely affected the productivity of GOA marine and surrounding terrestrial environments during the 4,000 or more years of human presence in the GOA region

Trends since the 1989 *Exron Valdez* oil spill suggest that the pace of change in human-caused effects may have accelerated The spill itself changed attitudes toward acceptable risks of

human-caused disruption, while economic trends have brought about more intense use of some resources and diminishing use of others Understanding these trends will sharpen strategies for long-term monitoring and extend our understanding of how human uses may affect ecosystem productivity

In the period before contact with Europeans, Kodiak, Prince William Sound, and most other areas affected by the oil spill were populated by Alutiq peoples, linguistically related to the Yupik Eskimos of the Bering Sea coast and the Aleut cultures of the western Alaska Peninsula and Aleutian Islands All of these cultures were "ocean-facing," deriving most of their livelihood from the sea, with relatively little economic dependence on upland resources (Dumond 1983)

The cultural values and economic systems of these communities appear to have been very stable The central role of marine mammal and fish resources in the Alutiq subsistence economies profoundly influenced the social organization of precontact societies and shaped their spiritual and cultural values In the face of environmental variability, rituals and other cultural observances focused on assuring predictable marine resource abundance Failure of a prime resource such as a salmon run could threaten the extinction of an entire community

While the Alutuq had highly developed technologies for exploiting fishery resources with minimum expenditures of time and labor, strongly conservative values and attitudes toward environmental change and resource use tended to limit overharvesting Property rights to resources such as salmon streams or sea otter hunting areas were vested in clans and villages, who were responsible for stewardship of the resource and its spiritual embodiments (Cooley 1963) Elements of these values remain strong in some GOA communities

Notwithstanding the high value attributed to environmental stability and sustainability, human activity was a significant factor in pre-contact changes in resource abundance in other parts of the Pacific littoral (Jackson et al 2001) Human-caused effects might have extended to the salmon resources exploited by the Alutiq And certainly sea otters were extirpated from the interior waters of Prince William Sound before the arrival of Europeans in the middle of the 18th century (Lensink 1964, Simenstad et al 1978)

The hundred years following contact brought an end to the relative cultural and economic stability European traders and fur hunters possessed weapon

technologies and an organizational infrastructure that allowed them to quickly dominate the small, fragmented Alutiq communities Europeans also brought upland-facing cultural attitudes that reflected diminished concern for the sustainability and stability of ocean resources Whatever constraints against overexploitation may have been afforded by the sophisticated system of Alutiq property rights and clan-based institutional systems, all were quickly brushed aside For resources that attracted European commercial attention, the results were invariably disastrous

The sea otter was the first resource to attract commercial attention Though the trade in pelts was fabulously profitable at the outset, the resource base that made the trade possible quickly shrunk in the face of unremitting harvest pressure to supply Asian and European markets By the time of the transfer of Alaska to the United States, only remnant populations remained (Rogers 1962)

Improved transportation and food preservation technologies in the late 19th century opened the region's salmon resources to markets thousands to tens of thousands of kilometers distant Canned salmon production grew from 1.3 million cases in 1900 to a peak of 8.5 million in 1936, and then collapsed from overexploitation to 1.6 million cases in 1959, the year Alaska became a state Not until the late 1970s did the institutional development of fishery entry limitations make it possible to meet the biological requirements of sustained salmon harvests without dissipating most of the potential economic gains in excess costs

Despite its long and rich history of human occupation and use, the GOA marine environment remains relatively unsullied, at least in the popular understanding As is described in section 7 14 1, the closing years of the 20th century saw significant declines in commercial fishing, marine transportation of oil, and logging Subsistence use of GOA resources partially rebounded after the 1989 oil spill, while tourism and recreational uses of the GOA resources and environment grew

Many of the benefits of the GOA environment are largely non-market, non-use, existence values with heavy emphasis on the future Future existence of endangered populations of wild salmon stocks, future protection of charismatic megafauna such as killer whales and sea otters, and the global marine commons are examples (Brown 2000) Contingent valuation studies conducted in 1990 provided an immediate post-spill benchmark of the economic existence value of GOA resources directly affected by the oil spill (NOAA 1993) No follow up work has been done to confirm subsequent changes in GOA existence values Other economic studies, however, suggest that the public continues to assign high values to the existence of healthy environments, and apply increasingly sophisticated and stringent criteria for evaluating environmental health, particularly in relation to environments viewed as relatively pristine (Whitehead and Hoban 1999) The GEM mission of sustaining a healthy ecosystem and its focus on long-term monitoring have been shaped by the need for a long-term understanding of how human activity shapes the environment, and how human- and non-human-caused environmental change can be distinguished

7 14 1 Socioeconomic Profile of the Region

The bulk of the land area draining into the spill-affected parts of the GOA is found in five boroughs (a county-level governmental unit unique to Alaska), a portion of a sixth borough, and one unorganized census area Just under 400,000 people, 63 percent of Alaska's population, live in this physiographic GOA region as of the 2000 census (about 71,000 people in the region directly affected by the oil spill Prince William Sound, lower Cook Inlet, Kodiak Island, and the Alaska Peninsula) Two to three times that number use the area seasonally for work and recreation An estimated 700,000 out-of-state tourists visit the region each year (ADCED 2002, Northern Economics Inc 2002) Although this area is larger in geographic scope than the GEM region, it reflects the scope of the potential human impacts on the GEM region

The GOA region has grown rapidly throughout the 20th century, but that growth has recently decelerated During the 1990s, population grew by 19 percent and non-agricultural jobs by 26 percent, the slowest decadal rates since the 1930s (Williams 2000)

Most growth in the 1990s has occurred in three urbanized areas Anchorage, the bedroom communities of the southern Matanuska and Susitna valleys, and the urbanized west-central Kenai Peninsula around the cities of Kenai and Soldotna. In the remainder of the region, including almost all the areas immediately impacted by the spill, growth has been slower. Table 7 16 shows how boundaries of the overall region and the subregion directly affected by the spill are defined. During the 1990s, population in the directly affected subregion grew by seven percent, less than half as fast as the population of the GOA region as a whole. The 2000 census found 35,470 people residing in the directly affected subregion (U.S. Bureau of the Census 2001).

Migration to and from the GOA region has been highly volatile High wages and low unemployment in Alaska relative to the Pacific Northwest have generally stimulated net inmigration to the region, while the reverse condition has led to a net population exodus Over the last half century in Alaska and the Pacific Northwest, economic cycles have tended to be out of phase, amplifying the migratory swings

Demographic data for the 1989-99 interval and preliminary information for 1999-00 suggest that the 1990s were the first decade since the 1930s in which newcomers to Alaska failed to replace all of those who left The GOA region is likely to have experienced similar net outmigration over the decade of the 1990s (Williams 2002)

The major reason for the recent net outmigration was the attraction created by the fast-growing economy in the Pacific Northwest and the rest of the nation, and the relatively torpid rate of economic growth in Alaska

Borough or Census Area	GOA Economic Region	Oil Spill (GEM) Region
Anchorage Borough	All	None
Aleutians East Borough	All	None
Kenai Peninsula Borough	All	South and southeast portion Homer Seldovia Port Graham and Seward
Kodiak Island Borough	All	Al!
Lake and Peninsula Borough	Southern portion only Chignik Chignik Lagoon Chignik Lake Ivanof Bay and Perryville	Southern portion only Chignik Chignik Lagoon Chignik Lake Ivanof Bay and Perryville
Matanuska-Sustina Borough	All	None
Valdez-Cordova Census Area	All	Prince William Sound and Cordova census subareas

 Table 7 16
 Representation of Boroughs and Census Areas in Gulf of Alaska

 and Oil Spill Regions
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Over the long term, net migration has been less important to Alaska population growth than the state's chronic excess of births over deaths Average annual net migration in the twenty years between 1979 and 1999 was +1487 persons, while the average excess of births over deaths during the same period was +8928 (Williams 2000)

This persistent excess has been a consequence of three longstanding features of the state's demographics—fertility rates well above the national averages in all racial groups, an unusually large percentage of residents of child-bearing age, and an unusually small share of the population in the older age groups where natural mortality is highest

As is described in subsequent sections, commercial fishing, marine transportation of oil, and the wood products industries in the GOA region have all declined in recent years, while tourism and recreation-related industries have grown, as has federal spending Money transfers to households have also grown, most notably from the state's permanent fund dividend, an annual payment to all residents from earnings on the state's \$25-billion oil-money savings account (U S Bureau of Economic Analysis 2002) Deepening of local economics through support sector growth has played a role too, with Alaska businesses and households buying more locally and importing less from outside the state Continuation of these trends would suggest a continuation of slow economic and population growth (Goldsmith 2001)

The fundamentals of Alaska's economy are likely to remain rooted for some time in the state's natural resources, including the indirect effects of oil revenue recycled through state government As the world's population grows, the demand for access to Alaska's scenic beauty and open spaces of the state is likely to increase as well Beyond the economic effects of increased tourism, the intangible quality of Alaska as a place of wilderness, beauty and a special way of life will continue to attract migrants to the last frontier, increasing pressures of human uses and activities on the GOA environment

7.14.1.1 Prince William Sound-Southeast Kenai

The Prince William Sound-Southeast Kenai (PWS-SEK) region is a coastal belt extending from the mouth of the Copper River on the east, in an arc around Prince William Sound, southwest along the GOA coast, and around the southern tip of the Kenai Peninsula to just past Port Graham and Nanwalek It includes numerous offshore islands The region is mountainous throughout, and three of its four largest communities are located at the heads of deep fiords All of the PWS-SEK region is within the Chugach or Kenai mountains, and the region's boundaries are roughly the same as those of the Chugach Regional Native Corporation Most of its land area is in or adjacent to the Chugach National Forest

Between 1990 and 2000, the population of the PWS-SEK region grew less than six percent, well below the rates in the GOA region or the state In 2000, 12,211 people lived in PWS-SEK, eighty percent of whom live in seven communities. The three largest communities—Cordova (population 2,454), greater Seward (3,430), and Valdez (4,036)—are predominantly non-Native, although Valdez and Cordova are home to Alaska Native village corporations and tribes. Of the five other communities, Chenega Bay (86), Port Graham (171), Nanwalek (177), and Tatitlek (107) are Alaska Native villages, and Whittier (182) is mostly non-Native (U S Bureau of the Census 2001)

Of the seven communities, only Valdez, Whittier and Seward have highway access to the state's main road system Whittier and Seward have Alaska Railroad passenger and freight service Cordova, Valdez, Whittier, Tatitlek, Chenaga Bay, and Seward are served by the Alaska Marine Highway System Except for Valdez, all of the communities grew during the 1990s, although at rates well below the average of the state or GOA region The population of Valdez declined by one percent

The economic base of the seven communities in PWS-SEK is almost entirely resource dependent (Fried and Windisch-Cole 1999a) The Cordova economy is based on commercial fishing, primarily for pink and red salmon Recent declines in the value of landings have been a hardship to the community and to the Prince William Sound Aquaculture Corporation that operates hatcheries in the sound Some biologists have expressed concern that the 600 million or more smolt that hatcheries annually release into the sound and adjacent waters have had a deleterious effect on wild salmon (Hilborn 1992)

In recent years formerly important herring fisheries have been closed due to inadequate stocks However, Cordova has recently benefited from an increase in small-scale tourism, and some cruise ships have visited the port, but the community remains in economic distress Valdez, as the terminus of the trans-Alaska pipeline, depends on the oil industry, but did not suffer seriously from the downsizing that occurred in the industry during the 1990s This is due to additional labor required in Valdez to implement safety and pollution prevention measures adopted in the wake of the 1989 spill The state's official oil production forecast suggests that crude shipments will roughly maintain their current level over the next decade (see section 7 14 2)

Notwithstanding its dependence on oil, the Valdez economy is more diversified than any other community in PWS Valdez has used revenue from its large oil-related tax base in ways designed to stimulate economic diversification. The city invested \$48 million in cargo and port facilities in an attempt to become the major entry port for cargo headed to the Alaska Interior. The scheme has yielded some success. Other investments in seafood processing have also resulted in additional jobs, but their cost-effectiveness remains uncertain. Although the population of Valdez declined slightly in the 1990s, jobs do not appear to have experienced a similar decline (Alaska Department of Labor 2001).

The major growth industry in Valdez is tourism and recreation The number of fishing charter boats operating out of the local small boat harbor doubled between 1997 and 1999 Although cruise ship visits have become an important part of the summer economy, cruise ship visitation in 2002 is anticipated to be around twenty-six cruise ships, down from forty-five in 2001 (Valdez Convention and Visitor's Bureau, personal communication) As cruise ship operators redeploy vessels away from foreign waters, the number of visits is expected to increase

Seward, more than any other community in the GOA region, has transitioned from an economic dependence on fluctuating seafood and timber markets to a visitor and recreation-based economy. Most economic growth since 1990 has been driven by the visitor industry, with employment in trade, services and transportation growing at a 5.9 percent annual rate. The community has capitalized on its road and railroad access to market itself as the major jumping-off point for visits to the Kenai Fjords National Park and Alaska Maritime National Wildlife Refuge. Seward's Alaska SeaLife Center has created another visitor attraction. More than 260,000 cruise ship passengers disembarked at Seward in 2000 (Goldsmith and Martin 2001).

Commercial fishing has trended downward in importance throughout the 1990s, but it remains a significant part of the Seward economy The nearby state prison and other government facilities, including the headquarters for the Kenai Fjords National Park, are also important year-round employers Although a major sawmill was opened in 1993, it never became competitive, and has remained closed since 1994

Although its growing dependence on the seasonal visitor industry has been a concern, in the 1990s Seward developed a diverse and dynamic economy "Over the last decade, it has successfully exploited its location beyond people's expectations" (Fried and Windisch-Cole 1999b)

Whittier depends on transportation and visitor-related businesses The other four small communities in the PWS-SWK region augment commercial fishing, logging, aquaculture, and other cash-based activities with subsistence fishing, hunting, and gathering

7.14.1.2 Western Kenai Peninsula Borough

The western Kenai Peninsula (WKP) region encompasses all the drainages to the northwest of the crest of the Kenai Mountains except those at the southern tip of the peninsula around Port Graham and Nanwalek In addition, it includes the relatively sparsely populated area on the west side of Cook Inlet

In terms of its physiography the area faces Cook Inlet (Barnes 1958), its economy has been closely linked since the 1960s with the oil and gas developments in the inlet and on the nearby uplands

The WKP region is connected to Alaska's main road system, and is only a few hours by car from Anchorage, the state's largest metropolitan area Homer and Kenai have scheduled air service from Anchorage

The region grew twenty-three percent in the 1990s, making it second only to the Matanuska-Susitna Borough as the fastest growing area in the GOA region (Williams 2000) In addition to oil and gas, the WKP economy depends on commercial fishing, sport fishing and other outdoor recreation About 46,500 people live in the WKP region, with over two-thirds living in or near the cities of Kenai and Soldotna Soldotna is the headquarters of the Kenai Peninsula Borough and the Kenai Borough School District, the fourth and first-largest employers in the borough Government at all levels accounts for twenty-three percent of the nonagricultural jobs in the borough, slightly less than the twenty-six percent statewide (Fried and Windisch-Cole 1999)

The southern Kenai Peninsula contains Seldovia (286 persons) and Homer (3946) Homer, on the north side of Kachemak Bay, lies at the southern terminus of the state's main road system, and has been popularized in the colorful writings of author Tom Bodett as "the end of the road "

Homer has attracted a significant number of retirees According to the 2000 census, 10 1 percent of Homer residents are older than 64, the highest percentage of any community in the state The percentage of over-64 residents in the borough as a whole is 7 3 percent, the highest in the GOA region The statewide percentage of residents over age 64 is 5 7 percent (Williams 2000)

7.14.1.3 Kodiak Island Borough

The Kodiak Island Borough occupies the Kodiak Archipelago west of the GOA, and a largely uninhabited strip of the Alaska Peninsula coastline across the stormy Shelikof Strait The borough population in 2000 was 13,913, of which sixty-four percent (8864) lived in the City of Kodiak, the adjacent Coast Guard station, or on the road system nearby The borough population grew six percent between 1990 and 2000, about one-third as fast as growth in the GOA region as a whole (U S Bureau of the Census 2001)

There are six outlying communities, the Alaska Native villages of Port Lions, Ouzinkie, Larsen Bay, Karluk, Old Harbor, and Akhiok, none of which have road connections to each other or the city of Kodiak

The region's only scheduled jet service is to the Kodiak municipal airport, colocated at the US Coast Guard air station The Alaska Marine Highway System serves Kodiak and Port Lions Other communities depend exclusively on air taxis or unscheduled private vessels for access

The economy of the archipelago depends heavily on commercial fishing and seafood processing, with the borough's population swelling in the fishing season (Alaska Department of Labor 2001) Kodiak is one of the world's major centers of seafood production and has long been among the largest ports in the nation for seafood volume and value of landings

Village residents largely depend on subsistence hunting and fishing Kodiak Island also has a growing recreation and tourism economy and is home to a stateowned commercial rocket launch facility that held its first successful launch in 1999 The U S Coast Guard Station, with 1,840 permanent residents in 2000, is a major employer

7.14.1.4 Alaska Peninsula

The Alaska Peninsula is on the western edge of the northern GOA, and encompasses the Aleutians East Borough and the southern part of the Lake and Peninsula Borough The total population of the region is 3,153 Sand Point, with 952 residents, and King Cove, with 792, are the largest communities (U S Bureau of the Census 2001) Aside from government spending, the cash economy of the area depends on the success of the fishing fleets

Five smaller communities on the south side of the Alaska Peninsula lie within the area directly affected by the *Exxon Valdez* oil spill. Chignik, Chignik Lagoon, Chignik Lake, Ivanof Bay, and Perryville The population of this area is 456, but may double during the fishing season All five of these communities are in the Lake and Peninsula Borough and served by scheduled air taxi service Chignik is also served by the Alaska Marine Highway ferries on a seasonal basis

Sand Point, Chignik, Chignik Lagoon, and King Cove serve as regional salmon fishing centers In addition to salmon and salmon roe, fish processing plants in Chignik produce herring roe, halibut, cod, and crab About half the permanent population of these communities is Alaska Native

Chignik Lake, Ivanof Bay, and Perryville are predominantly Alaska Native villages and maintain a subsistence lifestyle, relying on salmon, trout, marine fish and shellfish, crab, clams, moose, caribou, and bear Commercial fishing provides

cash income Many residents leave during the summer months to fish or work for fish processors elsewhere in the region

7.14.1 5 Anchorage/Mat-Su Urban Area

Anchorage, located at the head of Cook Inlet, and the Matanuska-Susitna (Mat-Su) Borough just to the north of Anchorage, constitute the economic, financial and industrial capital of the state Although outsiders often conceive of Alaska as sparsely populated, the state is also highly urban, and becoming more so In 2000, fifty-one percent of Alaska's population lived in the Anchorage/Mat-Su metropolitan area, up from forty-eight percent a decade earlier Between 1990 and 2000, Anchorage/Mat-Su added 53,584 residents, more than the 2000 population of Juneau and Ketchikan combined, the state's third and fourth largest urban areas (U S Bureau of the Census 2001) Although Anchorage/Mat-Su is situated outside the oil spill subregion, its geographic proximity suggests that growth there will—as it has in the past—produce environmental impacts in the area directly affected by the oil spill This is likely to be particularly true where the surface transportation connections already exist, as they do to Seward, Whittier, and Valdez

No economic development is likely to occur anywhere in the state without links to Anchorage It serves as headquarters for the state's major financial institutions, its oil companies, major media outlets, largest labor unions, religious organizations, and most of its federal military and civilian government bureaucracy The Anchorage airport is the major funnel through which most of the state's visitor traffic and a significant share of its seafood harvest pass

Many Anchorage/Mat-Su residents work in other parts of the state, especially construction workers, oil workers, and fishermen (Fried 2000) These workers provide Anchorage with a direct source of income earned in other parts of the state With the most diversified economy in the state, Anchorage is better positioned than any other community in the state to maintain growth in the face of economic hardship

7 15 Economics and Ecological Impacts of Human Use Activities in the Northern Gulf of Alaska

"At first glance, Prince William Sound presents an aspect of pristine and untrammeled wilderness, and this is one of her major delights Anchored in a sechided cove or ascending a trackless ridge, it is easy to imagine oneself as the first explorer Yet, a closer examination of the shoreline quickly reveals subtle signs of former habitation Decayed, sawed off stimps line the shores – witness to former hand-logging operations The logs were used for cabins, firewood, fishtraps, cannery pilings, mining timbers, rath oad ties, for farm pens and

even ship building If one rummages around the moss, alder and devils club along the shores, virtually every bay reveals the rotted foundations of some old cabin or for pen Abandoned, frail human structures do not last long in this damp climate and under such heavy winter snow-loads And perhaps this is as it should be "

fiom Cruising Guide to Prince William Sound Alaska Jim and Nancy Lethcoe

This quote from a book about sailing in Prince William Sound is a fitting introduction to a section on human use activities in the northern GOA At least a portion of the public has a perception that, prior to the *Exxon Valdez* oil spill, the region had little human impact To the contrary, there has been a succession of different types of human habitation and economic activities in the northern GOA Many of these activities had a high level of impact on both the environment and other users and residents of the region

The earliest inhabitants of the region were nomadic Asian explorers crossing the Bering Land Bridge and spreading southward The dates of first human occupation in Prince William Sound are not known, but radio carbon dating estimates go as far back as 205 AD

Beginning in the 1700s, the northern GOA was used by a succession of explorers and developers Russian and English fur traders in the 1700s were followed by development of fish canneries in the late 1880s The first fox farms were developed in 1894 at Seal Island Mining activity in the region also developed in the latter part of the 1890s In 1897, Klondike gold was discovered, opening up the region as a gateway to Alaska's interior Mining began in the northern GOA in 1896 The communities of Ellamar and Latouche were built to develop copper mines The Kennicott copper mine was developed around 1905 and resulted in the Valdez to Copper River and Northwestern Railway in 1911

Mining and fox farming gradually declined, and military activity during World War II added a new type of activity to the region Whittier remained an active military port until 1960 Commercial fisheries were developed and expanded in the 1950s, 1960s and 1970s The late 1970s were dominated by development of the trans-Alaska pipeline and the terminal at Valdez The 1980s and 1990s have shown a large expansion in recreation and tourism

7 15 1 Commercial Fishing

Commercial fishing is by far the predominant human activity in the northern GOA and is thought at this time to have the potential for the most significant impacts on the GOA ecosystem Within the GOA, the major commercial fisheries are salmon, Pacific herring, pollock, cod, halibut, and shellfish Tens of thousands of individuals participate in these fisheries

The period before the 1989 oil spill was a time of relative prosperity for many commercial fishermen Since 1989, commercial fishing in the northern GOA has undergone dramatic changes as a result of changes in salmon markets, declining abundance of other fish stocks, institutional changes associated with fishery "rationalization," harvest limitations designed to protect endangered species, and other factors

Communities within the GEM region have varying levels of dependence on commercial fishing The communities most dependent on commercial fishing are Cordova, Kodiak (and the outlying six villages within the Kodiak Island Borough), Chignik, Chignik Lagoon, Sand Point and King Cove Commercial fishing is an important but less dominant economic sector in the road accessible communities of Valdez, Whittier, Seward, and Homer

7.15.1.1 Salmon

Commercial fishing for pink, sockeye, sockeye, chum, coho and chinook salmon has long been a mainstay of the northern GOA commercial fishing industry Salmon are harvested by seine, drift gillnet and set gillnet gear Pink salmon are the dominant species in PWS, contributing over eight percent of total salmon landings by volume and contributing the largest share of ex-vessel value In Cook Inlet, Kodiak and the Alaska Peninsula, sockeye are by far the dominant species

PWS exhibits a pattern of odd-even run strength for pink salmon that persists even with the influence of hatchery production The very low catch levels in 1992 and 1993 were due to closures associated with the *Exaon Valdez* oil spill Harvests since then have increased, but unlike most other Alaska fisheries, are now highly dependent on hatchery returns

Non-profit hatcheries have operated in Prince William Sound since the mid 1970s The Prince William Sound Aquaculture Corporation (PWSAC) began operations in 1976 and operates five hatcheries the W F Noerenberg, Armin F Koernig, Cannery Creek, Main Bay and Gulkana facilities The Valdez Fisheries Development Association has operated the Solomon Gulch hatchery since 1979 (Kron 1993) Much smaller salmon enhancement programs operate in Cook Inlet and Kodiak

Returns of both wild and hatchery salmon fluctuate greatly from year to year During the period 1960-1976, when the pink salmon fishery was supported wholly by wild stocks, the average pink salmon catch in Prince William Sound was 3 3 million fish (Eggers et al 1991) The pink salmon harvest during this period fluctuated from 01 to 73 million fish Since hatchery releases were begun, the average pink salmon catch has been 197 million

In 2001, 76 percent of the total pink salmon return was harvested by PWSAC to cover the costs of hatchery operations In 2002, the percentage was reduced to fiftyfour percent in an attempt to make more of the salmon resource available to commercial fishermen PWSAC has significant long-term financial obligations, with over \$30 million in outstanding state loans

Salmon prices and market demand for salmon produced in the northern GOA as well as other parts of Alaska are at relatively depressed levels The primary reason for the market tiend has been a huge increase in world production of farmed salmon Alaska salmon face both price and quality competition from salmon originating in Chile, Norway, Canada and other farmed salmon-producing countries

7.15.1.2 Herring

Herring are harvested predominantly for sac roe for export to foreign markets Quotas are established for each discrete stock Herring fisheries in the region are currently at low levels In the 2000 season, Prince William Sound and Cook Inlet were both closed due to low abundance Limited herring fisheries occurred in Kodiak and the Alaska Peninsula

7.15.1.3 Shellfish

Most of the shellfish fisheries in the northern GOA are closed to commercial fishing due to inadequate stocks Within PWS, no crab harvests have been permitted for several years, and there is no evidence of recovery The decline of PWS crab is thought to be associated with the growth of the sea otter population, which preys heavily on shellfish (Trowbridge 1995)

Miscellaneous fisheries for PWS scallops, Cook Inlet scallops and hard shell clams, and Kodiak sea cucumbers and dungeness crab offer limited opportunities for fishermen

7.15.1.4 Groundfish

GOA groundfish catches have ranged from a low of 135,400 metric tons in 1978 to a high of 352,800 metric tons in 1984 The 2001 groundfish harvest was 181,400 metric tons (NPFMC 2001) Pollock has been the dominant species in the overall catch, followed by Pacific cod and sablefish Groundfish abundance in the GOA has been relatively stable, rising slowly since the mid 1980s The estimated long-term annual yield for GOA groundfish is about 450 thousand metric tons The recent five-year average yield has been about 230 thousand tons per year The wide disparity between the potential and recent yield is due to fishing restrictions imposed by the North Pacific Fishery Management Council to reduce incidental catches of Pacific halibut A major portion of the GOA groundfish biomass consists of arrowtooth flounder, with little or no current commercial value A 1989 National Marine Fisheries Service trawl survey estimated that arrowtooth flounder made up

the greatest proportion of total biomass at nearly every site surveyed (NPFMC 2001)

A specific Prince William Sound pollock quota has been established since 1995 The sound's pollock harvest has averaged 1,800 metric tons since 1995 This harvest occurs mostly during the winter months and is processed in Cordova and Seward

7.15.1.5 Halibut

The Gulf of Alaska is managed by the International Pacific Halibut Commission as Area 3B The 2001 harvest quote for Area 3B was 164 million pounds

Halibut harvested in the central and western Gulf are delivered to the ports of Cordova, Homer, Seward, Valdez and Whittier In 2001, 12.2 million pounds of halibut was landed in Homer, making it the number one port in landings among the entire west coast Most of the halibut landed in Homer is iced, loaded into refrigerator vans and trucked to the Pacific Northwest for distribution to markets

7.15.1.6 Future Resource Outlook and Issues for Commercial Fisheries

Commercial fisheries in the GEM area have been in a state of dynamic flux for the past several years Among the ongoing issues affecting commercial fishers are the following:

<u>Environmental and oceanographic conditions</u> Ocean survival is a key factor in regulating the magnitude of returning salmon and the level of harvest. Since the 1970s, the ocean environment has been favorable off Alaska, and salmon runs increased. However, there are indications that North Pacific circulation patterns may be shifting away from conditions favorable for Alaska salmon production (Mantua et al 1997). If the warm water regime off Alaska reverses to a cold regime, natural salmon production will decrease throughout Alaska to levels observed in the 1960s. Hatchery production and other salmon enhancement efforts may aid in maintaining harvests if natural production declines, but the outlook remains uncertain. GOA pollock and cod stocks are likely to decrease over the next several years, while most other GOA groundfish remain stable.

A major ecological concern with all types of removals by fishing activities is the sustainability of fish stocks, which could be affected by directed fisheries or as a result of discarded bycatch in other fisheries and high seas interception. This concern drives responsible fishery management. The predominant fishery stocks historically fluctuate because of natural variability and climate cycles, and for that reason, harvest rates are set at sustainable fractions of the available biomass. However, concern still exists that setting harvest rates without a complete understanding of those fluctuations could lead to unintentional overharvest, resulting in population declines that could take years to rebound.

In addition, bycatch may have unintended consequences on non-targeted fish populations In many fisheries, observers monitor the bycatch In addition, bycatch is often only a small fraction of the overall mortality However, bycatch is not monitored in all fisheries, and may be significant in some Another ecological concern with all types of fishing is the removal of marine nutrients (nitrates, phosphates, iron) that are key to sustaining the long-term productivity of watersheds (Finney et al 2000) Fishing for a dominant anadromous species such as salmon may lower the productive capacity of a watershed not only for salmon, but for a wide range of plants, fish, and mammals that are known to depend on marine nutrients When combined with the loss of nutrients associated with development of riparian (river and other waterfront) habitats and wetlands, the loss of marine nutrients may contribute to oligotrophy or "starvation" of the watershed Unfortunately, not enough monitoring data on marine nutrients in tributaries of the GOA are available to understand the degree to which oligotrophication is occurring

A third ecological concern with fishing is the potential for unintentional degradation of habitats and attendant losses of plant and animal species Sportfishing activities in watersheds have substantially degraded some riparian habitats in Southcentral Alaska, resulting in lost vegetation, lost fish habitat, and siltation, and necessitating walkways and management restrictions Various types of marine fishing methods and gear, such as pots and bottom trawls (very large bag-shaped nets), also have the potential for degrading sea-bottom habitat and reducing populations of sedentary species such as corals and seaweeds

Protection has already been afforded to marine habitats in some sensitive areas by excluding gear types that are thought to be injurious to habitat For example most state waters are closed to bottom trawling In the eastern GOA, both state and

More information on how to define critical marine habitats is essential to balancing fishing opportunities and protection of habitat federal waters are now closed to trawling and dredging in part to protect coral habitats from possible trawling impacts There are numerous trawl-and-dredge closure areas near Kodiak Island, the Alaska Peninsula, and the Aleutian Islands But not all areas of the Bering Sea and GOA (especially those that have sandy and sediment bottom types) are vulnerable to trawling impacts Given the amount of marine habitats already subject to closure,

more information on how to define critical marine habitats, a possible role for GEM, is essential to balancing fishing opportunities and protection of habitat

Commercial fishing also has the potential to affect other elements of the marine ecosystem, such as bird and marine mammal populations Effects result either directly, through entanglement in fishing nets or disturbance to haul-outs and rookeries, or indirectly, through impacts on food supplies Areas where marine mammals feed and that are adjacent to their haul-out areas have been closed to commercial fishing in parts of the Bering Sea, Aleutian Islands, and GOA A recent National Marine Fisheries Service (NMFS) Biological Opinion (NMFS 2000) concludes that lack of food is the reason why the endangered Steller sea lion is not recovering from serious declines in the GOA and Bering Sea. On the basis of this opinion, NMFS has severely limited fixed-gear and trawl fishing for several groundfish species, a major food source for the Steller sea lion. However, this

opinion has been extremely controversial, and several independent teams of science reviewers have concluded that there is no evidence that sea lions are nutritionally limited and no evidence that fisheries are causing prey depletion

Salmon fisheries in the GOA are notable because hatcheries produce the majority of some salmon species in some areas and, in specific fisheries, the majority

of salmon harvested Billions of juvenile salmon are released annually from hatcheries in three areas within the northern GOA Cook Inlet, Kodiak, and PWS Within this region, 56% of the salmon in the traditional commercial harvest were of hatchery origin in 1999 The percentage is higher if cost-recovery fisheries are also included In PWS in particular, hatchery production provides a majority of the pink and chum salmon harvested and a substantial

Information on the interactions between hatchery and wild fish appears to be essential to long-term fishery management programs

fraction of the sockeye and coho salmon harvested In 1999, hatchery pink salmon contributed 84% of the number of pink salmon harvested by commercial fisheries in PWS

Ecological concerns related to hatcheries include reduced production of wild fish because of competition between hatchery and wild salmon during all stages of the life cycle, loss of genetic diversity in wild salmon, and overharvest of wild salmon during harvest operations targeting hatchery salmon Information on the interactions between hatchery and wild fish in specific locations, as well as on the impact of salmon produced in hatcheries in both Asia and North America on food webs in the GOA, appears to be essential to long-term fishery management programs

<u>Resource and Legal Issues</u> Actions taken under the Endangered Species Act (ESA) as a result of depressed levels of Steller sea lions have created economic hardship for commercial groundfish fishers from several communities, particularly Kodiak, King Cove and Sand Point The National Marine Fisheries Service developed a biological opinion that pointed to commercial fishing as one of the factors in declining numbers of Steller sea lions Regulations designed to protect the species by limiting groundfish fishing were put in place in 2002 The status of harbor seals and sea otters is also uncertain, and ESA actions in relation to these species could create additional difficulties for fishers and marine resourcedependent communities

<u>Regulatory Actions</u> The North Pacific Fisheries Management Council (NPFMC) is considering a groundfish "rationalization" program for the GOA groundfish fisheries A similar program covering Bering Sea fisheries established individual fisheries quotas (IFQs), and made other major changes to fisheries management The fishing interests in the northern GOA will be profoundly affected by the decisions of the NPFMC on these issues

Since its implementation several years ago, the NPFMC's IFQ share system has spread halibut and sablefish landings over a longer period of time, and as a result,

the fresh market has largely displaced frozen production Road-accessible Homer is now the largest halibut landing port on the west coast, with over 10 million pounds delivered per year Most of the halibut landed there are placed in iced totes and delivered to processing and distribution companies in the Pacific Northwest via refrigerated van

Commercial Fishing Summary

Reasons for monitoring Many commercial fisheries in the northern GOA are at very depressed levels or are currently closed. Interactions with protected species or species that have a subsistence priority may create new problems for commercial fishing in the future. Future activities can have significant ecological impacts.

Type of impacts Commercial fishing activities create resource conflicts and impact other user groups through gear loss and discard, oil and fuel spills Resource competition can affect other fish, bird and marine mammal populations Removal of marine nutrients can affect productivity of watersheds Fishing gear and techniques may degrade habitat Hatchery production and salmon farms can have negative environmental effects

Who is monitoring ADF&G is the primary agency for monitoring commercial fishing effort and harvests in state waters The National Marine Fisheries Service has primary responsibility for monitoring fishing effort and harvests in offshore marine waters (three to 200 miles offshore) The International Pacific Halibut Commission has primary responsibility for monitoring effort and harvests for halibut

Regulatory Authority The Alaska Board of Fisheries has regulatory authority for fisheries that occur in state waters The North Pacific Fishery Management Council has regulatory authority for fisheries that occur in offshore marine waters Recommendations from the NPFMC require action by the Secretary of Commerce to take effect

7 15 2 Recreation/Tourism

Recreation and tourism are the fastest growing economic activities and human uses in the northern GOA, but incomplete data leave many uncertainties regarding the characteristics of use and rates of growth

7.15.2.1 Commercial Recreation on Excursion Vessels

Commercial excursion boats operating out of Valdez, Whittier, Seward, Homer and, to a lesser extent, Kodiak provide sightseeing trips for visitors This group is comprised of several large companies that take most of the passengers, with smaller companies providing services to a much smaller sector of the market According to a 1990 survey of excursion boat passengers visiting the Kenai Fjords National Park itself, most boat passengers (77 percent) were from other states (72 percent) or other countries (5 percent) (Kenai Fjords National Park 1990) The 5-year data series includes only passengers traveling into Kenai Fjords National Park, and excludes excursion boat passengers that stay within Resurrection Bay This limited data series is shown in Table 7 17 below

-	-
1996	71 243
1997	67 934
1998	81 538
1999	93 266
2000	86 963
2001	85 047

Table 7 17	Kenaı Fjords	Excursion	Boat I	Passengers
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Source Kenai Fjords Visitation Report, Mike Tetreau, personal communication

Excursion boat visitation appears to have declined slightly in 2000 and 2001, but this may reflect a trend toward more Resurrection Bay trips as excursion operators attempted to accommodate the demand for shorter trips typically sought by cruise ship passengers As limited as the Kenai Fjords' data may be, it is superior to the situation for other areas in the northern GOA, where data is completely lacking

7.15.2.2 Trends in Sport Fishing Effort

Data on sport fishing effort is also limited ADF&G data shows the use of private boats for fishing out of Seward and Valdez increased steadily from 1988 through 1995, dropped sharply in 1996, and has increased slowly since that time (ADF&G various years) Because ADF&G changed the way these data were compiled for the years after 1995, they are of only limited usefulness for long-term trend analysis

Overall sport fishing effort within the northern GOA is centered on the roadaccessible areas Cordova, Seward and Homer are the most popular ports for marine fishing Whittier and Kodiak are less popular ports for marine fishing Freshwater angling is concentrated along the road-accessible areas of Cook Inlet and the Susitna River watershed The number of resident sport anglers in southcentral Alaska has been on a slightly decreasing trend since 1992, but the total number of anglers has increased due to the growth in the numbers of non-resident anglers Non-resident licenses sold in Alaska increased 46 percent between 1987 and 1997 (see Figure 7 16) The ADF&G has a study underway to investigate the reasons for the declining number of resident anglers (ADF&G various years)

7.15.2.3 Cruise Ships

Cruise ships dock at five ports in the greater GOA region Anchorage, Homer, Seward, Valdez and Whittier Seward dominates in cruise ship dockings Cruise ship patrons typically take passage on either a northbound or southbound run, choosing to fly to or from Anchorage on the reverse leg of their trip Seward has the important features of proximity to Anchorage as well as access to the Kenai Fjords National Park and the ease of combining a rail or scenic bus ride segment Seward



Figure 7.16 Alaska sport fishing licenses: 1987 and 1997

also offers considerable time savings for cruise ships traveling to or from the Pacific Northwest, compared with travel to the Port of Anchorage. Cruise ship docking in Seward can offer passengers a one-week turnaround schedule via return air. The growth of cruise ship use in the oil spill region has been well documented (Figure 7.17).

Cruise ship visitors are non-consumptive users of resources within the northern GOA as they move from port to port, but may become consumptive users when in port. Short-duration sport fishing trips are a popular activity for passengers while in port. Recreation and tourist users, including cruise ship users, can be compatible or incompatible with other uses and groups of users, based on their use characteristics. For example, cruise ship passengers are probably not affected by seeing groups of boaters or kayakers. However, boaters and kayakers may have their experience adversely affected by too many contacts with cruise ships.

Cruise ships often carry more people than populate many Alaska towns. One well known impact of cruise ships is air and water pollution. Cruise ships also affect other user groups by their presence in the northern GOA and, in some areas, by competing with local residents for sport fish harvests. In July 2001, Alaska enacted a law to regulate cruise ship and ferry wastewater discharges in marine waters. The new law sets discharge limits for greywater (sink, shower and galley water) and blackwater (treated sewage) for fecal coliform and suspended solids. It limits discharge to areas at least one mile offshore and requires vessels to be moving at least six knots during discharge. Sampling of discharges is required, and the Alaska Department of Environmental Conservation (ADEC) has independent authority to perform additional sampling. Finally, the new law requires improved



Figure 7.17 Cruise ship visitors to Seward and Valdez 1991 through 2001 Source: Seward Chamber of Commerce and Valdez Convention and Visitors Bureau, 1997-2001. (McDowell Group 1991-1997)

record keeping and reporting of vessel disposal of wastewater, hazardous waste and garbage.

Seward will continue to be the major southcentral Alaska port for cruise ship passengers to embark and disembark. Valdez anticipates a sharp decline in cruise ship passengers in 2002 due to Holland America ending its port calls in that community. The cruise ship visitation in Valdez in 2002 is anticipated to be around twenty-six cruise ships, down from 45 in 2001 (Valdez Convention & Visitors bureau, personal communication).

7.15.2.4 Recreation/Tourism Issues

Sport fishing within the northern GOA has created local environmental damage in some areas by concentrating activity in fragile areas. One area of major concern is the Kenai River, famous for its king and sockeye sport fishing. ADF&G evaluated these impacts along the Kenai River in 1994 (ADF&G 1994) to provide a baseline for future assessments. Sport fishing can also contribute to localized depletion of fish stocks.

Increased hiking and camping on coastal areas and riverbanks can lead to trampling erosion and related impacts on local water quality. The Chugach National Forest is currently completing an analysis of remote recreation carrying capacity in areas around Prince William Sound that may provide information on use impacts and appropriate levels of use. The Alaska Division of Parks completed an analysis of carrying capacity for the Kenai River in 1991 which identified areas of the river where crowding was diminishing user satisfaction for fishing and other recreational experiences (Alaska State Parks 1993). In October 2001, the North Pacific Fishery Management Council recommended an individual fisheries quota (IFQ) program for commercial charter operators fishing for halibut Requiring new charter operators to purchase halibut shares to take out sport charters may tend to shift sports fishing effort toward currently nonlimited species, such as Pacific cod, ling cod and rockfish, creating localized depletions and potential resource concerns If commercial halibut charter prices increase as a result of the IFQ program, use of the resource by non-charter private boats may increase in reaction Impacts on the resource base could be significant

The growing use of jet skis for recreational use and their potential for disturbing nesting waterfowl has led the Alaska Department of Fish and Game (ADF&G) to ban jet ski use in Kachemak Bay

Some residents of Prince William Sound communities expressed concern with a potential huge flood of new recreational users to the region as a result of completion of the Whittier tunnel, providing road access to the sound and potential impacts to shorelines, tidelands and nearshore waters, as well as the fish and wildlife populations that rely on these habitats The tunnel opened on June 7, 2000 and had a total of 88,000 vehicles for the remainder of that year In 2001, the Whittier tunnel vehicle traffic totaled 85,772 through December 17th (Gordon Burton, personal communication) The initial level of traffic through the Whittier tunnel is much lower than anticipated by the Alaska Department of Transportation and Public Facilities Local residents speculate that the use tolls imposed after the first year of operation have discouraged users

Recreation/Tourism Summary

Reasons for monitoring Immediate impacts of high use levels on habitat as well as localized depletion of fisheries resources Although recreational users may impact other user groups, areas of conflict are largely unstudied

Type of impacts Potential for resource depletion, damage to fragile habitat, disturbance to wildlife on rookeries and haulouts, competition among user groups, water quality degradation from discharges and spills

Agencies managing for a subsistence priority can create impacts on other user groups using resources within the northern GOA

Who is monitoring ADF&G is the primary agency for monitoring sport fishing effort and harvests The U S Forest Service monitors uses within Chugach National Forest The National Park Service monitors use levels within the Kenai Fjords National Park

Regulatory Authority The Alaska Board of Fisheries and Board of Game have regulatory authority over sport fishing and hunting within state lands and waters

The North Pacific Fishery Management Council has made a recommendation for new regulations dealing with halibut charter vessels

The US Coast Guard has enforcement authority for vessel operations in marine waters

7 15 3 Oil and Gas Development

The oil and gas industry is a major economic force in Prince William Sound (PWS) and Cook Inlet Crude oil from the Alaska North Slope is transported by pipeline to Valdez, where it is loaded onto tankers and shipped to the continental United States, abroad, and to a refinery on Cook Inlet, near Kenai Whatever their destination, tankers carrying this oil traverse PWS and the GOA on their journey (Fried and Windisch-Cole, 1999)

The number of tanker voyages from the Port of Valdez has declined from 640 in 1995 to 411 in 1999, partly due to a four percent increase in the average load per vessel, but mostly as the result of reduced North Slope production (ADEC 2000)

Annual shipments through PWS peaked at 705 million barrels in 1988 and have declined in every year since Shipments in 2001 are estimated at 366 million barrels, almost exactly one-half of what they were at the peak The annual rate of change in shipments has varied from -10 percent in 1998-99, when oil prices were low, to -1 percent last year (2000-01), when prices were high The state of Alaska's official oil production forecast issued in December 2001 predicts that North Slope production will increase nine percent in 2002, and then remain relatively constant through 2009 (see Figure 7 18) The forecasters acknowledge, however, that unexpected changes in oil prices could shift the trajectory up or down (Alaska Department of Revenue 2001)



Figure 7 18 PWS oil shipments

Commercialization of North Slope natural gas reserves—estimated at more than 90 trillion cubic feet—could cause PWS tanker traffic to increase Under one concept, proposed more than 30 years ago and still popular in Alaska, a gas pipeline would be built parallel to the oil line, terminating at a liquefied natural gas (LNG) facility near Valdez LNG from the plant would be exported in specially built tankships to the Far East, Mexico, or the US West Coast A similar, but much smaller LNG plant has operated in Cook Inlet since 1966

A separate gas-to-liquid (GTL) commercialization proposal would transform the gas to methanol liquid or a chemically related product that would be shipped to Valdez in the existing trans-Alaska oil pipeline (Alaska Highway Natural Gas Policy Council 2001)

Three recent studies, sponsored separately by the North Slope gas owners, the state, and an independent energy consulting firm, concluded that the GTL and LNG proposals (including a pipeline project terminating at an LNG plant in northern Cook Inlet) are likely to be less feasible than alternatives in which the gas is shipped by pipeline through Canada to markets in the continental United States (Alaska Highway Natural Gas Policy Council 2001, Purvin & Gertz, Ltd 2000, Brown 2002) Volumes of gas to be shipped under the various commercialization proposals range up to 2.2 trillion cubic feet per year, equivalent in energy content to roughly 350 million barrels of oil (Purvin & Gertz, Ltd 2000) In most applications, substitution of gas for oil reduces greenhouse gas emissions by about fifteen percent No project for commercializing North Slope gas has yet attracted commitments for the \$7 billion to \$20 billion in investment expected to be required

Megaprojects do not have an exclusive franchise on potential petroleum developments in the GOA area The first producing oil wells in Alaska were at Katalla, southeast of Cordova Small-scale production continued there from 1902, until destruction of the local refinery by fire in 1933 The Chugach Alaska Corporation, owner of much of the Katalla oil and gas acreage, believes that modern technology may make the Katalla oil resource economical to redevelop (Chugach Alaska Corporation 2001)

Modern oil development in Alaska began in 1957 in the Cook Inlet basin, with discovery of oil at the Swanson River field in the Kenai National Wildlife Refuge In 2001, the basin produced eleven million barrels of oil, about three percent of the volume coming from the North Slope (Alaska Oil and Gas Conservation Commission 2001)

Most of the oil and much of the natural gas produced from the Cook Inlet comes from offshore platforms Underwater pipelines transport oil and gas to terminals on both sides of Cook Inlet Much of Cook Inlet oil production is delivered to a local refinery in Nikiski, north of Kenai, for processing

State forecasters expect oil production from the Cook Inlet basin over the next several years to increase, reaching fifteen million barrels per year in state fiscal year 2003-04 An aggressive state leasing program initiated in 1999, together with planned increases in federal offshore lease offerings, could stimulate additional new production thereafter (Alaska Department of Revenue 2001)

Much of the new exploration in Cook Inlet, however, has been targeted toward natural gas Cook Inlet gas has provided low cost energy to the Anchorage metropolitan area since 1962, and since the late 1960s has provided energy and feedstock to an LNG plant and a large fertilizer manufacturing facility at Nikiski The bulk of the region's electricity comes from gas-fired generation

In recent years Cook Inlet gas sales have ranged close to a quarter trillion cubic feet The region's utilities and major industrial users believe that additional discoveries or imports from the North Slope will be needed in the next decade to sustain current industrial gas uses and meet the growing demand for utility gas and electric generation (ADNR 2002)

Major concerns about oil and gas development in the northern GOA include the potential for oil spills from vessel traffic, such as the 1987 T/S *Glaciei Bay* spill in Cook Inlet and the 1989 EVOS Small chronic spills, pipeline corrosion and subsequent leaks, disposal of drilling wastes and potential impacts on water quality, and the introduction of exotic species from ballast waters are other major concerns Only six thousand gallons of crude oil were reported spilled in the region from 1998 to 1999 (ADEC 2001)

Oil producers, shippers, and refiners are required to have contingency plans detailing response capabilities and specific response actions in the event of a spill In addition, the Oil Pollution Act of 1990 authorized regional citizens advisory groups in PWS and Cook Inlet to oversee oil and gas activities These groups, along with state and federal agencies, maintain oversight of oil industry operations in their respective regions

Oil and Gas Development Summary

Reasons for monitoring Increased North Slope development could result in increased tanker traffic and more underwater pipelines. Cook Inlet production is mostly offshore or near the shore and could have impacts on marine system.

Type of impacts Potential for oil spills from vessel traffic small chronic spills pipeline corrosion and subsequent leaks, disposal of drilling wastes, introduction of exotic species in ballast waters

Who is monitoring ADEC and the U S Coast Guard require oil producers shippers and refiners to have contingency plans detailing capabilities and planned actions in response to spills Regional citizens advisory councils in Prince William Sound and Cook Inlet provide citizen oversight and conduct some monitoring activities

Regulatory authority US Coast Guard regulates tanker traffic US EPA and ADEC are primary agencies regulating activities because of potential impacts on water quality

7 15 4 Subsistence

Subsistence is an important traditional activity practiced by residents of northern GOA communities to provide food and cultural enrichment Fifteen predominantly Alaska Native communities in the GEM region, with a total population of about 2,200 people, rely heavily on harvests of subsistence resources such as fish, shellfish, seals, deer, and waterfowl Subsistence harvests in 1998 varied among communities from 250 to 500 pounds per person, indicating strong dependence on subsistence resources Subsistence activities also support the culture and traditions of these communities Many families in other communities also rely on the subsistence resources of the spill area

In addition to the cultural aspects of subsistence, its economic importance comes from import substitution Rural residents are able to rely on wild foods rather than food imported into the region Dependence on subsistence production is typically higher in remote areas and lower near population centers, although there are exceptions to this general trend

Knowledge of subsistence patterns and consumption largely relies on focused household surveys conducted by the ADF&G's Subsistence Division The division's analysis and monitoring focuses on subsistence production, consumption, sharing patterns and species of concern Subsistence studies are typically conducted at irregular intervals, often oriented towards a specific management issues or need, such as the *Exaon Valdez* oil spill The household studies provide a cross-sectional profile of use patterns at a particular time Due to the focus on oil spill impacts and the availability of funding, several subsistence studies conducted in communities across the oil spill region over the past ten years have provided a wealth of data and information The declining frequency of subsistence studies suggests that future changes in use patterns within northern GOA communities may not be as well documented

ADF&G researchers have developed village contacts who provide accurate tracking of subsistence harvests of salmon, seals, sea lions, marine mammals and halibut It is more difficult for ADF&G to track subsistence harvests of marine invertebrates and marine fish, so there is a much lower level of confidence in the estimated use levels for these species

In a recent report funded jointly by the Minerals Management Service (MMS) and ADF&G, researchers analyzed subsistence patterns for communities within the area affected by the *Exion Valdez* oil spill (Fall et al 2001) The communities analyzed were Chenega Bay, Cordova, Tatitlek, Valdez, Kenai, Nanwalek, Port Graham, Seldovia, Akhiok, Karluk, Kodiak City, Larsen Bay, Old Harbor, Ouzinkie, Port Lions, Chignik, Chignik Lagoon, Chignik Lake, Ivanof Bay, and Perryville

The study tracked wild food harvests measured in pounds per capita before and after the *Exxon Valdez* oil spill, producing the following findings

- Subsistence production averages over 300 pounds per person pei year throughout the region In predominantly Native communities, subsistence production averages 352 pounds annually per person In Cordova, subsistence production averages 200 pounds per person annually and in Kodiak, it averages 148 pounds per person
- Subsistence production uses nearly seventeen different types of resources per household
- The studies show a very high participation rate in subsistence harvests and use, particularly in predominantly Native communities where ninety-nine percent of residents used subsistence resources
- Subsistence production is often distributed through an extensive network of sharing In predominantly Native communities, 87 5 percent of households received resources and 78 3 percent of households gave away resources
- Following the *Exaon Valdez* oilspill, there was an immediate decline of over fifty percent in subsistence harvests Equally important as the decline in production was the reduction in the range of resources used At first the reduction was due to fear of oil contamination, and later, due to the scarcity of resources
- The impacts of the oil spill caused a disruption in sharing and teaching of children and a temporary increase in household income associated with spill cleanup activities during the year following the spill
- In the years from 1990 to the present, there has been a gradual rebound in subsistence production from the EVOS communities But, communities in Prince William Sound have been slower to rebound than areas outside the sound
- Since the EVOS, several communities have increased their dependence on fish and reduced their dependence on marine mammals and shellfish

In addition to ADF&G's Subsistence Division and the Federal Subsistence Board, others monitoring subsistence uses and harvests of certain species include the Alaska Board of Fisheries and the North Pacific Fishery Management Council The Council recently completed an analysis of impacts relating to subsistence halibut and has recommended new regulations for that species

The National Marine Fisheries Service (NMFS) follows the status of the beluga whale population and funds operation of the Alaska Beluga Committee The Committee has attempted to understand beluga whale subsistence harvests through an informal network of contacts The Cook Inlet Marine Mammal Council, comprised of Cook Inlet beluga whale subsistence hunters, works independently of the Alaska Beluga Committee to focus on beluga whales in Cook Inlet
The Alaska Native Harbor Seal Commission partners with ADF&G's Division of Subsistence in a harvest assessment project to interview hunters and collect data on the subsistence harvest of seals This effort is currently funded by the National Marine Fisheries Service The US Fish & Wildlife Service has a program to monitor the harvests of sea otters USFWS also monitors waterfowl

ADF&G's Subsistence Division has been working to coordinate and report on the various monitoring efforts However, their efforts have been funded through special research funding, such as EVOS Although another round of surveys is anticipated in 2004, future funding for ADF&G's Subsistence Division to continue coordination of subsistence monitoring as well as periodic household surveys within northern GOA communities is uncertain

The impact of subsistence harvests on injured resources, particularly marine mammals, has not been determined In some cases, it may become necessary to address the impact of subsistence on recovery, as was necessary for Cook Inlet beluga whales ADF&G and NMFS are working cooperatively to combine research efforts on harbor seals The results of this research program may improve understanding of the status of harbor seals and reasons for population declines within the northern GOA However, the program will not address the effects of subsistence harvests on this resource

7.15.4.1 Current and Potential Future Issues, Subsistence

Subsistence activities and production are related to many factors, such as population growth within villages and communities and changes in the abundance and distribution of fish and wildlife resources The criminal settlement subsistence restoration program, using money from the *Exxon Valdez* settlement, has funded thirty-two projects totaling \$5.6 million in support of subsistence restoration (Fall et al 2001) These included fish enhancement projects, development of infrastructure for subsistence activities, cultural education and mariculture The *Exxon Valdez* Trustee Council's Habitat Protection Program has protected over 650,000 acres within the northern GOA through outright purchase of lands or conservation easements This program ensures that the lands protected will remain part of the productive ecosystem, thus aiding support of the resource base for subsistence production

Increasing use within Prince William Sound by boaters, fishers, hunters and other recreational users may affect future subsistence opportunities through direct competition or the indirect effects of increased traffic in areas where subsistence harvests occur In 1995, a consulting firm evaluated the impact of completion of the Whittier tunnel on subsistence uses within six communities Chenega Bay, Tatitlek, Cordova, Whittier, Hope and Cooper Landing (Stephen R Braund & Associates 1995)

The study found that subsistence users from the GOA communities identified increased boat traffic within Prince William Sound and the potential increased direct competition for fish and wildlife resources from increased numbers of visitors as their greatest concerns related to the opening of the Whittier tunnel Although use of the Whittier tunnel has been much lower than forecast, the overall trend in increasing recreation use in the region may create conflicts with subsistence activities

Recent changes in subsistence regulation and management may affect other user groups, including sport and commercial fishers, hunters and others

Some future issues may include

- Definitions of federally-recognized subsistence users could greatly increase the number of subsistence users from outside the GOA region For example, the Federal Subsistence Board currently plans to allow all recognized subsistence users from anywhere in Alaska to participate in subsistence harvests on the Kenai Peninsula The Board earlier moved to restrict subsistence salmon fishing within the Copper River watershed to those living in the region
- The Federal Subsistence Board has received proposals to extend its jurisdiction to include marine waters and species
- In two decisions in Southeast Alaska, the Federal Subsistence Board has preemptively closed state fisheries in fresh water to make sure that there would be enough fish for subsistence in federal harvest areas During the 2001 fishing season, the Federal Subsistence Board preemptively closed all the commercial sport, sport and state subsistence fisheries operating within federal waters in both the Kuskokwim and Yukon drainages to ensure that the federal subsistence users would have access to salmon resources
- In a recent decision, the Federal Subsistence Board increased the limits for subsistence harvests in the Copper River by fish wheels, with no upper limit on king salmon If the subsistence harvest of king salmon is substantially increased in Copper River fisheries, sport and commercial users could face restrictions
- The North Pacific Fishery Management Council took final action in April 2002 to define subsistence halibut fishing in Alaska waters Subsistence management actions include a limit on the number of hooks, a 30-fish annual limit, a system to permit temporary transfer of subsistence rights, and a gear stacking allowance for multiple subsistence fishers on a single vessel
- The decline of the beluga whale in Cook Inlet provides an example of a resource problem alleged to be caused by subsistence harvests Under the Marine Mammal Protection Act, state and federal agencies were unable to take any action to address the declining resource until the population reached the point where it could be classified as depleted under the

Endangered Species Act If the beluga whales fail to recover, many commercial activities within Cook Inlet could face restriction

Subsistence Summary
Reasons for monitoring Subsistence uses have not yet recovered and are a priority use under state and federal law
Type of impacts Subsistence harvests of recovering species have the potential for causing at least localized depletion of some species
Agencies managing for a subsistence priority can create impacts on other user groups using resources within the northern GOA
Who is monitoring ADF&G is the primary agency for monitoring subsistence uses and harvests
Regulatory Authority The U S Fish and Wildlife Federal Subsistence Board has regulatory and allocation authority within federal lands in Alaska
The Alaska Board of Fisheries and Board of Game have regulatory authority over subsistence within state lands and waters
The North Pacific Fishery Management Council has made a recommendation for new regulations dealing with subsistence halibut
Federal laws, such as the Marine Mammal Protection Act and the Migratory Bird Treaty Act regulate subsistence uses in both state and federal waters

7 15.5 Timber and Forest Products

Ancestors of the Alutuq peoples who occupied most of the GOA area are believed to have migrated into the region from treeless areas to the west and north In the late 18th century, at the time of the first contacts with Europeans, the Alutuq made relatively little use of timber resources except for heat (Dumond 1983)

Many small logging and sawmill operations grew up in the 19th century to support local fish processing and mining operations In the early 20th century, most of the sawlog timber resources of the Prince William Sound area, the Kenai Peninsula and the Kodiak Archipelago came under the control of the U S Forest Service In addition to supporting local fish processing and mining, GOA forests also supplied railroad ties and timber for bridges to the Alaska Railroad and the Copper River & Northwestern Railway

Throughout most of the 20th century, the timber industry remained small From 1910 through 1986, total commercial harvests from government land in the GOA region averaged less than four million board feet (MMBF) per year, and never exceeded 12 MMBF per year As part of a policy to encourage timber-based manufacturing within the national forest and nearby communities, the US Forest Service largely prohibited the export from Alaska of unprocessed timber (Rogers 1962) Until 1987, there were essentially no forest products exported from the region to anywhere outside Alaska

That all changed in the 1980s, when regional and village Native corporations, established under the Alaska Native Claims Settlement Act (ANCSA) began receiving lands selected by them in accordance with the act. For the first time in the history of the GOA region, significant timber resources moved under the control of private, profit-seeking corporations. Most of the high-quality timber has since been logged in an effort to monetize the timber assets as rapidly as possible. Annual harvest volumes from the region grew from less than ten MMBF in 1986, to a peak of about 235 MMBF in 1995, and then quickly declined (USDA Forest Service, Chugach National Forest 2000b). Although a major sawmill was opened in Seward in 1993, it never became competitive, and has remained closed since 1994. As allowed under federal law, almost all of the private timber was exported from the state, most being sold abroad as unprocessed logs (Fried and Windisch-Cole, 1999).

Since 1996, a dwindling supply of high-quality timber and a depressed world market for softwood have caused a dramatic decline in harvest from the GOA region No major timber operations are currently operating in PWS Some logging continues in the Kodiak Archipelago, and small-scale timber operations are planned for parts of the Kenai Peninsula Improving market conditions and rising softwood prices could significantly increase the market for significant volumes of currently marginal timber, especially on Afognak Island

A significant factor affecting forest planning in the GOA area is a major spruce bark beetle infestation. A series of timber sales of beetle-damaged stands on state lands have been proposed (USDA Forest Service and State of Alaska 2000). Harvest from the state's proposed sales would encompass an estimated 115 MMBF over a maximum of five years, but adverse market conditions have caused commercial interest in the offerings to wane, and some recent sales have received no bids. In 2000 the state offered almost 12 MMBF, but the amount cut was less than three MMBF (ADNR 2000).

Concerns about logging include long-term effects on the marine ecosystem of bark detritus at log transfer sites, impacts on anadromous streams from siltation, and upland habitat destruction The Alaska Department of Environmental Conservation reported in 2000 that twenty-four percent of the water bodies on the state's list of polluted sites are listed due to some aspect of logging (ADEC 2000) A significant issue related to logging is the increased access to previously remote lands provided by logging roads Logging operations on the Kenai Peninsula alone have added more than 3,000 miles of roads in the region This increased access has encouraged all-terrain vehicle use in sensitive habitats, such as the headwaters of salmon streams

Timber and Forest Products Summary

Reasons for monitoring Immediate impacts of logging on anadromous fish and riparian habitat Point source impacts of wood processing facilities on air and water quality Long-term habitat and water quality degradation from past logging and pollution of uplands and marine sediments

Type of impacts Erosion, wide swings in water temperature, loss of habitat, changes in carbon cycle, increased human pressure due to access Industrial air and water quality impacts from wood processing

Who is monitoring USFS on federal land ADNR on state and private land ADF&G monitors impacts on economically important sport commercial and subsistence species ADEC and EPA monitor effects of bark deposition the on marine environment EPA and ADEC monitor point source industrial effects on air and water quality

Regulatory Authority State and federal laws have established regulatory authority over most aspects of logging and wood processing Federal laws include the Clean Water Act, the Endangered Species Act, the Wilderness Act, the Federal Land Planning and Management Act, the National Forest Management Act, the Forest and Rangeland Renewable Resources Planning Act and others, state authorities in Alaska Statutes include Title 16 (ADF&G), Title 47 (ADEC), and the Forest Practices Act

7 15 6 Urbanization and Road Building

Urban areas within the GEM region are likely to continue to grow from natural population growth and from immigration from smaller communities within Alaska and from outside the state Increasing urbanization diminishes some basic environmental qualities, even when development is planned and regulated with care Along with greater numbers and density of residents comes additional air pollution, water pollution, use of lands for solid waste disposal, increased levels of noise, and other effects Continued expansion of urban areas and increasing density of development of suburban zones inevitably degrade the habitat Changes in land surfaces can change entire hydrologic systems and cause water pollution problems Urban growth leads to increasing disposal of human waste Anchorage, the largest population center in the state, only completes primary treatment for sewage effluent piped into Cook Inlet, although almost all metropolitan communities in the country are required to complete secondary treatment The City received a 301 Clean Water Act Section (H) waiver to allow primary sewage treatment only, whereas almost all metropolitan communities in the country are required to complete secondary treatment The inherent turbidity of Cook Inlet water was a significant factor in EPA's grant of the waiver

Treated waste or street runoff may lead to changes in species composition and productivity of watersheds within the region A 1998 study of the Kenai River showed a decreased diversity of benthic invertebrates in areas of the river below

storm drain outfalls (Litchfield and Milner 1998) What was important in this study was the discovery that even though the benthic invertebrate community was still in place, certain species were missing from the surveyed areas Based on this study, it appears as if some key indicator species could be used to measure at least some of the effects of storm runoff pollution

As part of its stormwater discharge permit through ADEC, the Municipality of Anchorage is mapping the impervious surfaces within its area and studying the response of stream macroinvertebrates Under a US Environmental Protection Agency (EPA) Clean Water Act Section 319 grant from ADEC, the US States Department of Agriculture Cooperative Extension Service is also studying the effects of impervious surfaces A pilot project is planned for the Anchorage area, and if successful, the methodology may be applied to other areas in the future

Diminished environmental quality from increased population density is not limited strictly to urban areas As population density increases in previously rural areas — for example along the Kenai River — there has been a documented loss of environmental quality In 1994, ADF&G published a study evaluating the cumulative impacts of development and human uses on fish habitat on the Kenai River (Liepitz 1994) Factors diminishing water quality include wetlands loss, point source pollution from outhouses or faulty septic systems, and household spills of oils and other contaminants

Wetlands play an important ecological role in filtration for water quality and stormwater protection The Municipality of Anchorage has a wetlands plan, with high- and low-value wetlands identified There is no plan delineating the extent of wetlands and analyzing their function and values for the rest of the region, however

The ADEC is responsible for monitoring and regulating state water However, due to staff and funding limitations, the agency does not attempt to track down and resolve household or small commercial violations The US Geological Survey operates a National Water Quality Assessment (NAWQA) program tracking water quality and non-point pollution sources in urban watersheds The goals of the NAWQA Program are to describe current water quality conditions for a large part of the nation's freshwater streams and aquifers, describe how water quality is changing over time, and improve our understanding of the primary natural and human factors affecting water quality (USGS 2001) The Cook Inlet Basin is part of the NAWQA program The Cook Inlet study will provide increased understanding of water quality in the streams and ground water of the Cook Inlet Basin and identify factors that influence water quality

Roads are an important factor in habitat damage and water quality degradation. A 2001 study (Western Native Trout Campaign 2001) evaluated the relationship between public roadless lands and existing native trout populations in western states This report evaluates the diminished status of wild trout and the habitat damage associated with development of road systems The report concludes that roadless areas are essential to persistence and rebuilding of native salmonid populations

Human access to streams increases as the number of miles of road increases Trampling of stream banks, changes in stream configuration created by culverting of roads, reduction in riparian zone vegetation, and a multitude of other problems created by road building and access lead to aquatic habitat degradation and loss of basic productivity Increased human access to small rivers and streams containing relatively large animals such as salmon and river otters also usually leads to loss of aquatic species through illegal taking, despite the best efforts of law enforcement Indeed, limitations in budgets usually lead resource management and protection agencies to focus scarce resources on sensitive areas during critical seasons, leaving degradation to take its course in less sensitive locations

Within the northern GOA, roadbuilding and urbanization are of most concern within the Cook Inlet area There are no agencies monitoring or evaluating the effects of roads on habitat and water quality within this area

Urbanization and Road Building Summary

Reasons for monitoring Direct impacts to fish and wildlife species Immediate loss of wetlands and water quality

Type of impacts Erosion, wide swings in water temperature, erratic water flow and diminished water quality, loss of habitat, changes in carbon cycle, increased human pressure due to access

Who is monitoring The Municipality of Anchorage has a wetlands plan but little ongoing involvement ADF&G and private research groups (such as the Western Native Trout Campaign) study the cumulative effects of roadbuilding and development The USGS NAWQA program monitors water quality within the Cook Inlet Basin

Regulatory Authority ADF&G has Title 16 authority over anadromous fish streams The ADEC and the U S EPA have regulatory authority over water quality The Army Corps of Engineers has regulatory authority over development on wetlands

7 15 7 Other Industrial Activity

Large oil spills like the *Exxon Valdez* oil spill are rare occurrences More common are smaller discharges of refined oil products, crude oil and a variety of hazardous substances These occur frequently in the commercial fishing, petroleum, and timber industries and in a wide variety of commercial establishments such as gas stations and dry cleaners One of the worst spills near the Kenai River was due to repeated discharges of dry cleaning fluid over many years (ADEC, River Terrace spill 2002) Under state law, the release of hazardous substances and oil must be reported to the Alaska Department of Environmental Conservation (ADEC) Table 7 18 shows the number of spills by area for the year 2000 In 2000, a total of 604 spills were reported in the GEM region, resulting in a total discharge of 39,744 gallons of refined oil products, crude oil and hazardous substances Although small spills were reported throughout this region, the largest number of spills (497) and the greatest volume of discharge (24,340 gallons) occurred in Cook Inlet Most spills (90 percent) involved refined oil products, accounting for about 88 percent of the total volume discharged Only 3,000 gallons of crude oil were reported spilled in the GEM region during 2000 (ADEC 2002)

	total number of spills	total gallons spilled
Cook Inlet		· · · · · · · · · · · · · · · · · · ·
hazardous substances	37	5 421
refined oil products	454	18,844
crude oil	6	75
Kodiak		
hazardous substances	4	161
refined oil products	39	8,767
crude oil	0	0
Prince William Sound		
hazardous substances	9	53
refined oil products	48	6198
crude oil	7	225

Table 7 18 Spills Reported in 2000

Source ADEC 2002

Spills reported to ADEC include spills onshore as well as discharges into the marine environment The effects of these small spills depend on such variable factors as the volume of the discharge, its toxicity and persistence in the environment, the time of year the spill occurred and the significance of the affected environment in the life history of species of concern

Other Industrial Activity Summary

Reasons for monitoring Direct contamination of water quality Danger of loss of fish and wildlife

Type of impacts Erosion wide swings in water temperature, loss of habitat changes in carbon cycle increased human pressure due to access Industrial air and water quality impacts

Who is monitoring The ADEC and U S EPA do some limited monitoring

Regulatory Authority The ADEC and U S EPA have regulatory authority over water quality

7 15 8 Contaminants and Food Safety

The presence of industrial and agricultural contaminants in aquatic environments has generated worldwide concerns about potential effects on marine organisms and human consumers The remoteness of the northern GOA from centers of industry and human population does not necessarily offer protection Industrial and agricultural contaminants can be transported great distances by atmospheric and marine mechanisms, and evidence of persistent organochlorines (DDT), polychlorinated biphenyls (PCBs), dichlorodiphenyldichloroethylene (DDE), other organic pollutants, and heavy metals has been found in the arctic, subarctic, and areas adjacent to the GOA (Crane and Galasso 1999) For example, measurable amounts of organochlorines have been found in precipitation and fishes of the Copper River Delta, a tributary of the GOA that forms the eastern boundary of PWS (Ewald et al 1998)

In the case of mercury and other metals, such as inorganic arsenic, cadmium, and selenium, low concentrations of the contaminants may be present in the natural environment, with industrial and agricultural sources contributing additional quantities In many cases there is no known local or regional environmental, industrial or agricultural source of the contaminant

A variety of geophysical pathways bring these materials into the GOA, including ocean currents and prevailing winds In particular, the prevailing atmospheric circulation patterns transfer various materials as aerosols from Asia to the east across the North Pacific (Pahlow and Riebsell 2000) where they enter the marine environment in the form of rain or snow Some of these contaminants, such as PCBs and DDT, can bioaccumulate in living marine organisms For example, research sampling of transient killer whales that eat marine mammals indicated concentrations of PCBs and DDT derivatives that are many times higher than those concentrations found in resident fish-eating whales The sources of these contaminants are not specifically known There is also concern about the potential effects of contaminants on people, especially those who consume fish and shellfish, waterfowl, and marine mammals At higher levels of exposure, many of the chemicals noted above can cause adverse effects in people, such as the suppression of the immune system caused by PCBs

The state of Alaska does not monitor environmental pollutants in the marine environment or marine organisms on a regular basis, although a small fish-testing program was begun in the summer, 2002 There is no ongoing program for sampling food safety in subsistence resources in coastal communities, although the oil spill provided the opportunity to sample subsistence resources for hydrocarbons in the affected areas from 1989 through 1994 Federal funding for a joint federalstate-Alaska Native initiative has been requested from Congress The National Oceanic and Atmospheric Administration (NOAA) has annually measured chemicals in mollusks and sediments since 1984, as well as in the livers of bottomdwelling groundfish and in sediments at the sites of fish capture The Prince William Sound Regional Citizens' Advisory Council has measured hydrocarbon concentrations and sources within areas of PWS and the GOA This program focuses on sampling of intertidal mussels and nearby sediments

Contaminants and Food Safety Summary

Reasons for monitoring Industrial and agricultural contaminants are concentrated in fish and wildlife species. This can cause mortality in affected fish and wildlife as well as danger to humans consuming contaminated fish and wildlife

Type of impacts Persistence within the environment and potentially spreading to fish, wildlife and humans

Who is monitoring NOAA monitors chemicals in mollusks, sediments and bottom-dwelling groundfish

Regulatory Authority The U S EPA has regulatory authority over contaminants in aquatic environments

7 15 9 Global Warming

Although driven by forces outside the control of Alaska's natural resource managers, global warming is an essential consideration for development and implementation of the GEM program. The earth's climate is predicted to change because human activities, such as the combustion of fossil fuels and increased agriculture, deforestation, landfills, industrial production, and mining, are altering the chemical composition of the atmosphere through the buildup of greenhouse gases. These gases are primarily carbon dioxide, methane, nitrous oxide and chlorofluorocarbons. Their heat-trapping property is undisputed, as is the fact that global temperatures are rising. Observations collected during the last century suggest that the average land surface temperature has risen 0.45° to 0.6° C

Precipitation has increased by about one percent over the world's continents in the last century, with high-latitude areas tending to see more significant increases in rainfall and rising sea levels. This increase is consistent with observations that indicate the northern GOA sea surface temperature has increased by 0.5° C since 1940, and that precipitation in Alaska (excluding Southeast Alaska) increased eleven percent from 1950 through 1990

Increasing concentrations of greenhouse gases are likely to accelerate the rate of climate change The changes seen in the northern GOA and their relationship to other warming and cooling cycles in the North Pacific and the combined effects on global climate are important for understanding how humans affect biological production Some populations of fish and marine mammals that show longtime trends, up or down, or sharp rapid changes in abundance, are actively managed through harvest restraints The extent to which harvest restraints may be effective in establishing or altering trends in abundance of exploited species can only be understood within the context of climate change

A rise in sea level is one of the anticipated changes from global warming, leading to flooding of low-lying property, loss of coastal wetlands, erosion of beaches, saltwater intrusion into fresh water wells and increased costs for maintenance and/or replacement of roads causeways and bridges (USEPA 1998) Among other impacts, an increase in ocean level may have profound impacts on salmon production. The loss of estuarine wetlands from the 1964 earthquake resulted in major losses of pink salmon habitat in Prince William Sound

Global warming may also have a negative effect on use of water resources throughout Alaska by leading to earlier and more concentrated spring runoff periods There could be detrimental effects on forests within the northern GOA, for species that are adapted to a cooler temperature regime

Global Warming Summary

Reasons for monitoring Danger of losses to fish and wildlife Salt water intrusion into freshwater supplies

Type of impacts Flooding of low-lying property, loss of coastal wetlands, erosion of beaches, salt water intrusion into freshwater wells increase in public costs for maintenance and replacement of roads and bridges

Who is monitoring US EPA

Regulatory Authority U S EPA has regulatory authority over activities that add to global warming Many sources are international and not subject to regulation

7.16 References

ADCED 2002 Alaska Visitor Statistics Program IV Factsheet

- ADEC 2000 Strategy document Alaska's nonpoint source pollution strategy Juneau, Alaska, Alaska Department of Environmental Conservation
- ADEC 2001 Spills database Juneau, Alaska Department of Environmental Conservation
- ADEC, ADNR, ADF&G, and Office of the Governor 2001 Alaska's clean water actions protecting our waters Juneau, Alaska Department of Environmental Conservation
- ADEC, River Terrace spill 2002
- ADF&G 1998 Report on the failure of western Alaska salmon runs and the link to ocean and climate changes Juneau, Alaska, Alaska Department of Fish and Game
- ADF&G various years Harvest, catch and participation in Alaska sport fisheries Fishery data series
- ADNR 2000 Five-year schedule of timber sales in the Kenai-Kodiak area, FY-01 through FY-05
- ADNR 2002 Alaska natural gas in-state demand study Anchorage, Alaska Department of Natural Resources
- Aebischer, NJ, JC Coulson, and JM Colebrook 1990 Parallel long-term trends across four marine trophic levels and weather Nature 347 753-755
- Ahlnaes, K, TC Royer, and TH George 1987 Multipole dipole eddies in the Alaska coastal current detected with Landsat thematic mapper data Journal of Geophysical Research 92 13041-13047
- Anley, DG and RJE Broekelheid 1990 Seabirds of the Farallon Islands Stanford University Press Stanford
- Ainley, DG, WJ Sydeman, SA Hatch, and UW Wilson 1994 Seabird population trends along the west coast of North America causes and extent of regional concordance Studies Avian Biology 15 119-133
- Alaska Department of Labor 2001 1999 Alaska employmnet and earnings summary report by census area
- Alaska Department of Revenue 2001 Juneau, Tax Division, Alaska Department of Revenue
- Alaska Highway Natural Gas Policy Council 2001 Report to the Governor Anchorage, Alaska Department of Community and Economic Development
- Alaska Oil and Gas Conservation Commission 2001 Annual report 2000 Anchorage, Alaska Department of Administration.
- Alaska Sea Grant College Program 1993 Is it food? University of Alaska Fairbanks

- Alaska State Parks 1993 The Kenai River carrying capacity study final report by the Division of Parks and Outdoor Recreation with assistance from the National Parks Service Rivers, Trails and Conservation Assistance Program and Shelby Research Associates
- Allen, M R , P A Stott, J F B Mitchell, R Schnur, and T L Delworth 2000 Quantifying the uncertainty in forecasts of anthropogenic climate change Nature 407 617-620
- Allen, S E 1996 Topographically generated, subinertial flows within a finite length canyon Journal of Physical Oceanography 26 1608-1632
- Allen, S E 2000 On subinertial flow in submarine canyons effects of geometry Journal of Geophysical Research 105 1285-1298
- Alverson, D L 1992 A review of commercial fisheries and the Steller sea lion (*Eumetopias jubatus*) the conflict arena Reviews in Aquatic Sciences 6 203-256
- Anderson, DW, F Gress, KF Mais, and PR Kelly 1980 Brown pelicans as anchovy stock indicators and their relationships to commercial fishing CalCOFI
- Anderson, G C and R E Munson 1972 Primary productivity studies using merchant vessels in the North Pacific Ocean Pages 245-251 in Takenoti, A Y, editor Biological oceanography of the northern North Pacific Ocean Idemitsu Shoten, Tokyo
- Anderson, P J, J E Blackburn, and B A Johnson 1997 Declines of forage species in the Gulf of Alaska, 1972-1995, as an indicator of regime shift Pages 531-543 in Forage fishes in marine ecosystems proceedings of the international symposium on the role of forage fishes in marine ecosystems Alaska Sea Grant College Program, University of Alaska
- Anderson, P J and J F Piatt 1999 Community reorganization in the Gulf of Alaska following ocean climate regime shift Marine Ecology Progress Series 189 117-123
- Anthony, J A and D D Roby 1997 Variation in lipic content of forage fishes and its effect on energy provisioning rates to seabird nestlings Pages 725-729 in Forage fishes in marine ecosystems proceedings of the international symposium on the role of forage fishes in marine ecosystems Alaska Sea Grant College Program, Fairbanks, Alaska
- Armstrong, D A , P A Dinnel, J M Orensanz, J L Armstrong, T L McDonald, R F Cusimano, R S Nemeth, M L Landolt, M L Skalski, R F Lee, and R J Huggett 1995 Status of selected bottom fish and crustacean species in Prince William Sound following the *Exxon Valdez* oil spill Pages 485-547 in Wells, P G , J N Butler, and J S Hughes, editors *Exxon Valdez* oil spill fate and effects in Alaskan waters American Society for Testing and Materials, Philadelphia
- Bacon, C E, W M Jarman, J A Estes, M Simon, and R J Norstrom 1998 Comparison of organochlorine contaminants among sea otter (*Enhydi a*)

lutis) populations in California and Alaska Environmental Toxicology and Chemistry 18 452-458

- Bailey, E P and G H Davenport 1972 Die-off of common murres on the Alaska Peninsula and Unimak Island Condor 74 215-219
- Bailey, E P and G W Kaiser 1993 Impacts of introduced predators on nesting seabirds in the northeast Pacific Pages 218-226 in Vermeer, K, KT Briggs, K H Morgan, and D Siegel-Causey, editors The status, ecology, and conservation of marine birds of the North Pacific Canadian Wildlife Service, Ottawa
- Bailey, K M 2000 Shifting control of recruitment of walleye pollock *Theragra chalcogramma* after a major climatic and ecosystem change Marine Ecology Progress Series 198 215-224
- Bailey, K M, N A Bond, and P J Stabeno 1999 Anomalous transport of walleye pollock larvae linked to ocean and atmospheric patterns in May 1996 Fisheries Oceanography 8 264-273
- Bailey, K M , A L Brown, M M Yoklavich, and K L Mier 1996 Interannual variability in growth of larval and juvenile walleye pollock *Theragra chalcogramma* in the western Gulf of Alaska, 1983-91 Fisheries Oceanography 6 137-147
- Bailey, K M , M F Canino, J M Napp, S M Spring, and A L Brown 1995 Contrasting years of prey levels, feeding conditions and mortality of larval walleye pollock *Thei agi a chalcogi amma* in the western Gulf of Alaska Marine Ecology Progress Series 119 11-23
- Bailey, K M, S A Macklin, R K Reed, R D Brodeur, W J Ingraham, J F Piatt, M Shima, R C Francis, P J Anderson, T C Royer, A B Hollowed, D A Somerton, and W S Wooster 1995 ENSO events in the northern Gulf of Alaska, and effects on selected marine fisheries California Cooperative Oceanic Fisheries Investigations Reports (CalCOFI) 36 78-96
- Bailey, K M, Quinn II, T J, P Bentzen, and W S Grant 1999 Population structure and dynamics of walleye pollock, *Theragra chalcogramma* Advances in Marine Biology 37 179-255
- Baird, P A and P J Gould 1986 The breeding biology and feeding ecology of marine birds in the Gulf of Alaska Pages 121-503 MMS/NOAA OCSEAP Final Report 45
- Baird, P H 1990 Influence of abiotic factors and prey distribution on diet and reproductive success of three seabird species in Alaska Ornis Scandinavica 21 224-235
- Bakus, G J 1978 Benthic ecology in the Gulf of Alaska Energy/Environment '78 Society of Petroleum Industry Biologists, Los Angeles, California 169-192
- Ballachey, B E, J L Bodkin, and A R DeGange 1994 An overview of sea otter studies Pages 47-59 in Loughlin, T R, editor Marine mammals and the *Exxon Valdez* Academic Press, San Diego

- Banse, K 1982 Cell volumes, maximal growth rates of unicellular algae and ciliates, and the role of ciliates in the marine pelagial Limnology and Oceanography 27 1059-1071
- Barnes, F F 1958 Cook Inlet Susitna Lowland National Park Service, U S D o t I Landscapes of Alaska Berkeley and Los Angeles, University of California Press
- Barrett-Lennard, LG, GM Ellis, CO Matkin, and JKB Ford in press A propensity for isolationism genetic analysis of social segregation within and between sympatric killer whale ecotypes
- Barrett-Lennard, LG, K Heise, E Saulitis, G Ellis, and C Matkin 1995 The impact of killer whale predation on Steller sea lion populations in British Columbia and Alaska Unpublished Report Vancouver, North Pacific Universities Marine Mammal Research Consortium
- Baumgartner, A and E Reichel 1975 The world water balance Elsevier New York
- Baur, D C , M J Bean, and M L Gosliner 1999 The laws governing marine mammal conservation in the United States Pages 48-86 in Twiss, J R Jr and R R Reeves, editors Conservation and management of marine mammals Smithsonian University Press, Washington, D C
- Beamish, R J , K D Leask, O A Ianov, A A Balanov, A M Orlov, and B Sinclair 1999 The ecology, distribution, and abundance of mid-water fishes of the Subarctic Pacific gyres Progress in Oceanography 43 399-442
- Beamish, RJ, DJ Noakes, GA McFarlane, L Klyashtorin, VV Ivanov, and V Kurashov 1999 The regime concept and natural trends in the production of Pacific salmon Canadian Journal of Fisheries and Aquatic Sciences 56 516-526
- Beissinger, S R 1995 Population trends of the marbled murrelet projected from demographic analyses Pages 385-393 in Ralph, C J, G L Hunt Jr, M G Raphael, and J F Piatt, editors Ecology and conservation of the marbled murrelet Pacific Southwest Research Station, U S D A Forest Service, Berkeley
- Ben-David, M, R T Bowyer, L K Duffy, D D Roby, and D M Schell 1998b Social behavior and ecosystem processes river otter latrines and nutrient dynamics of terrestrial vegetation. Ecology 79 2567-2571
- Ben-David, M, RW Flynn, and DM Schell 1997b Annual and seasonal changes in diets of martens evidence from stable isotope analysis Oecologia 280-291
- Ben-David, M, TA Hanley, DR Klein, and DM Schell 1997a Seasonal changes in diets of coastal and riverine mink the role of spawning Pacific salmon Canadian Journal of Zoology 803-811
- Ben-David, M, TA Hanley, and DM Schell 1998a Fertilization of terrestrial vegetation by spawning Pacific salmon the role of flooding and predator activity Oikos 47-55
- Berger, A , J Imbrie, J Hays, G Kukla, and B Saltzman 1984 Milankovitch and climate Reidel Boston

- Bickham, JW, TR Loughlin, JK Wickliffe, and VN Burkanov 1998a Genetic variation in the mitochondrial DNA of Steller sea lions haplotype diversity and endemism in the Kuril Islands Biosphere Conservation 1 107-117
- Bickham, JW, JC Patton, and TR Loughlin 1996 High variability for controlregion sequences in a marine mammal implications for conservation and biogeography of Steller sea lions (*Eumetopias jubatus*) Journal of Mammalogy 77 95-108
- Bigg, MA, GE Ellis, JKB Ford, and KC Balcomb 1987 Killer whales a study of their identification, genealogy, and natural history in British Columbia and Washington State Phantom Press Nanaimo
- Bilby, R E, B R Fransen, and P A Bisson 1996 Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams evidence from stable isotopes Canadian Journal of Fisheries and Aquatic Sciences 164-173
- Blackburn, J E and P J Anderson 1997 Pacific sand lance growth, seasonal availability, movements, catch variability, and food in the Kodiak - Cook inlet area of Alaska Pages 409-426 in Forage fishes in marine ecosystems proceedings of the international symposium on the role of forage fishes in marine ecosystems Alaska Sea Grant College Program, University of Alaska, Fairbanks
- Bodkin, J L, A M Burdin, and D A Ryzanov 2000 Age and sex specific mortality and population structure in sea otters Marine Mammal Science 16 201-219
- Bodkin, J L and R Jameson 1991 Patterns of seabird and marine mammal carcass deposition along the central California coast, 1980-1986 Canadian Journal of Zoology 69 1149-1155
- Bodkin, J L and K W Kenyon in press Sea otters in Feldham G A and B Thompson, editors Wild mammals of North America Johns Hopkins University Press
- Bodkin, J L , D Mulcahy, and C J Lensink 1993 Age specific reproduction in the sea otter (Enhydra lutris), an analysis of reproductive tracts Canadian Journal of Zoology 71 1811-1815
- Bodkin, J L and M S Udevitz 1994 An intersection model for estimating sea otter mortality along the Kenai Peninsula Pages 81-95 in Loughlin, T R, editor Marine mammals and the *Exxon Valdez* Academic Press, San Diego
- Bodkin, J L and M S Udevitz 1999 An aerial survey method to estimate sea otter abundance Pages 13-29 in Garner, G W, S C Amstrup, J L Laake, B F J Manly, L L McDonald, and D G Robertson, editors Marine mammal survey and assessment methods Balkema Press, Netherlands
- Boersma, P D and M J Groom 1993 Conservation of storm petrels in the North Pacific Pages 112-121 in Vermeer, K, KT Briggs, and D Siegel-Causey, editors Status and ecology of temperate North Pacific seabirds Canadian Wildlife Service, Ottawa

- Bogard, S J , P J Stabeno, and J D Schumacher 1994 A census of mesoscale eddies in Shelikof Strait, Alaska during 1989 Journal of Geophysical Research 99 18243-18254
- Booth, B C 1988 Size classes and major taxonomic groups of phytoplankton at two locations in the Subarctic Pacific Ocean in May and August, 1984 Marine Biology 97 275-286
- Booth, B C , J Lewin, and J R Postel 1993 Temporal variation in the structure of autotrophic and heterotrophic communities in the subarctic Pacific Progress in Oceanography 32 57-99
- Bower, A 1991 A simple kinematic mechanism for mixing fluid parcels across a meandering jet Journal of Physical Oceanography 21 173-180
- Boyd, PW, AJ Watson, CS Law, ER Abraham, T Trull, R Murdoch, DCE
 Bakker, AR Bowie, KO Buesseler, H Chang, M Charette, P Croot, K
 Downing, R Frew, M Gall, M Hadfield, J Hall, M Harvey, G Jameson, J
 LaRoche, M Liddicoat, R Ling, M T Maldonado, R M McKay, S Nodder,
 S Pickmere, R Pridmore, S Rintoul, K Safi, P Sutton, R Strzepek, K
 Tanneberger, S Turner, A Waite, and J Zeldis 2000 A mesoscale
 phytoplankton bloom in the polar Southern Ocean stimulated by iron
 fertilization Nature 407 695-702
- Braddock, JF, JE Lindstrom, TR Yeager, BT Rasley, and EJ Brown 1996 Patterns of microbial activity in oiled and unoiled sediments in Prince William Sound American Fisheries Society Symposium 18 94-108
- Braham, H W and M E Dahlheim 1982 Killer whales in Alaska documented in the Platforms of Opportunity Program Report to the International Whale Commission 32 643-646
- Breiwick, J W 1999 Gray whale abundance estimates, 1967/68-1997/98 ROI, RY, and K Page 62 in Rugh, D J, M M Muto, S E Moore, and D P DeMaster, editors Status review of the Eastern North Pacific stock of gray whales U S Department of Commerce, National Oceanic and Atmospheric Administration
- Brodeur, R D , G W Boehlert, E Casillas, M B Eldridge, J H Helle, W T Peterson, W R Heard, S T Lindley, and M H Schiewe 2000 A coordinated research plan for estuarine and ocean research on Pacific salmon Fisheries 25 7-16
- Brodeur, R D , B W Frost, S R Hare, R C Francis, and Ingraham Jr , W J 1996 Interannual variations in zooplankton biomass in the Gulf of Alaska and covariation with California current zooplankton biomass California Cooperative Oceanic Fisheries Investigations Reports (CalCOFI) 80-100
- Brodeur, R D and D M Ware 1992 Long-term variability in zooplankton biomass in the subarctic Pacific Ocean Fisheries Oceanography 1 32-38
- Brodeur, R D and D M Ware 1995 Interdecadal variability in distribution and catch rates of epipelagic nekton in the Northeast Pacific Ocean Pages 329-356 in Beamish, R J, editor Climate change and northern fish populations Canadian Special Publication of Fisheries and Aquatic Sciences

- Broecker, W S 1982 Glacial to interglacial changes in ocean chemistry Progress in Oceanography 11 151-197
- Brower Jr, WA, RG Baldwin, Williams Jr, CN, JL Wise, and LD Leslie 1988 Climate atlas of the outer continental shelf waters and coastal regions of Alaska Volume I, Gulf of Alaska Asheville, NC, National Climatic Data Center
- Brown, E 2000 personal communication Institute of Marine Sciences, School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, Alaska
- Brown, G 2000 Renewable natural resources management and use without markets Journal of Economic Literature 38
- Brown, J 2002 Remarks to the Resource Development Council for Alaska Alaska Support Industry Alliance and Anchorage Chamber of Commerce, June 28, 2002, Anchorage, Alaska
- Brown Gladden, J G , M M Ferguson, M K Freisen, and J W Clayton 1999 Population structure of North American beluga whales (*Delphinapterus leucas*) based on nuclear DNA microsatellite variation and contrasted with the population structure revealed by mitochondrial DNA variation Molecular Ecology 8 347-363
- Burger, A E and J F Piatt 1990 Flexible time budgets in breeding common murres buffers against variable prey abundance Studies Avian Biology 14 71-83
- Burrell, D C 1986 Interaction between silled fjords and coastal regions Pages 187-220 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C
- Burton, G 2001 personal communication Alaska Department of Transportation and Public Facilities
- Byrd, GV, DE Dragoo, and DB Irons 1998 Breeding status and population trends of seabirds in Alaska in 1997 US Fish and Wildlife Service Homer
- Byrd, GV, DE Dragoo, and DB Irons 1999 Breeding status and population trends of seabirds in Alaska in 1998 Homer, US Fish and Wildlife Service
- Cairns, D K 1987 Seabirds as indicators of marine food supplies Biological Oceanography 5 261-271
- Calambokidis, J, G H Steiger, J M Straley, T Quinn, L M Herman, S Cerchio, R Salden, M Yamaguchi, F Sato, J R Urban, J Jacobson, O Von Zeigesar, K C Balcomb, C M Gabriele, M E Dahlheim, N Higashi, S Uchida, J K B Ford, Y Miyamura, P Ladrón de Guevara, S A Mizroch, L Schlender, and K Rasmussen 1997 Abundance and population structure of humpback whales in the North Pacific basin Southwest Fisheries Science Center LaJolla
- Caley, K J, M H Carr, M A H1xon, T P Hughes, J P Jones, and B A Menge 1996 Recruitment and the local dynamics of open marine populations Annual Review of Ecology and Systematics 27 477-500

- Calkins, D 1986 Marine mammals Pages 527-558 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C
- Calkins, D G 1978 Feeding behavior and major prey species of the sea otter, Enhydra lutris, in Montague Strait, Prince William Sound, Alaska Fishery Bulletin 76 125-131
- Calkins, D G 1984 Susitna hydroelectric project phase II annual report big game studies Vol IX, belukha whale Alaska Department of Fish and Game Anchorage
- Calkins, D G 1986 Sea lion investigations in southern Alaska Page 23 Final report to the National Marine Fisheries Service, Alaska region Alaska Department of Fish and Game, Anchorage
- Calkins, D G 1998 Prey of Steller sea lions in the Bering Sea Biosphere Conservation 1 33-44
- Calkins, D G and E Goodwin 1988 Investigation of the declining sea lion population in the Gulf of Alaska Unpublished Report Alaska Department of Fish and Game Anchorage
- Calkins, D G and K W Pitcher 1982 Population assessment, ecology and trophic relationships of Steller sea lions in the Gulf of Alaska Pages 447-546 in Environmental assessment of the Alaskan continental shelf U S Department of Commerce and U S Department of the Interior
- Calvin, N I and R J Ellis 1978 Quantitative and qualitative observations on Laminaria digitata and other subtidal kelps of southern Kodiak Island, Alaska Marine Biology 47 331-336
- Canino, M F, K M Bailey, and L S Incze 1991 Temporal and geographic differences in feeding and nutritional condition of walleye pollock larvae *Thei agi a chalcogi amma* in Shelikof Strait, Gulf of Alaska Marine Ecology Progress Series 79 27-35
- Carlson, PR, TR Burns, BF Molnua, and WC Schwab 1982 Submarine valleys in the northeast Gulf of Alaska characteristics and probable origin Marine Geology 47 217-242
- Carroll, M L and R C Highsmith 1996 Role of catastrophic disturbance in mediating Nucella-Mytilus interactions in the Alaskan rocky intertidal Marine Ecology Progress Series 138 125-133
- Carscadden, J and B S Nakashima 1997 Abundance and changes in distribution, biology and behavior of capelin in response to cooler waters of the 1990s Pages 457-468 in Forage fishes in marine ecosystems proceedings of the international symposium on the role of forage fishes in marine ecosystems Alaska Sea Grant College Program, University of Alaska, Fairbanks
- Chapman, D C 2000 A numerical study of the adjustment of a narrow stratified current over a sloping bottom Journal of Physical Oceanography 30 2927-2940

- Chapman, D C and S J Lentz 1994 Trapping of a coastal density front by the bottom boundary layer Journal of Physical Oceanography 24 1464-1479
- Childers, A 2000 personal communication Institute of Marine Sciences, School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, Alaska
- Chisholm, SW 2000 Stirring times in the Southern Ocean Nature 407 685-687
- Chugach Alaska Corporation 2001
- Chumbley, K, J Sease, M Strick, and R Towell 1997 Field studies of Steller sea lions (*Eumetopias jubatus*) at Marmot Island, Alaska 1979 through 1994
- Cianelli, L and R Brodeur 1997 Bioenergetics estimation of juvenile pollock food consumption in the Gulf of Alaska Pages 71-76 in Forage fishes in marine ecosystems proceedings of the international symposium on the role of forage fishes in marine ecosystems Alaska Sea Grant College Program, University of Alaska, Fairbanks
- Clark, WG, SR Hare, AM Parma, J Sullivan, and RJ Trumble Decadal changes in growth and recruitment of Pacific halibut (Hippoglossus stenolepis) draft
- Coats, D A, E Imamura, A K Fukuyama, J R Skalski, S Kimura, and J Steinbeck 1999 Monitoring of biological recovery of Prince William Sound intertidal sites impacted by the *Exxon Valdez* oil spill 1997 biological monitoring survey Seattle, NOAA NOAA Technical Memorandum NOS OR&R I NOAA Hazardous Materials Response Division, Seattle, WA
- Connell, J H 1972 Community interactions on marine rocky intertidal shores Annual Review of Ecology and Systematics 3 169-192
- Cooley, R A 1963 Politics and conservation the decline of the Alaska salmon Harper & Row New York
- Cooney, R T 1983 Some thoughts on the Alaska Coastal Current as a feeding habitat for juvenile salmon Pages 256-268 in Pearcy, W G, editor The influence of ocean conditions on the production of salmonids in the North Pacific Sea Grant College Program, Oregon State University
- Cooney, R T 1986 The seasonal occurrence of *Neocalanus cristatus, Neocalanus plumchrus,* and *Eucalanus bungu* over the shelf of the northern Gulf of Alaska Continental Shelf Research 5 541-553
- Cooney, R T 1988 Distribution and ecology of zooplankton in the Gulf of Alaska Bulletin of the Ocean Research Institute of Tokyo 26 27-41
- Cooney, R T 1989 Acoustic evidence for the vertical partitioning of biomass in the epipelagic zone of the Gulf of Alaska Deep-Sea Research 36 1177-1189
- Cooney, R T 1993 A theoretical evaluation of the carrying capacity of Prince William Sound, Alaska, for juvenile Pacific salmon. Fisheries Research 18 77-87
- Cooney, R T unpublished Institute of Marine Science, University of Alaska, Fairbanks, Alaska

- Cooney, R T, J R Allen, M A Bishop, D L Eslinger, T Kline, B L Norcross, C P McRoy, J Milton, E V Patrick, A J Paul, D Salmon, D Scheel, G L Thomas, S L Vaughan, and T M Willette 2001 Ecosystem control of pink salmon (*Onchorhynchus gorbuscha*) and Pacific herring (*Chipea pallasi*) populations in Prince William Sound, Alaska Fisheries Oceanography 10 (Suppl 1) 1-13
- Cooney, R T and K O Coyle 1982 Trophic implications of cross-shelf copepod distributions in the southeastern Bering Sea Marine Biology 70 187-196
- Cooney, R T, K O Coyle, E Stockmar, and C Stark 2001 Seasonality in surfacelayer net zooplankton communities in Prince William Sound, Alaska Fisheries Oceanography 10 (Suppl 1) 97-109
- Costa, D P 1982 Energy, nitrogen and electrolyte flux and sea-water drinking in the sea otter, Enhydra lutris Physiological Zoology 55 34-44
- Coyle, K O 1997 Distribution of large calanoid copepods in relation to physical oceanographic conditions and foraging auklets in the western Aleutian islands University of Alaska, Fairbanks
- Crane, K and J L Galasso 1999 Arctic environmental atlas Washington, D C U S Naval Research Laboratory, Office of Naval Research
- Crawford, W R 1984 Energy flux and generation of diurnal shelf waves along Vancouver Island Journal of Physical Oceanography 14 1600-1607
- Crawford, W R, J Y Cherniawsky, F A Whitney, and M G G Foreman 1999 Eddies in the Gulf of Alaska and Alaska Stream EOS, Transactions of the American Geophysical Union 80
- Crawford, W R and R E Thomson 1984 Diurnal period shelf waves along Vancouver Island a comparison of observations with theoretical models Journal of Physical Oceanography 14 1629-1646
- Cronin, M A , J Bodkin, B Ballachey, J Estes, and J C Patton 1996 Mitochondrial-DNA variation among subspecies and populations of sea otters (Enhydra lutris) Journal of Mammalogy 72 546-557
- Cummins, P F and L -Y Oey 2000 Simulation of barotropic and baroclinic tides off northern British Columbia Journal of Physical Oceanography 27 762-781
- Dagg, M 1993 Grazing by the copepod community does not control phytoplankton production in the open subarctic Pacific Ocean Progress in Oceanography 32 163-184
- Dagg, M J and Walser Jr, E W 1987 Ingestion, gut passage, and egestion by the copepod Neocalanus plumchrus in the laboratory and in the Subarctic Pacific Ocean Limnology and Oceanography 32 178-188
- Dahlheim, M E and C O Matkin 1994 Assessment of injuries to Prince William Sound killer whales Pages 163-171 in Loughlin, T R, editor Marine mammals and the *Exxon Valdez* Academic Press, San Diego
- Danielson, S 2000 personal communication Institute of Marine Sciences, School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, Alaska

- Dayton, P K 1971 Competition, distuibance, and community organization the provision and subsequent utilization of space in a rocky intertidal community Ecological Monographs 41 351-389
- Dayton, P K 1975 Experimental studies of algal canopy interactions in a sea-otter dominated kelp community at Amchitka Island, Alaska Fisheries Bulletin U S 73 230-237
- Dayton, P K, S F Thrush, M T Agardy, and R J Hoffman 1995 Environmental effects of marine fishing Aquatic Conservation of Marine and Freshwater Ecosystems 5 205-232
- Dean, T A , J L Bodkin, S C Jewett, D H Monson, and D Jung 2000 Changes in sea urchins and kelp following a reduction in sea otter density as a result of the *Exxon Valdez* oil spill Marine Ecology Progress Series 199 281-291
- Dean, TA, SC Jewett, DR Laur, and RO Smith 1996b Injury to epibenthic invertebrates resulting from the *Exxon Valdez* oil spill American Fisheries Society Symposium 18 424-439
- Dean, TA, MS Stekoll, SC Jewett, RO Smith, and JE Hose 1998 Eelgrass (Zostera marina L) in Prince William Sound, Alaska effects of the Exxon Valdez oil spill Marine Pollution Bulletin 36 201-210
- Dean, T A, M S Stekoll, and R O Smith 1996a Kelps and oil the effects of the *Exxon Valdez* oil spill on subtidal algae American Fisheries Society Symposium 18 412-423
- DeGange, A R, A M Doroff, and D H Monson 1994 Experimental recovery of sea otter carcasses at Kodiak Island, Alaska, following the Exron Valdez oil spill Marine Mammal Science 10 492-496
- DeGange, A R and G A Sanger 1986 Marine birds Pages 479-526 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C
- Denman, K L , H J Freeland, and D L Mackas 1989 Comparison of time scales for biomass transfer up the marine food web and coastal transport processes Canadian Special Publication of Fisheries and Aquatic Sciences 108 255-264
- Denny, M W 1988 Biology and mechanics of the wave-swept environment Princeton University Press Princeton
- Dethier, M N and D O Duggins 1988 Variations in strong interactions in the intertidal zone along a geographic gradient a Washington-Alaska comparison Marine Ecology Progress Series 50 97-105
- Divoky, G J 1998 Factors affecting the growth of a black guillemot colony in northern Alaska University of Alaska Fairbanks
- Dizon, A E, S J Chivers, and W F Perrin 1997 Molecular genetics of marine mammals The Society for Marine Mammalogy Spec Publ No 3 388

- Dodimead, A J, F Favorite, and T Hirano 1963 Salmon of the North Pacific Ocean Part II Review of oceanography of the subarctic Pacific region International North Pacific Fisheries Commission Bulletin 13 1-195
- Doroff, A M and J L Bodkin 1994 Sea otter foraging behavior and hydrocarbon levels in prey Pages 193-208 in Loughlin, T R, editor Marine mammals and the *Eazon Valdez* Academic Press, San Diego
- Doroff, A M and A R DeGange 1994 Sea otter, Enhydra lutris, prey composition and foraging success in the northern Kodiak Archipelago Fishery Bulletin 92 704-710
- Driskell, W B, A K Fukuyama, J P Houghton, D C Lees, A J Mearns, and G Shigenaka 1996 Recovery of Prince William Sound intertidal infauna from *Excon Valdez* oiling and shoreline treatments, 1989 through 1992 American Fisheries Society Symposium 18 362-378
- Duggins, D O , C A Simenstad, and J A Estes 1989 Magnification of secondary production by kelp detritus in coastal marine ecosystems Science 245 170-173
- Dumond, D E 1983 Alaska and the northeast coast in Jennings, J D, editor Ancient North Americans W H Freeman and Company, New York
- Ebeling, A W and D R Laur 1998 Fish populations in kelp forests without sea otters effects of severe storm damage and destructive sea urchin grazing Pages 169-191 in VanBlaricom, G R and J A Estes, editors The community ecology of sea otters Springer Verlag, Berlin
- Ebert, T A and D C Lees 1996 Growth and loss of tagged individuals of the predatory snail Nucella lamellosa in areas within the influence of the *Exxon Valdez* oil spill in Prince William Sound American Fisheries Society Symposium 18 349-361
- Edie, A G 1977 Distribution and movements of Steller sea lion cows (*Eumetopias jubata*) on a pupping colony University of British Columbia, Vancouver
- Egbert, G D and R D Ray 2000 Significant dissipation of tidal energy in the deep ocean inferred from satellite altimeter data Nature 405 775-778
- Eggers, D M, L R Peltz, B G Bue, and T M Willette 1991 Trends in abundance of hatchery and wild stocks of pink salmon in Cook Inlet, Prince William Sound, and Kodiak, Alaska *in* Proceedings of the international symposium on interactions between wild and enhanced salmon Nanaimo, British Columbia
- Emery, W J and K Hamilton 1985 Atmospheric forcing of interannual variability in the northeast Pacific Ocean connections with El Niño Journal of Geophysical Research 90 857-868
- Enfield, D 1997 Multi-scale climate variability besides ENSO, what else?, in a colloquim on El Niño-Southern Oscillation (ENSO) atmospheric, oceanic, societal, environmental and policy perspectives July 20-August 1, 1997, Boulder, Colorado

- Erickson, D, E Pikitich, P Suuronen, E Lehtonen, C Bublitz, C Klinkert, and C Mitchell 1999 Selectivity and mortality of walleye pollock escaping from the codend and intermediate (extension) selection of a pelagic trawl Final Report Anchorage
- Erikson, D E 1995 Surveys of murre colony attendance in the northern Gulf of Alaska following the *Exion Valdez* oil spill Pages 780-819 in Wells, P G , J N Butler, and J S Hughes, editors *Exion Valdez* oil spill fate and effects in Alaskan waters American Society for Testing and Materials, Philadelphia
- Eslinger, D, RT Cooney, CP McRoy, A Ward, T Kline, EP Simpson, J Wang, and JP Allen 2001 Plankton dynamics observed and modeled responses to physical factors in Prince William Sound, Alaska Fisheries Oceanography 10 (Suppl 1) 81-96
- Estes, J A 1999 Response to Garshelis and Johnson Science 283 175
- Estes, J A , C E Bacon, W M Jarman, R J Norstrom, R G Anthony, and A K Miles 1997 Organochlorines in sea otters and bald eagles from the Aleutian Archipelago Marine Pollution Bulletin 34 486-490
- Estes, J A and J L Bodkin in press Marine otters in Perrin, W F, B Wursig, H G M Thewissen, and C R Crumly, editors Encyclopedia of marine mammals Academic Press
- Estes, J A and D O Duggins 1995 Sea otters and kelp forests in Alaska generality and variation in a community ecological paradigm Ecological Monographs 65 75-100
- Estes, J A and C Harrold 1988 Sea otters, sea urchins, and kelp beds some questions of scale Pages 116-142 in VanBlaricom, G R and J A Estes, editors The community ecology of sea otters Springer Verlag, Berlin
- Estes, J A , R J Jameson, and E B Rhode 1982 Activity and prey selection in the sea otter influence of population status on community structure American Naturalist 120 242-258
- Estes, J A and J F Palmisano 1974 Sea otters their role in structuring nearshore communities Science 185 1058-1060
- Estes, J A, M T Tinker, T M Williams, and D F Doak 1998 Killer whale predation on sea otters linking oceanic and nearshore ecosystems Science 282 473-476
- EVOSTC 2000 Gulf Ecosystem Monitoring⁻ a sentinel monitoring program for the conservation of the natural resources of the northern Gulf of Alaska, GEM science program NRC review draft Anchorage, Alaska, *Exion Valdez* Oil Spill Trustee Council
- Fall, J, R Mıraglıa, W Sımeone, C J Utermohle, and R J Wolfe 2001 Long term consequences of the *Exxon Valdez* oil spill for coastal communities of Southcentral Alaska OCS Study, MMS 2001-032, Technical Report No 163
- Farmer, D M and J D Smith 1980 Generation of lee waves over the sill in Knight Inlet, in fjord oceanography Pages 259-270 in Freelan, H J, D M Farmer, and C D Levings, editors NATO conference on fjord oceanography, Victoria, B C, 1979 Plenum Press, New York

- Favorite, F 1974 Flow into the Bering Sea through Aleutian Island passes Pages 3-38 in Hood, D W and E J Kelley, editors Oceanography of the Bering Sea with emphasis on renewable resources proceeding of an international symposium Institute of Marine Science, University of Alaska, Fairbanks
- Favorite, F, A J Dodimead, and K Nasu 1976 Oceanography of the subarctic Pacific region, 1960-71 International North Pacific Fisheries Commission Bulletin No 33, 1-187
- Feder, H M and A Blanchard 1998 The deep benthos of Prince William Sound, Alaska, 16 months after the Erron Valdez oil spill Marine Pollution Bulletin 36 118-130
- Feder, H M and S C Jewett 1986 The subtidal benthos Pages 347-398 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C
- Feder, H M and G E Kaiser 1980 Intertidal biology in Colonell, J M, editor Port Valdez, Alaska environmental studies 1976-1979 Institute of Marine Sciences, University of Alaska, Fairbanks
- Feder, H M, A S Naidu, and A J Paul 1990 Trace-element and biotic changes following a simulated oil-spill on a mudflat in Port Valdez, Alaska Marine Pollution Bulletin 21 131-137
- Feder, H M and A J Paul 1974 Age, growth and size-weight relationships of the soft-shell clam, *Mya arenaria*, in Prince William Sound, Alaska Pages 45-52 Proceedings national shellfisheries association University of Alaska, Fairbanks
- Feder, H M and A J Paul 1980 Food of the king crab, *pai alithodes camtschatica* and the dungeness crab, *cancer magister* in Cook Inlet, Alaska Pages 240-246 Proceedings of the national shellfisheries association University of Alaska, Fairbanks
- Feder, H M and A J Paul 1980 Seasonal trends in meiofaunal abundance on two beaches in Port Valdez, Alaska Syesis 13 27-36
- Ferrero, R C , D P DeMaster, P S Hill, M Muto, and A L Lopez 2000 Alaska marine mammal stock assessments, 2000 U S Department of Commerce Seattle
- Ferrero, R C , S E Moore, and R C Hobbs in press Development of beluga, Delphinapterus leucas, capture and satellite tagging protocol in Cook Inlet, Alaska Marine Fisheries Review, Special Issue
- Finney, B P 1998 Long-term variability of Alaska sockeye salmon abundance determined by analysis of sediment cores North Pacific Anadromous Fish Commission Bulletin 388-395
- Finney, B P, I Gregory-Eaves, J Sweetman, M S V Douglas, and J P Smol 2000 Impacts of climatic change and fishing on Pacific salmon abundance over the past 300 years Science 290 795-799

- Flather, R A 1988 A numerical investigation of tides and diurnal-period continental shelf waves along Vancouver Island Journal of Physical Oceanography 18 115-139
- Ford, J K B 1991 Vocal traditions among resident killer whales (*Or cirius or ca*) in coastal waters of British Columbia Canadian Journal of Zoology 69 1454-1483
- Ford, J K B, G Ellis, and K C Balcomb 1994 Killer whales the natural history and genealogy of *Oi cinus oi ca* in British Columbia and Washington state University of British Columbia Press and University of Washington Press Vancouver and Seattle
- Ford, J K B, G M Ellis, L G Barrett-Lennard, A B Morton, and K C Balcomb III 1998 Dietary specialization in two sympatric populations of killer whales (*Or cirius or ca*) in coastal British Columbia and adjacent waters Canadian Journal of Zoology 76 1456-1471
- Foreman, MGG, WR Crawford, JY Cherniawsky, RF Henry, and MR Tarbotton 2000 A high-resolution assimilating tidal model for the northeast Pacific Ocean Journal of Geophysical Research 105 28629-28651
- Foreman, M G G and R E Thomson 1997 Three-dimensional model simulations of tides and buoyancy currents along the west coast of Vancouver Island Journal of Physical Oceanography 27 1300-1325
- Forney, K A , J Barlow, M M Muto, M Lowry, J Baker, G Cameron, J Mobley, C Stinchcomb, and J V Caretta 2000 U S Pacific marine mammal stock assessments 2000 U S Department of Commerce
- Foster, M S 1990 Organization of macroalgal assemblages in the Northeast Pacific the assumption of homogeneity and the illusion of generality Hydrobiologia 192 21-33
- Foster, M S and D R Schiel 1988 Kelp communities and sea otters keystone species or just another brick in the wall Pages 92-108 in VanBlaricom, G R and J A Estes, editors The community ecology of sea otters Springer Verlag, Berlin
- Foy, R J and A J Paul 1999 Winter feeding and changes in somatic energy content for age 0 Pacific herring in Prince William Sound, Alaska Transactions of the American Fisheries Society 128 1193-1200
- Francis, R C and S R Hare 1994 Decadal-scale regime shifts in the large marine ecosystems of the north-east Pacific a case for historical science Fisheries Oceanography 3 279-291
- Francis, R C , S R Hare, A B Hollowed, and W S Wooster 1998 Effects of interdecadal climate variability on the oceanic ecosystems of the northeast Pacific Fisheries Oceanography 7 1-21
- Freeland, H J and K L Denman 1982 A topographically controlled upwelling center off southern Vancouver Island Journal of Marine Research 40 1069-1093

- Freeland, HJ, KL Denman, CS Wong, F Whitney, and R Jacques 1997 Evidence of change in the winter mixed layer in the northeast Pacific Ocean Deep-Sea Research 44 2117-2129
- Freeland, H J and D M Farmer 1980 Circulation and energetics of a deep, strongly stratified inlet Canadian Journal of Aquatic Science 37 1398-1410
- Fried, N 2000 The Matanuska-Susitna Borough Alaska Department of Labor and Workforce Development, Alaska Economic Trends 20
- Fried, N and B Windisch-Cole 1999a Prince William Sound Alaska Department of Labor and Workforce Development, Alaska Economic Trends 19
- Fried, N and B Windisch-Cole 1999b The Kenai Peninsula Alaska Department of Labor and Workforce Development, Alaska Economic Trends
- Fritz, LW, RC Ferrero, and RJ Berg 1995 The threatened status of Steller sea lions, Eumetopias jubatus, under the Endangered Species Act effects on Alaska groundfish fisheries management Marine Fisheries Review 57 14-27
- Frost, B W 1983 Interannual variation of zooplankton standing stock in the open Gulf of Alaska Pages 146-157 in Wooster, W S, editor From year to year interannual variability of the environment and fisheries of the Gulf of Alaska and eastern Bering Sea Washington Sea Grant Program, University of Washington, Seattle
- Frost, B W 1991 The role of grazing in nutrient rich areas of the open sea Limnology and Oceanography 36 1616-1630
- Frost, B W 1993 A modeling study of processes regulating plankton standing stock and production in the open subarctic Pacific Ocean Progress in Oceanography 32 17-56
- Frost, K, L Lowry, and J Ver Hoef unpublished Alaska Department of Fish and Game and University of Fairbanks School of Fisheries and Ocean Science, Fairbanks, Alaska
- Frost, K J and L F Lowry 1986 Sizes of walleye pollock, Theragra chalcogramma, consumed by marine mammals in the Bering Sea Fishery Bulletin 84 192-197
- Frost, K J and L F Lowry 1990 Distribution, abundance, and movements of beluga whales, *Delphinapterus leucas*, in coastal waters of western Alaska Advances in research on the beluga whale, *Delphinapterus leucas* Pages 39-57 in Smith, T G , D J St Aubin, and J R Geraci, editors Canadian Bulletin of Fisheries and Aquatic Sciences Canadian Bulletin of Fisheries and Aquatic Sciences, Ottawa
- Frost, K J and L F Lowry 1994 Habitat use, behavior, and monitoring of harbor seals in Prince William Sound, Alaska, *Exxon Valdez* oil spill restoration project annual report (Restoration Project 93046) Alaska Department of Fish and Game, Wildlife Conservation Division Fairbanks
- Frost, K J, L F Lowry, E H Sinclair, J ver Hoef, and D C McAllister 1994 Impacts on distribution, abundance, and productivity of harbor seals Pages 97-118

in Loughlin, T R, editor Marine mammals and the *Exron Valdez* Academic Press, San Diego, California

- Frost, K J, L F Lowry, J Small, and S J Iverson 1996 Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Exxon Valdez oil spill restoration project annual report (Restoration Project 95064) Alaska Department of Fish and Game, Division of Wildlife Conservation Fairbanks
- Frost, K J, L F Lowry, and J Ver Hoef 1995 Habitat use, behavior, and monitoring of harbor seals in Prince William Sound, Alaska, *Exion Valdez* oil spill restoration project annual report (Restoration Project 94064 and 94320F) Alaska Department of Fish and Game, Wildlife Conservation Division Anchorage
- Frost, K J, L F Lowry, and J M Ver Hoef 1998 Monitoring, habitat use and trophic interactions of harbor seals in Prince William Sound Exxon Valdez Oil Spill Restoration Office Anchorage
- Frost, K J , L F Lowry, and J M Ver Hoef 1999 Monitoring the trend of harbor seals in Prince William Sound, Alaska, after the Exxon Valdez oil spill. Marine Mammal Science 15 494-506
- Frost, K J , L F Lowry, J M Ver Hoef, and S J Iverson 1997 Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Exaon Valdez oil spill restoration project annual report (Restoration Project 96064) Alaska Department of Fish and Game, Division of Wildlife Conservation Fairbanks
- Frost, K J , L F Lowry, J M Ver Hoef, S J Iverson, and T Gotthardt 1998
 Monitoring, habitat use, and trophic interactions of harbor seals in Prince
 William Sound, Alaska, Exxon Valdez oil spill restoration project annual
 report (Restoration Project 97064) Alaska Department of Fish and Game,
 Division of Wildlife Conservation Fairbanks
- Frost, K J, C A Manen, and T L Wade 1994 Petroleum hydrocarbons in tissues of harbor seals from Prince William Sound and the Gulf of Alaska Pages 331-358 in Loughlin, T R, editor Marine mammals and the Exion Valdez Academic Press, San Diego
- Frost, K J, M A Simpkins, and L F Lowry 2001 Diving behavior of non-pup harbor seals in Prince William Sound, Alaska Marine Mammal Science 17
- Fukuyama, A K, G Shigenaka, and R Z Hoff 2000 Effects of residual Exxon Valdez oil on intertidal Protothaca staminea mortality, growth, and bioaccumulation of hydrocarbons in transplanted clams Marine Pollution Bulletin 40 1042-1050
- Fulton, J D 1983 Seasonal and annual variations of net zooplankton at Ocean Station "P", 1956-1980 Canadian Data Report of Fisheries and Aquatic Sciences 374 65
- Funk, F 2000 Abundance, biology, and historical trends of Pacific herring, *Clupea pallasi*, in Alaskan waters REX workshop trends in herring populations and trophodynamics PICES

- Furness, R W and D N C Nettleship 1991 Seabirds as monitors of changing marine environments Proceedings of the International Ornithological Congress 20 2237-2280
- Gaines, S D and J Roughgarden 1987 Fish and offshore kelp forests affect recruitment to intertidal barnacle populations Science 235 479-481
- Ganopolski, A and S Rahmstorf 2001 Rapid changes of glacial climate simulated in a coupled climate model Nature 409 153-158
- Gargett, A 1997 Optimal stability window A mechanism underlying decadal fluctuations in north Pacific salmon stocks Fisheries Oceanography 109-117
- Garrett, C J R and J W Loder 1981 Dynamical aspects of shallow sea fronts Philosophical Transactions of the Royal Society of London A302 563-581
- Garshelis, D L 1997 Sea otter mortality estimated from carcasses collected after the *Exxon Valdez* oil spill Conservation Biology 11 905-916
- Garshelis, DL, JA Garshelis, and AT Kimker 1986 Sea otter time budgets and prey relationships in Alaska Journal of Wildlife Management 50 637-647
- Garshelis, D L, A M Johnson, and J A Garshelis 1984 Social organization of sea otters in Prince William Sound, Alaska Canadian Journal of Zoology 62 2648-2658
- Gawarkiewicz, G 1991 Linear stability models of shelfbreak fronts Journal of Physical Oceanography 21 471-488
- Gawarkiewicz, G and D C Chapman 1992 The role of stratification in the formation and maintenance of shelf-break fronts Journal of Physical Oceanography 22 753-772
- Gay III, S M and S L Vaughan 2001 Seasonal hydrography and tidal currents of bays and fjords in Prince William Sound, Alaska Fisheries Oceanography 10 (Suppl 1) 159-193
- Gentry, R L 1971 Social behavior of the Steller sea lion University of California, Santa Cruz
- Gentry, R L and J H Johnson 1981 Predation by sea lions on northern fur seal neonates 45 423-430
- Gilfillan, E S, D S Page, E J Harner, and P D Boehm 1995a Shoreline ecology program for Prince William Sound, Alaska, following the *Exion Valdez* oil spill part 3 - biology Pages 398-443 in Wells, P G, J N Butler, and J S Hughes, editors *Exion Valdez* oil spill fate and effects in Alaskan waters American Society for Testing and Materials, Philadelphia
- Gilfillan, E S, T H Suchanek, P D Boehm, E J Harner, D S Page, and N A Sloan 1996b Shoreline impacts in the Gulf of Alaska region following the *Exion Valdez* oil spill Pages 444-487 in Wells, P G, J N Butler, and J S Hughes, editors *Exion Valdez* oil spill fate and effects in Alaskan waters American Society for Testing and Materials, Philadelphia
- Gill, V and S Hatch unpublished data US Geological Survey, Anchorage, Alaska

- Gill, V A 1999 Breeding performance of black-legged kittiwakes (*Rissa tridactyla*) in relation to food availability a controlled feeding experiment Anchorage, University of Alaska
- Gisiner, R C 1985 Male territorial and reproductive behavior in the Steller sea lion, *Eumetopias jubatus* University of California, Santa Cruz
- Goldsmith, S 2001 Economic projections Alaska and the Southern Railbelt 2000-2025 Prepared by the Institute of Social and Economic Research for Chugach Electric Association
- Goering, J J, W E Shiels, and C J Patton 1973 Primary production Pages 253-279 in Hood, D W, W E Shiels, and E J Kelley, editors Evironmental studies of Port Valdez Institute of Marine Science, University of Alaska, Fairbanks
- Goldsmith, S and S Martin 2001 ANILCA and the Seward economy for the Alaska State Office, National Audubon Society Anchorage, Institute of Social and Economic Research, University of Alaska
- Groot, C and L Margolis 1991 Pacific salmon life histories University of British Columbia Press Vancouver
- Haldorson, L 2001 personal communication Fisheries Division, School of Fisheries and Ocean Sciences, University of Alaska, Juneau, Alaska
- Hampton, M A , P R Carlson, and H J Lee 1986 Geomorphology, sediment and sedimentary processes Pages 93-143 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C
- Hansen, D J and J D Hubbard 1999 Distribution of Cook Inlet beluga whales (*Delphinapterus leucas*) in winter U S Department of the Interior, Minerals Management Service Anchorage
- Hare, S R and N J Mantua 2000 Empirical evidence for North Pacific regime shifts in 1977 and 1989 Progress in Oceanography 47 103-146
- Hare, S R, N J Mantua, and R C Francis 1999 Inverse production regimes Alaska and west coast Pacific salmon Fisheries 24 6-14
- Hart, J L 1973 Pacific fishes of Canada Bulletin of the Fisheries Research Board of Canada 180 740
- Hatch, S 2001 personal communication U S Geological Survery, Anchorage, Alaska

Hatch, S unpublished data US Geological Survery, Anchorage, Alaska

- Hatch, S and V Gill unpublished data US Geological Survey, Anchorage, Alaska
- Hatch, S A 1984 Nestling diet and feeding rates of rhinoceros auklets in Alaska Pages 106-115 in Nettleship, D N, G A Sanger, and P F Springer, editors Marine birds their feeding ecology and commercial fisheries relationships Canadian Wildlife Service, Ottawa

- Hatch, S A 1993 Ecology and population status of northern fulmars (*Fulmarus glacialis*) of the North Pacific Pages 82-92 in Vermeer, K, KT Briggs, KH Morgan, and D Siegel-Causey, editors Status, ecology, and conservation of marine birds of the North Pacific Canadian Wildlife Service, Ottawa
- Hatch, S A , G V Byrd, D B Irons, and G L Hunt 1993 Status and ecology of kittiwakes (*Rissa tridactyla* and *R brevirostris*) in the North Pacific Pages 140-153 in Vermeer, K , K T Briggs, K H Morgan, and D Siegel-Causey, editors The status, ecology and conservation of marine birds of the North Pacific Canadian Wildlife Service, Special Publication, Ottawa
- Hatch, S A and M A Hatch 1983 Populations and habitat use of marine birds in the Semidi Islands Murrelet 64 39-46
- Hatch, S A and M A Hatch 1989 Attendance patterns of murres at breeding sites implications for monitoring Journal of Wildlife Management 53 483-493
- Hatch, S A and G A Sanger 1992 Puffins as samplers of juvenile pollock and other forage fish in the Gulf of Alaska Marine Ecology Progress Series 80 1-14
- Hay, D E, J Boutillier, M Joyce, and G Langford 1997 The eulachon (*Thaleichthys pacificus*) as an indicator species in the North Pacific Pages 509-530 in Forage fishes in marine ecosystems proceedings of the international symposium on the role of forage fishes in marine ecosystems Alaska Sea Grant College Program, University of Alaska, Fairbanks
- Hayes, D L and K J Kuletz 1997 Decline of pigeon guillemot populations in Prince William Sound, Alaska, and apparent changes in distribution and abundance of their prey Pages 699-702 in Forage fishes in marine ecosystems proceedings of the international symposium on the role of forage fishes in marine ecosystems Alaska Sea Grant College Program, Fairbanks
- Hays, J D , J Imbrie, and N J Skackleton 1976 Variations in the Earth's orbit pacemaker of the ice ages Science 194 1121-1132
- Hazard, K 1988 Beluga whale, *Delplunapterus leucas* Pages 195-235 in Lentfer, J W, editor Selected marine mammals of Alaska species accounts with research and management recommendations U S Marine Mammal Commission, Washington, D C
- Heggie, D T and D C Burrell 1981 Deepwater renewals and oxygen consumption in an Alaskan fjord Estuarine, Coastal and Shelf Science 13 83-99
- Heinrich, A K 1962 The life history of plankton animals and seasonal cycles of plankton communities in the oceans Journal du Conseil Conseil International pour l'Exploration de la Mer 27 15-24
- Heyning, J E and M E Dahlheim 1988 Or cinus or ca Mammalian Species 304 1-9
- Hickey, B M 1997 The response of a steep-sided narrow canyon to strong wind forcing Journal of Physical Oceanography 27 697-726
- Highsmith, R C , T L Rucker, M S Stekoll, S M Saupe, M R Lindeberg, R N Jenne, and W P Erickson 1996 Impact of the *Exaon Valdez* oil spill on intertidal biota American Fisheries Society Symposium 18 212-237

- Highsmith, R C , M S Stekoll, W E Barber, L Deysher, L McDonald, D Strickland, and W P Erickson 1994 Comprehensive assessment of coastal habitat, *Exxon Valdez* oil spill state/federal natural resource damage assessment final report (Coastal Habitat Study Number 1A) Fairbanks, School of Fisheries and Ocean Sciences, University of Alaska Coastal Habitat Study Number 1A
- Hilborn, R 1992 Hatcheries as future of salmon in Northwest Fisheries 175
- Hobbs, R 2000 personal communication National Marine Fisheries Service, National Marine Mammal Laboratory, Seattle, Washington
- Hobbs, R C , D J Rugh, and D P DeMaster in press Abundance of beluga whales in Cook Inlet, Alaska, 1994-1998 Marine Fisheries Review
- Hoelzel, A R, M E Dahlheim, and S J Stern 1998 Low genetic variation among killer whales (Orcinus orca) in the Eastern Northern Pacific, and genetic differentiation between foraging specialists Journal of Heredity 89
- Hollowed, A B and W S Wooster 1992 Variability of winter ocean conditions and strong year classes of northeast Pacific groundfish Pages 433-444 ICES marine science symposium
- Hollowed, A B and W S Wooster 1995 Decadal-scale variations in the eastern subarctic Pacific II Response of northeast Pacific fish stocks Pages 373-385 in Beamish, R J, editor Climate change and northern fish populations National Research Council of Canada, Ottawa
- Hood, D W and S T Zimmerman 1986 The Gulf of Alaska, physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce Washington, D C
- Hoover-Miller, A, K R Parker, and J J Burns 2000 A reassessment of the impact of the *Exxon Valdez* oil spill on harbor seals (*Phoca vitulina richai dsi*) in Prince William Sound, Alaska Marine Mammal Science 17 111-135
- Hoover-Miller, A A 1994 Harbor seal (Phoca vitulina) biology and management in Alaska Washington, D C
- Hostettler, F D , R J Rosenbauer, and K A Kvenholden 2000 Reply response to comment by Bence et al Organic Geochemistry 31 939-943
- Houghton, J P, A K Fukuyama, D C Lees, Teas III, H, H L Cumberland, P M Harper, T A Ebert, and W B Driskell 1993 Evaluation of the 1991 condition of Prince William Sound shorelines following the *Exxon Valdez* oil spill and subsequent shoreline treatment Volume II, 1991 biological monitoring survey Seattle, NOAA, Hazardous Materials Response and Assessment Division
- Houghton, J P , D C Lees, W B Driskell, and S C Lindstrom 1996a Evaluation of the condition of Prince William Sound shorelines following the Exxon Valdez oil spill and subsequent shoreline treatment Volume I, 1994 biological monitoring survey Seattle, NOAA, Hazardous Materials Response and Assessment Division NOAA Technical Memorandum NOS ORCA 91

- Houghton, J P, D C Lees, W B Driskell, S C Lindstrom, and A J Mearns 1996b Recovery of Prince William Sound epibiota from Exxon Valdez oiling and shoreline treatments, 1989 through 1992 American Fisheries Society Symposium 18 379-411
- Houghton, R W, Olson, and Celone 1986 Observation of an anticyclonic eddy near the continental shelf break south of New England Journal of Physical Oceanography 16 60-71
- Hunt Jr, GL, CL Badumi, RD Brodeur, KO Coyle, NB Kachel, JM Napp, SA Salo, JD Schumacher, PJ Stabeno, DA Stockwell, T Whitledge, and S Zeeman 1999 The Bering Sea in 1998 a second consecutive year of weather forced anomalies EOS, Transactions of the American Geophysical Union 89 561-566
- Hunt Jr, GL, B Burgesson, and GA Sanger 1981 Feeding ecology of seabirds of the eastern Bering Sea Pages 629-648 in Hood, DW and JA Calder, editors The eastern Bering Sea shelf oceanography and resources National Oceanic and Atmospheric Administration, Juneau
- Incze, L S , A W Kendall, Schumacher Jr , J D , and R K Reed 1989 Interactions of a mesoscale patch of larval fish (*Theragra chalcogramma*) with the Alaska Coastal Current Continental Shelf Research 9 269-284
- Incze, LS, DW Siefert, and JM Napp 1997 Mesozooplankton of Shelikof Strait, Alaska abundance and community composition Continental Shelf Research 17 287-305
- Irons, D unpublished data US Fish and Wildlife Service, Anchorage, Alaska
- Irons, D B 1992 Aspects of foraging behavior and reproductive biology of the black-legged kittiwake University of California,Irvine
- Irons, D B 1996 Size and productivity of black-legged kittiwake colonies in Prince William Sound before and after the *Exxon Valdez* oil spill Pages 738-747 in Rice, S D, R B Spies, D A Wolf, and B A Wright, editors Proceedings of the *Exxon Valdez* oil spill symposium
- Irons, D B, S J Kendall, W P Erickson, L L McDonald, and B K Lance 2000 Nine years of *Exxon Valdez* oil spill effects on marine birds in Prince William Sound, Alaska The Condor 102 723-737
- Iverson, S J , K J Frost, and L F Lowry 1997 Fatty acids signatures reveal fine scale structure of foraging distribution of harbor seals and their prey in Prince William Sound, Alaska Marine Ecology Progress Series 151 255-271
- Jackson, J B , M X Kırby, W H Berger, K A Bjorndal, L W Botsford, B J Bourque, R H Bradbury, R Cooke, J Erlandson, J A Estes, T P Hughes, S Kıdwell, C B Lange, H S Lenihan, J M Pandolfi, C H Peterson, R S Steneck, M J Tegner, and R R Warner 2001 Historical overfishing and the recent collapse of coastal ecosystems Science 293 629-638
- Jacob, K H 1986 Seismicity, tectonics, and geohazards of the Gulf of Alaska regions Pages 145-186 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska

Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C

- Jameson, R J 1989 Movements, home ranges, and territories of male sea otters off central California Marine Mammal Science 5 159-172
- Jameson, R J and A M Johnson 1993 Reproductive characteristics of female sea otters Marine Mammal Science 9 156-167
- Jewett, S C , T A Dean, R O Smith, and A Blanchard 1999 Exxon Valdez oil spill impacts and recovery in the soft-bottom benthuc community in and adjacent to eelgrass beds Marine Ecology Progress Series 185 59-83
- Jewett, S C and H M Feder 1982 Food and feeding habits of the king crab Paralithodes camtschatica near Kodiak Island, Alaska Marine Biology 66 243-250
- Jewett, S C and H M Feder 1983 Food of the tanner crab Chionoecetes bairdi near Kodiak Island, Alaska Journal of Crustacean Biology 3 196-207
- Johnson, W R , T C Royer, and J L Luick 1988 On the seasonal variability of the Alaska Coastal Current Journal of Geophysical Research 12423-12437
- Jones, ML, SL Swartz, and S Leatherwood 1984 The gray whale *Eschrichus 1 obustus* Academic Press London
- Joyce, T, Bishop, and Brown 1992 Observations of offshore shelf water transport induced by a warm core ring Deep-Sea Research 39 97-113
- Kajimura, H and T R Loughlin 1988 Marine mammals in the oceanic food web of the eastern subarctic Pacific Bulletin of the Ocean Research Institute of Tokyo 26 187-223
- Kannan, K, KS Guruge, NJ Thomas, S Tanabe, and JP Giesy 1998 Butyltin residues in southern sea otters (Enhydra lutris nereis) found dead along California coastal waters Environmental Science and Technology 32 1169-1175
- Kastelein, R A , N Vaughan, and P R Wiepkema 1990 The food consumption of Steller sea lions (*Eumetopias jubatus*) Aquatic Mammals 15 137-144
- Kawamura, A 1988 Characteristics of the zooplankton biomass distribution in the standard Norpac net catches in the North Pacific region Bulletin of Plankton Society of Japan 35 175-177
- Kenai Fjords National Park 1990 Visitor services project, report no 30
- Kendall, AW, RI Perry, and S Kim 1996 Fisheries oceanography of walleye pollock in Shelikof Strait, Alaska Fisheries Oceanography 5 203
- Kenyon, KW 1969 The sea otter in the eastern Pacific Ocean North American Fauna 68 352
- Kenyon, KW 1982 Sea otter, Enhydra lutris Pages 704-410 in Chapman, J A and G A Feldhamer, editors Wild mammals of North America The Johns Hopkins University Press, Baltimore

- Kenyon, K W and D W Rice 1961 Abundance and distribution of the Steller sea lion Journal of Mammalogy 42 223-234
- Kırsch, J, G L Thomas, and R T Cooney 2000 Acoustic estimates of zooplankton distributions in Prince William Sound, spring, 1996 Fisheries Research 47 245-260
- Kitaysky, AS, JC Wingfield, and JF Piatt 1999 Dynamics of food availability, body condition and physiological stress response in breeding kittiwakes Functional Ecology 13 577-584
- Klein, W H 1957 Principal tracks and mean frequencies of cyclones and anticyclones in the northern hemisphere Washington, D C , U S Weather Bureau, U S Government Printing Office Research Paper Number 40
- Klinck, J M 1996 Circulation near submarine canyons a modeling study Journal of Geophysical Research 101 1211-1223
- Kline Jr, T C 1999a Temporal and spatial variability of ¹³C/¹² C and ¹⁵N/¹⁴N in pelagic biota of Prince William Sound, Alaska Canadian Journal of Fisheries and Aquatic Sciences 56 (Suppl 1) 94-117
- Kline, TC, JJ Goering, OA Mathisen, PH Poe, and PL Parker 1990 Recycling of elements transported upstream by runs of Pacific salmon I $\Box^{15}N$ and $\Box^{13}C$ evidience in Sashin Creek, Southeastern, Alaska Canadian Journal of Fisheries and Aquatic Sciences 47 136-144
- Kline, T C , J J Goering, O A Mathisen, P H Poe, P L Parker, and R S Scalan 1993
 Recycling of elements transported upstream by runs of Pacific salmon II
 □¹⁵N and □¹³C evidence in the Kvichak River watershed, Bristol Bay,
 Southwestern, Alaska Canadian Journal of Fisheries and Aquatic Sciences
 50 2350-2365
- Klinkhart, E.G. 1966 The beluga whale in Alaska Alaska Department of Fish and Game Federal Aid in Wildlife Restoration Project Report Volume VII
- Klosiewski, S P and K K Laing 1994 Marine bird populations of Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill Anchorage, U S Fish and Wildlife Service
- Koblinsky, C J, P P Nuler, and Schmitz Jr, W J 1989 Observations of wind-forced deep ocean currents in the North Pacific Journal of Geophysical Research 94 10773-10790
- Kron, T 1993 Prince William Sound enhancement programs and considerations relative to wild stocks Alaska Department of Fish and Game
- Kruse, G H, F C Funk, H J Geiger, K R Mabry, H M Savikko, and S M Siddeek 2000 Overview of state-managed marine fisheries in the Central and Western Gulf of Alaska, Aleutian Islands, and Southeastern Bering Sea, with reference to Steller Sea Lions Juneau, Alaska Department of Fish and Game Regional Information Report 5J00-10
- Kuletz, K J, D B Irons, B A Agler, and J F Piatt 1997 Long-term changes in diets of populations of piscivorus birds and mammals in Prince William Sound, Alaska Forage fishes in marine ecosystems proceedings of the international

symposium on the role of forage fishes in marine ecosystems Fairbanks, Alaska Sea Grant College Program, University of Alaska Fairbanks

- Kvitek, RG, CE Bowlby, and M Staedler 1993 Diet and foraging behavior of sea otters in southeast Alaska Marine Mammal Science 9 168-181
- Kvitek, R G and J S Oliver 1988 Sea otter foraging habits and effects on prey populations and communities in soft-bottom environments Pages 22-47 in VanBlaricom, G R and J A Estes, editors The community ecology of sea otters Springer Verlag, Berlin
- Kvitek, R G and J S Oliver 1992 Influence of sea otters on soft-bottom prey communities in Southeast Alaska Marine Ecology Progress Series 82 103-113
- Kvitek, RG, JS Oliver, AR DeGange, and BS Anderson 1992 Changes in Alaskan soft-bottom prey communities along a gradient in sea otter predation Ecology 73 413-428
- Lagerloef, G 1983 Topographically controlled flow around a deep trough transecting the shelf off Kodiak Island, Alaska Journal of Physical Oceanography 13 139-146
- Laidre, K, K E W Shelden, B A Mahoney, and D J Rugh in press Distribution of beluga whales and survey effort in the Gulf of Alaska Marine Fisheries Review
- Lambeck, K 1980 The Earth's variable rotation geophysical causes and consequences Cambridge University Press London
- Larkın, G A and P A Slaney 1997 Implications of trends in marine-derived nutrient influx to south coastal British Columbia salmonid production Fisheries 16-24
- Lawrence, J M 1975 On the relationship between marine plants and sea urchins Oceanography and Marine Biology Annual Review 13 213-286
- Leatherwood, S, CO Matkin, J D Hall, and G M Ellis 1990 Killer whales, *Oi nicus oi ca*, photo-identified in Prince William Sound, Alaska 1976-1987 Canadian Field-Naturalist 104 32-371
- LeBrasseur, R J 1965 Biomass atlas of net-zooplankton in the Northeastern Pacific Ocean, 1956-1964 Manuscript Report Series (Oceanography and Limnological)
- Leigh, Jr E G , R T Paine, J F Quinn, and T H Suchanek 1987 Wave energy and intertidal productivity Proceedings of the National Academy of Sciences USA 84 1314-1318
- Lensink, C 1964 Distribution and status of sea otters in Alaska Purdue University, West Lafayette, Indiana
- Lensink, C J 1962 The history and status of sea otters in Alaska Purdue University,Indiana
- Lentfer, J 1988 Selected marine mammals of Alaska Washington, D C
- Lethcoe, J and Lethcoe, N 1985 Cruising guide to Prince William Sound, Alaska Volume II eastern part Prince William Sound
- Lewis, J P 1996 Harbor seal investigations in Alaska Juneau, National Marine Fisheries Service Annual Report Award Number NA57FX0367
- Liepitz, G S 1994 An assessment of the cumulative impacts of development and human uses on fish habitat on the Kenai River Alaska Department of Fish and Game Technical Report No 94-6
- Lindberg, D R , J A Estes, and K I Warheit 1998 Human influences on trophic cascades along rocky shores Ecological Applications 8 880-890
- Lindeman, R L 1942 The trophodynamic aspect of ecology Ecology 23 399-418
- Litchfield, V and A Milner 1998 Kenai River bioassessment effects of storm drain outfall on the benthic invertebrate community Alaska Department of Fish and Game Report No 2A98-26
- Livingstone, D and T C Royer 1980 Observed surface winds at Middleton Island, Gulf of Alaska and their influence on ocean circulation Journal of Physical Oceanography 10 753-764
- Loeb, V, V Siegel, O Holm-Hansen, R Hewitt, W Fraser, W Trivelpiece, and S Trivelpiece 1997 Effects of sea-ice extent and krill or salp dominance on the Antarctic food web Nature 387 897-900
- Longhurst, A L 1976 Vertical migration Pages 116-137 in Cushing, D H and J J Walsh, editors The ecology of the seas W B Sanders Co, Philadelphia
- Loughlin, T R 1981 Home range and territoriality of sea otters near Monterey, California Journal of Wildlife Management 44 576-582
- Loughlin, T R 1997 Using the phylogeographic method to identify Steller sea lion stocks Pages 159-171 in Dizon, A E, S J Chivers, and W F Perrin, editors Molecular genetics of marine mammals Society for Marine Mammalogy Special Publication 3
- Loughlin, T R 1998 The Steller sea lion a declining species Biosphere Conservation 1 91-98
- Loughlin, T R , A S Perlov, and V A Vladimirov 1992 Range-wide survey and estimation of total number of Steller sea lions in 1989 Marine Mammal Science 8 220-239
- Loughlin, T R, D J Rugh, and C H Fiscus 1984 Northern sea lion distribution and abundance 1956-80 Journal of Wildlife Management 48 729-740
- Lowry, L and K Frost unpublished Alaska Department of Fish and Game and University of Alaska School of Fisheries and Ocean Science, Fairbanks, Alaska
- Lowry, L and K Frost unpublished data Alaska Department of Fish and Game and University of Alaska School of Fisheries and Ocean Science, Fairbanks, Alaska

- Lowry, L F and K J Frost unpublished Alaska Beluga Whale Committee surveys of beluga whales in Bristol Bay, Alaska, 1993-1994 Paper SC/51/SM____ presented to the IWC Scientific Committee, May, 1999
- Lowry, LF, KJ Frost, R Davis, RS Suydam, and DP DeMaster 1994 Movements and behavior of satellite-tagged spotted seals (Phoca largha) in the Bering and Chukchi Seas US Department of Commerce, National Oceanic and Atmospheric Administration
- Lowry, L F, K J Frost, and T R Loughlin 1989 Importance of walleye pollock in the diets of marine mammals in the Gulf of Alaska and Bering Sea, and implications for fishery management Pages 701-726 in Proceedings of the international symposium on the biology and management of walleye pollock, November 14-16, 1988 Anchorage, Alaska University of Alaska Sea Grant Program, Fairbanks
- Lowry, L F, K J Frost, J M Ver Hoef, and R A DeLong 2001 Movements of satellite-tagged non-pup harbor seals in Prince William Sound, Alaska Marine Mammal Science 17
- Lubchenco, J and S D Gaines 1981 A unified approach to marine plant-herbivore interactions I Populations and communities Annual Review of Ecology and Systematics 12 405-437
- Luick, J L , T C Royer, and W P Johnson 1987 Coastal atmospheric forcing in the northern Gulf of Alaska Journal of Geophysical Research 92 3841-3848
- Lynch-Stieglitz, J, W B Curry, and N Slowey 1999 Weaker gulf stream in the Florida Straits during the last glacial maximum Nature 402 644-648
- Lynde, M V 1986 The historical annotated landing (HAL) database documentation of annual harvest of groundfish from the northeast Pacific and eastern Bering Sea from 1956-1980
- Mackas, D L and B W Frost 1993 Distributions and seasonal/interannual variations in the phytoplankton and zooplankton biomass PICES Scientific Report 1 51-56
- Mackas, D L, R Goldblatt, and A G Lewis 1998 Interdecadal variation in developmental timing of *Neocalanus plumchrus* populations at Ocean Station P in the subarctic North Pacific Canadian Journal of Fisheries and Aquatic Sciences 55 1878-1893
- Mackas, D L , H Sefton, C B Miller, and A Raich 1993 Vertical habitat partitioning by large calanoid copepods in the oceanic subarctic Pacific during spring Progress in Oceanography 32 259-294
- Macklin, S A , G M Lackmann, and J Gray 1988 Offshore directed winds in the vicinity of Prince William Sound, Alaska Monthly Weather Review 116 1289-1301
- Mahoney, B A and K E W Shelden in press The native subsistence harvest of beluga whales, Delphinapterus leucas, in Cook Inlet, Alaska Marine Fisheries Review, Special Issue

- Malloy, R J and G F Merrill 1972 Vertical crustal movement on the sea floor The great Alaska earthquake of 1964, vol 6 oceanography and coastal engineering Washington, D C, National Research Council, National Academy of Sciences
- Mangel, J, L M Talbot, G K Meffe, M T Agardy, D L Alverson, J Barlow, D B Botkin, G Budowski, T Clark, J Cooke, R H Crozier, P K Dayton, D L Elder, C W Fowler, S Funtwicz, J Giske, R J Hofman, S J Holt, S R Kellert, L A Kimbal, D Ludwig, K Magnusson, Malayang III, C, C Mann, E A Norse, S P Nothridge, W F Perrin, C Perrings, R Peterman, G B Rabb, H A Regier, J E Reynolds, K Sherman, M P Sissenwine, T D Smith, A Starfield, R J Taylor, M F Tillman, C Toft, J Twiss, R John, J Wilen, and T P Young 1996 Principles for the conservation of wild living resources Ecological Applications 6 338-362
- Mann, K H and J R N Lazier 1996 Dynamics of marine ecosystems, biologicalphysical interactions in the oceans, 2nd ed Blackwell Science, Inc Cambridge
- Mantua, NJ, SR Hare, Y Zhang, JM Wallace, and RC Francis 1997 A Pacific interdecadal climate oscillation with impacts on salmon production Bulletin of the American Meteorological Society 78 1069-1079
- Mantyla and Reid 1983 Abyssal characteristics of the world ocean waters Deep-Sea Research 30 805-833
- Marchland, C, Y Sımrad, and Y Gratton 1999 Concentration of capelin (*Mallotus villosus*) in tidal upwelling fronts at the head of the Laurentian Channel in the St Lawrence estuary Canadian Journal of Fisheries and Aquatic Sciences 56 1832-1848
- Martin, J H 1990 Glacial-interglacial CO_2 change the iron hypothesis Paleoceanography 5 1-13
- Martin, J H 1991 Iron, Leibig's law, and the greenhouse Oceanography 4 52-55
- Martin, J H and R M Gordon 1988 Northeast Pacific iron distributions in relation to primary productivity Deep-Sea Research 35 177-196
- Martin, M H 1997 Data report 1996 Gulf of Alaska bottom trawl survey US Department of Commerce, National Oceanic and Atmospheric Administration
- Mathisen, O A 1972 Biogenic enrichment of sockeye salmon lakes and stock productivity Verhandlungen der Internationalen Vereinigung für Theoretische and Angewandte Limnologie 18 1089-1095
- Matkin, C 2000 personal communication North Gulf Oceanic Society, Homer, Alaska National Oceanic and Atmospheric Administration, Juneau, Alaska
- Matkin, CO unpublished data North Gulf Oceanic Society, Homer, Alaska
- Matkin, CO, G Ellis, L Barrett-Lennard, H Jurk, and E Saulitis 2000 Photographic and acousic monitoring of killer whales in Prince William Sound and Kenai Fjords, Alaska Homer, North Gulf Oceanic Society Restoration Project Annual Report 99012

300

- Matkin, CO, G Ellis, L Barrett-Lennard, H Jurk, D Sheel, and E Saulitis 1999 Comprehensive killer whale investigation restoration project 98012 annual report North Gulf Oceanic Society Homer
- Matkin, CO, GM Ellis, ME Dahlheim, and J Zeh 1994 Status of killer whales in Prince William Sound, 1985-1992 Pages 141-162 in Loughlin, TR, editor Marine mammals and the *Exxon Valdez* Academic Press, San Diego
- Matkin, CO, DR Matkin, GM Ellis, E Saulitis, and D McSweeney 1997 Movements of resident killer whales in southeastern Alaska and Prince William Sound, Alaska Marine Mammal Science 13 469-475
- Matkin, CO and EL Saulitis 1994 Killer whale (Orcinus orca) biology and management in Alaska
- Matkin, CO, D Scheel, G Ellis, L Barrett-Lennard, H Jurk, and E Saulitis 1998 Comprehensive killer whale investigation, *Exron Valdez* oil spill restoration project annual report (Restoration Project 97012) North Gulf Oceanic Society Homer
- McAllister, C D 1969 Aspects of estimating zooplankton production from phytoplankton production Journal of Fisheries Research Board of Canada 26 199-220
- The McDowell Group 1999 The economic impacts of the cruise ship industry in Anchorage
- McElroy, M P 1983 Marine biological controls on atmospheric CO $_{2}$ and climate Nature 302 $\,$ 328-329 $\,$
- McRoy, C P 1970 Standing stocks and other features of eelgrass (Zostera marina) populations on the coast of Alaska Journal of the Fisheries Research Board of Canada 27 1811-1821
- McRoy, C P and J J Goering 1974 Coastal ecosystems of Alaska Pages 124-145 in Odum, H T, B J Copeland, and E H McMahan, editors Coastal ecological systems of the United States, vol 3 The Conservation Foundation, Washington, D C
- Mearns, A J 1996 *Exion Valdez* shoreline treatment and operations implications for response, assessment, monitoring, and research American Fisheries Society Symposium 18 309-328
- Megrey, B A , A B Hollowed, S R Hare, S A Macklin, and P J Stabeno 1996 Contributions of FOCI research to forecasts of year-class strength of walleye pollock in Shelikof Strait, Alaska Fisheries Oceanography 5(Suppl 1) 1989-203
- Meier, M F 1984 Contribution of small glaciers in global sea level Science 226 1481-1421
- Melsom A, SD Meyers, HE Hurlburt, EJ Metzger, and JJ O'Brien 1999 El Niño induced eddies in the Gulf of Alaska, Earth interact
- Mendenhall, V M 1997 Preliminary report on the 1997 Alaska seabird die-off Anchorage, U S Fish and Wildlife Service

- Menge, B A 1995 Indirect effects in marine rocky intertidal interaction webs patterns and importance Ecological Monographs 65 21-74
- Menge, B A , E L Berlow, C A Blanchette, S A Navarette, and S B Yamada 1994 The keystone species concept variation in interaction strength in a rocky intertidal habitat Ecological Monographs 249 249-287
- Menge, B A and E D Sutherland 1987 Community regulation variation in disturbance, competition, and predation in relation to gradients of environmental stress and recruitment American Naturalist 130 730-757
- Merrick, R L and D G Calkins 1996 Importance of juvenile walleye pollock, *Thei agi a chalcogi anima*, in the diet of Gulf of Alaska Steller sea lions, *Eumetopias jubatus* Pages 153-166 in Brodeur, R D, P A Livingston, T R Loughlin, and A B Hollowed, editors Ecology of juvenile walleye pollock, *Thei agi a chalcogi anima* National Marine Fisheries Service, Seattle
- Merrick, R L, M K Chumbley, and G V Byrd 1997 Diet diversity of Steller sea lions (*Eumetopias jubatus*) and their population decline in Alaska a potential relationship Canadian Journal of Zoology 54 1342-1348
- Merrick, R L and T R Loughlin 1997 Foraging behavior of adult female and young-of-the-year Steller sea lions in Alaskan waters Canadian Journal of Zoology 75 776-786
- Merrick, R L , T R Loughlin, and D G Calkins 1987 Decline in abundance of the northern sea lion, Eumetopias jubatus, in Alaska, 1956-86 Fishery Bulletin 85 351-365
- Meyers, S D and S Basu 1999 Eddies in the eastern Gulf of Alaska from TOPEX/POSEIDON altimetry Journal of Geophysical Research 104 13333-13343
- Miller, C B 1988 *Neocalanus flemingeri*, a new species of Calanidae (Copepoda Calanoida) from the Subarctic Pacific Ocean, with a comparative redescription of *Neocalanus plumchrus* (Marukawa) 1921 Progress in Oceanography 20 223-274
- Miller, C B 1993 Pelagic production processes in the subarctic Pacific Progress in Oceanography 32 1-15
- Miller, C B and M J Clemons 1988 Revised life history analysis of the large grazing copepods in the Subarctic Pacific Ocean Progress in Oceanography 20 293-313
- Miller, C B, B W Frost, B Booth, P A Wheeler, M R Landry, and N Welschmeyer 1991a Ecological processes in the Subarctic Pacific iron limitation cannot be the whole story Oceanography 4 71-78
- Miller, C B , B W Frost, P A Wheeler, M R Landry, N Welschmeyer, and T M Powell 1991b Ecological dynamics in the subarctic Pacific, possibly iron limited system Limnology and Oceanography 36 1600-1615
- Miller, C B and R D Nielsen 1988 Development and growth of large calanid copepods in the Subarctic Pacific, May 1984 Progress in Oceanography 20 275-292

- Minobe, S 1997 A 50-70 year climatic oscillation over the North Pacific and North America Geophysical Research Letters 24 683-686
- Minobe, S 1999 Resonance in bidecadal and pentadecadal climate oscillations over the North Pacific role in climatic regime shifts Geophysical Research Letters 26 855-858
- Molnia, B F 1981 Distribution of continental shelf surface sedimentary units between Yakutat and Cross Sound, northeastern Gulf of Alaska Journal of the Alaska Geological Society 1 60-65
- Monson, D H and A R DeGange 1995 Reproduction, preweaning survival, and survival of adult sea otters at Kodiak Island, Alaska Canadian Journal of Zoology 73 1161-1169
- Monson, D H, D F Doak, B E Ballachey, A M Johnson, and J L Bodkin 2000 Long-term impacts of the Exxon Valdez oil spill on sea otters, assessed through age-dependent mortality patterns Pages 6562-6567 Proceedings of the National Academy of Sciences
- Monson, D H, J A Estes, J L Bodkin, and D B Siniff 2000 Life history plasticity and population regulation in sea otters Oikos 90 457-468
- Montevecchi, W A and R A Myers 1996 Dietary changes of seabirds indicate shifts in pelagic food webs Sarsia 80 313-322
- Moore, S E , K E W Shelden, L K Litzky, B A Mahone, and D J Rugh in press Beluga, Delphinapterus leucas, habitat associations in Cook Inlet, Alaska Marine Fisheries Review, Special Issue
- Muench, R D and D T Heggie 1978 Deep water exchange in Alaskan subarctic fjords Pages 239-267 in Kjerfve, B, editor Estuarine transport processes B Baruch Institute for Marine Biology and Coastal Research, University of South Carolina Press, Columbia
- Muench, R D, H O Mofjeld, and R L Charnell 1978 Oceanographic conditions in lower Cook Inlet spring and summer 1973 Journal of Geophysical Research 83 5090-5098
- Mueter, F J and B L Norcross 1999 Linking community structure of small demersal fishes around Kodiak Island, Alaska, to environmental variables Marine Ecology Progress Series 190 37-51
- Mueter, F J and B L Norcross 2000 Species composition and abundance of juvenile groundfish around Steller Sea Lion *Eumetopias jubantus* rookeries in the Gulf of Alaska Alaska Fishery Research Bulletin Alaska, State of Alaska, Department of Fish and Game
- Murphy, E C, A M Springer, D G Roseneau, and B A Cooper 1991 High annual variability in reproductive success of kittiwakes (*Rissa tridactyla*) at a colony in western Alaska Journal of Animal Ecology 60 515-534
- Musgrave, D, T Weingartner, and TC Royer 1992 Circulation and hydrography in the northwestern Gulf of Alaska Deep-Sea Research 39 1499-1519
- Myers, KW, RV Walker, HR Carlson, and JH Helle 2000 Synthesis and review of US research on the physical and biological factors affecting ocean

production of salmon Pages 1-9 in Helle, J H , Y Ishida, D Noakes, and V Radchenko, editors Recent changes in ocean production of Pacific salmon North Pacific Anadromous Fish Commission Bulletin , Vancouver

- Mysak, L, RD Muench, and JD Schumacher 1981 Baroclinic instability in a downstream varying channel Shelikof Strait, Alaska Journal of Physical Oceanography 11 950-969
- Nagasawa, K 2000 Winter zooplankton biomass in the Subarctic North Pacific, with a discussion on the overwintering survival strategy of Pacific Salmon (*Oncorphynchus* spp) Pages 21-32 in Helle, J H , Y Ishido, D Noakes, and V Radchenko, editors Recent changes in ocean production of Pacific salmon North Pacific Anadiomous Fish Commission Bulletin , Vancouver
- Nakata, H, K Kannan, L Jing, N J Thomas, S Tanabe, and J P Giesey 1998 Accumulation pattern of organochlorine pesticides and polychlorinated biphenyls in southern sea otters (*Enhydra hitris nereis*) found stranded along coastal California, USA Environmental Pollution 103 45-53
- Napp, J M, L S Incze, P B Ortner, D L Siefert, and L Britt 1996 The plankton on Shelikof Strait, Alaska standing stock, production, mecoscale variability and their relevance to larval fish survival Fisheries Oceanography 5 19-35
- Niebauer, HJ, J Roberts, and TC Royer 1981 Shelf break circulation in the northern Gulf of Alaska Journal of Geophysical Research 86 13041-13047
- Niebauer, HJ, TC Royer, and TJ Weingartner 1994 Circulation of Prince William Sound, Alaska Journal of Geophysical Research 99 14113-14126
- NMFS 2000 Endangered Species Act–Section 7 consultation, biological opinion and incidental take statement Silver Spring, MD, NMFS Office of Protected Resources
- NMFS 2001 Alaska groundfish fisheries draft programmatic supplemental environmental impact statement US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Region
- NMML unpublished data Cetacean Assessment and Ecology
- NOAA 1993 Report of the NOAA panel on contingent valuation Federal Register 58 10
- Norcross, B L 1998 Volume I, Final Report Defining habitats for juvenile groundfishes in southcentral Alaska with emphasis on flatfishes Fairbanks, University of Alaska, Coastal Marine Institute
- Norcross, B L , E D Brown, R J Foy, M Frandsen, S M Gay, M Jin, J Kirsch, T C Kline, D M Mason, C N K Mooers, E V Patrick, A J Paul, K D E Stokesbury, S J Thorton, S L Vaughan, and J Wang 1999 Life history and ecology of juvenile Pacific herring in Prince William Sound, Alaska Fisheries Oceanography
- Northern Economics Inc 2002 Alaska visitor's expenditures and options fall/winter 2000-01 prepared for Alaska Department of Community and Economic Development

- NPFMC 2000 Stock assessment and fishery evaluation report for groundfish resources of the Gulf of Alaska Anchorage, Alaska, North Pacific Fisheries Management Council
- NRC 1971 The great Alaska earthquake of 1964 National Academy Press Washington, D C
- NRC 1996 The Bering Sea ecosystem National Academy Press Washington, D C
- Nysewander, D R and J L Trapp 1984 Widespread mortality of adult seabirds in Alaska, August-September 1983 Anchorage, U S Fish and Wildlife Service
- O'Clair, C and S T Zimmerman 1986 Biogeography and ecology of the intertidal and shallow subtidal communities Pages 305-346 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C
- O'Corry-Crowe, G M, A E Dizon, R S Suydam, and L F Lowry in press Molecular genetic studies of population structure and movement patterns in a migratory species the beluga whale (*Delphinapterus leucas*) in the western Nearctic in Pfeiffer, C J, editor Molecular and cell biology of marine mammals Krieger, Florida
- O'Corry-Crowe, G M and L F Lowry 1997 Genetic ecology and management concerns for the beluga whale (*Delphinapterus leucas*) Pages 249-274 in Dizon, A E, S J Chivers, and W F Perrin, editors Molecular genetics of marine mammals
- O'Corry-Crowe, G M, R S Suydam, A Rosenberg, K J Frost, and A E Dizon 1997 Phlylogeography, population structure and dispersal patterns of the beluga whale *Delphunus leucas* in the western Nearctic revealed by mitochondrial DNA Molecular Ecology 6 955-970
- O'Daniel, D and J C Schneeweis 1992 Steller sea lion, *Eumetopias jubatus*, predation on glaucous-winged gulls, Larus glaucescens Canadian Field-Naturalist 106 268
- Oakley, K L and K J Kuletz 1996 Population, reproduction, and foraging of pigeon guillemots at Naked Island, Alaska, before and after the *Exxon Valdez* oil spill Pages 759-769 American Fisheries Society Symposium
- Okey, T A and D Pauly 1999 Trophic mass balance model of Alaska's Prince William Sound ecosystem, for the post-spill period 1994-1996 EVOS restoration project 98330-1annual report The Fisheries Centre, University of British Columbia Vancouver
- Okkonen, S 2001 personal communication Institute of Marine Sciences, School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, Alaska
- Okkonen, S R 1992 The shedding of an anticyclonic eddy from the Alaskan Steam as observed by the GEOSAT altimeter Geophysical Research Letters 19 2397-2400

- Olesiuk, P F, M A Bigg, G M Ellis, S J Crockford, and R J Wigen 1990 An assessment of the feeding habits of harbour seals (*Phoca vitulina*) in the Strait of Georgia, British Columbia, based on scat analysis Canadian Technical Report of Fisheries and Aquatic Sciences 1730
- Omori, M 1969 Weight and chemical composition of some important oceanic zooplankton in the North Pacific Ocean Marine Biology 3 4-10
- Orensanz, J M L , J Armstrong, D Armstrong, and R Hilborn 1998 Crustacean resources are vulnerable to serial depletion - the mutifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska Reviews in Fish Biology and Fisheries 8 117-176
- Orr, R T and T C Poulter 1967 Some observations on reproduction, growth, and social behavior in the Steller sea lion Proceedings of the California Academy of Sciences 35 193-226
- Ostrand, W D , K O Coyle, G S Drew, J M Maniscalco, and D B Irons 1998 Selection of forage-fish schools by murrelets and tufted puffins in Prince William Sound, Alaska The Condor 100 286-297
- Overland, J E 1990 Prediction of vessel icing at near-freezing sea surface temperatures Weather and Forecasting 5 62-77
- Page, D S, E S Gilfillan, P D Boehm, and E J Horner 1995 Shoreline ecology program for Prince William Sound, Alaska, following the Exxon Valdez oil spill Part 1 - study design and methods Pages 263-295 in Wells, P G, J N Butler, and J S Hughes, editors Exxon Valdez oil spill fate and effects in Alaskan waters American Society for Testing and Materials, Philadelphia
- Paine, R T 1966 Food web complexity and species diversity American Naturalist 100 65-75
- Paine, R T, J L Ruesink, A Sun, E L Soulanille, M J Wonham, C D G Harley, D R Brumbaugh, and D L Secord 1996 Trouble on oiled waters lessons from the Exxon Valdez oil spill Annual Review of Ecology and Systematics 27 197-235
- Paine, R T, J T Wootton, and P D Boersma 1990 Direct and indirect effects of Peregrine Falcon predation on seabird abundance Auk 107 1-9
- Parker, K S , T C Royer, and R B Deriso 1995 High-latitude climate forcing and tidal mixing by the 18 6-year lunar nodal cycle and low-frequency recruitment trends in Pacific halibut (Hippoglosus stenolepis), in climate change and northern fish populations Pages 447-458 Beamish, editor Canadian Special Publication of Fisheries and Aquatic Sciences
- Parsons, T R 1986 Ecological relations Pages 561-570 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C
- Parsons, T R and C M Lalli 1988 Comparative oceanic ecology of the plankton communities of the Subarctic Atlantic and Pacific Oceans Oceanography and Marine Biology Annual Review 26 317-359

- Parsons, T.R., M. Takahashi, and B. Hargiave 1984 Biological oceanographic processes, 3rd ed. Pergamon Press. New York
- Paul, A J and Paul J M 1999 First-year energy storage patterns of Pacific herring and walleye pollock insight into competitor strategies Pages 117-127 in Ecosystem approaches for fisheries management Sea Grant College Program, University of Alaska, Fairbanks
- Paul, A J, J M Paul, and R L Smith 1998 Seasonal changes in whole-body energy content and estimated consumption rates of age 0 walleye pollock from Prince William Sound, Alaska Estuarine, Coastal and Shelf Science 47 251-259
- Paul, A J and R Smith 1993 Seasonal changes in somatic energy content of yellowfin sole *Pleuronectes asper* Pallas 1814 Journal of Fish Biology 43 131-138
- Peixoto, J P and A H Oort 1992 Physics of climate American Institute of Physics New York
- Perry, SL, DP DeMaster, and GK Silber 1999 The great whales history and status of six species listed as endangered under the US Endangered Species Act of 1973 Marine Fisheries Review 61 1-74
- Peterson, C H 1991 Intertidal zonation of marine invertebrates in sand and mud American Scientist 79 236-249
- Peterson, C H 2000 The web of ecosystem interconnections to shoreline habitats as revealed by the *Exaon Valdez* oil spill perturbation a synthesis of acute direct vs indirect and chronic effects Advances in Marine Biology
- Peterson, C H 2001 The Exion Valdez oil spill in Alaska acute, indirect and chronic effects on the ecosystem Advances in Marine Biology 39 1-103
- Peterson, C H, Kennicutt II, M C, R H Green, P Montagna, Harper Jr, D E, E N Powell, and P F Rosigno 1996 Ecological consequences of environmental perturbations associated with offshore hydrocarbon production a perspective on long-term exposures in the Gulf of Mexico Canadian Journal of Fisheries and Aquatic Sciences 53 2637-2654
- Piatt, J personal communication. US Geological Survey, Anchorage, Alaska
- Piatt, J F unpublished data US Geological Survey, Anchorage, Alaska
- Piatt, J F and P Anderson 1996 Response of common murres to the Earon Valdez oil spill and long-term changes in the Gulf of Alaska marine ecosystem Pages 720-737 in Rice, S D, R B Spies, D A Wolf, and B A Wright, editors Proceedings of the Exxon Valdez oil spill symposium Bethesda
- Piatt, J F and R G Ford 1993 Distribution and abundance of marbled murrelets in Alaska Condor 95 662-669
- Platt, J F and R G Ford 1996 How many birds were killed by the Exxon Valdez oil spill? Pages 712-719 in Rice, S D, R B Spies, D A Wolfe, and B A Wright, editors Proceedings of the Exxon Valdez oil spill symposium Bethesda
- Piatt, J F and D N Nettleship 1985 Diving depths of four alcids Auk 102 293-297

- Piatt, J F and T I van Pelt 1993 A wreck of common murres (*Una aalge*) in the northern Gulf of Alaska during February and March of 1993 Anchorage, U S Fish and Wildlife Service
- Pickart, R S 2000 Bottom boundary layer structure and detachment in the shelfbreak jet of the Middle Atlantic Bight Journal of Physical Oceanography 30 2668-2686
- Piorkowski, R J 1995 Ecological effects of spawning salmon on several southcentral Alaskan streams University of Alaska, Fairbanks
- Pitcher, KW 1980 Food of the harbor seal, *Phoca vitulina iichaidsi*, in the Gulf of Alaska Fishery Bulletin 78 544-549
- Pitcher, K W 1981 Prey of the Steller sea lion, Eumetopias jubatus, in the Gulf of Alaska Fishery Bulletin 79 467-472
- Pitcher, K W 1984 The harbor seal (*Phoca vitulina iichaidsi*) Pages 65-70 in Burns, J J, K J Frost, and L F Lowry, editors Marine mammals species accounts Alaska Department of Fish and Game
- Pitcher, K W 1989 Harbor seal trend count surveys in southern Alaska, 1988 U S Marine Mammal Commission Washington, D C
- Pitcher, K W 1990 Major decline in the number of harbor seals, Phoca vitulina richardsi, on Tugidak Island, Gulf of Alaska Marine Mammal Science 6 121-134
- Pitcher, K W and D G Calkins 1981 Reproductive biology of Steller sea lions in the Gulf of Alaska Journal of Mammalogy 62 599-605
- Pitcher, K W and F H Fay 1982 Feeding by Steller sea lions on harbor seals Murrelet 63 70-71
- Pitcher, K W and D C McAllister 1981 Movements and haul out behavior of radiotagged harbor seals, *Phoca vitulina* Canadian Field-Naturalist 95 292-297
- Plafker, G 1972 Tectonics Pages 47-122 in The great Alaska earthquake of 1964, Vol 6 oceanography and coastal engineering National Research Council, National Academy of Sciences, Washington, D C
- Plakhotnik, A F 1964 Hydrological description of the Gulf of Alaska Page 289 in Moiseev, P A, editor Soviet fisheries investigations in the Northeast Pacific, part II
- Polovina, J J, G T Mitchum, and G T Evans 1995 Decadal and basin-scale variation in mixed layer depth and impact on biological production in the Central and North Pacific, 1960-88 Deep Sea Research 42 1701-1716
- Power, M E , D Tilman, J A Estes, B A Menge, W J Bond, L S Mills, G Daily, J C Castilla, J Lubchenco, and R T Paine 1996 Challenges in the quest for keystones Bioscience 46 609-620
- Prichard, A K 1997 Evaluation of pigeon guillemots as bioindicators of nearshore ecosystem health University of Alaska, Fairbanks

- Purcell, J E and M V Sturdevant 2001 Prey selection an dietary overlap among zooplantivorous jellyfish and juvenile fishes in Prince William Sound, Alaska Marine Ecology Progress Series 210 67-83
- Purvin & Gertz, Ltd 2000 Alaskan gas development strategies Purvin & Gertz, Ltd Calgary
- Quast, J C and E L Hall 1972 List of fishes of Alaska and adjacent waters with a guide to some of the literature
- Rafaelli, D and S Hawkins 1996 Intertidal ecology Chapman and Hall London
- Ramp 1986 The interaction of warm core rings with the shelf water and the shelf/slope front south of New England University of Rhode Island
- Rausch, R 1958 The occurrence and distribution of birds on Middleton Island, Alaska Condor 60 227-242
- Reeburgh, W S and G W Kipphut 1986 Chemical distributions and signals in the Gulf of Alaska, its coastal margins and estuaries Pages 77-91 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C
- Reed, R K and J D Schumacher 1986 Physical oceanography Pages 57-75 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C
- Reid, J L 1981 On the mid-depth circulation of the world ocean Pages 70-111 in Warren, B A and C Wunsch, editors Evolution of physical oceanography scientific surveys in honor of Henry Stommel MIT press, Cambridge
- Reid Jr , J L 1965 Intermediate waters of the Pacific Ocean The Johns Hopkins Oceanographic Studies
- Reid, K and J P Croxall 2001 Environmental response of upper trophic-level predators reveals a system change in an Antarctic marine ecosystem Proceedings of the Royal Society of London B Biological Sciences 268 377-384
- Reynolds Jr , J E and S A Rommel 1999 Biology of marine mammals Smithsonian University Press Washington, D C
- Rhoads, D C and D K Young 1970 The influence of deposit-feeding organisms on sediment stability and community trophic structure Journal of Marine Research 28 150-178
- Richardson, R W 1936 Winter air-mass convergence over the North Pacific Monthly Weather Review 64 199-203
- Ricketts, E F and J Calvin 1968 Between pacific tides, 4th ed Stanford University Press Stanford

- Riedman, M L and J A Estes 1990 The sea otter (*Enliydia lutis*) behavior, ecology and natural history U S Fish and Wildlife Service
- Riedman, M L , J A Estes, M M Staedler, A A Giles, and D R Carlson 1994 Breeding patterns and reproductive success of California sea otters Journal of Wildlife Management 58 391-399
- Robards, M, JF Piatt, A Kettle, and A Abookire 1999 Temporal and geographic variation in fish populations in nearshore and shelf areas of lower Cook Inlet Fishery Bulletin
- Roden, G 1970 Aspects of the mid-Pacific transition zone Journal of Geophysical Research 75 1097-1109
- Rogers, D E, B J Rogers, and R J Rosenthal 1986 The nearshore fishes Pages 399-415 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Ocean Assessments Division, National Oceanic and Atmospheric Administration, Department of Commerce, Washington, D C
- Rogers, G 1962 The future of Alaska the economic consequences of statehood Johns Hopkins Press Baltimore
- Rogers, I H, I K Birtwell, and G M Kurzynski 1990 The Pacific eulachon (*Thaleichthys pacificus*) as a pollution indicator organism in the Fraser River estuary, Vancouver, British Columbia The Science of the Total Environment 97/98 713-727
- Rogers, J C 1981 The North Pacific oscillation Journal of Climatology 1 39-57
- Ronholt, L L , H H Shippen, and E S Brown 1978 Demersal fish and shellfish resources of the Gulf of Alaska from Cape Spencer to Unimak Pass 1948-1976 a historical view Vol I Environmental Assessment of the Alaskan Continental Shelf, Final Reports of Principal Investigators 2 (Biological Studies) 1-304
- Rosen, D A S and A W Trites 2000 Pollock and the decline of Steller sea lions testing the junk-food hypothesis Canadian Journal of Zoology 78 1243-1250
- Rosenberg, D H 1972 A review of the oceanography and renewable resources of the Northern Gulf of Alaska Sea Grant Report 73-3 Fairbanks, Institute of Marine Science, University of Alaska IMS Report R72-23
- Roseneau, DG unpublished data US Fish and Wildlife Service, Homer, Alaska
- Rosenkranz, G 1999 Statistical modeling of tanner crab recruitment University of Alaska, Fairbanks
- Rotterman, L M and T Simon-Jackson. 1988 Sea otter Pages 237-275 in Lentfer, J W , editor Selected marine mammals of Alaska U S Marine Mammal Commission, Washington, D C
- Royer, T 2000 personal communication Center for Coastal Phyiscal Oceanography, Old Dominion University, Norfolk, Virginia

- Royer, T C 1975 Seasonal variations of waters in the northern Gulf of Alaska Deep-Sea Research 22 403-416
- Royer, T C 1981a Baroclinic transport in the Gulf of Alaska Part I Seasonal variations of the Alaska current Journal of Marine Research 39 239-250
- Royer, T C 1981b Baroclinic transport in the Gulf of Alaska Part II A freshwaterdriven coastal current Journal of Marine Research 39 251-266
- Royer, T C 1982 Coastal freshwater discharge in the northeast Pacific Journal of Geophysical Research 87 2017-2021
- Royer, T C 1993 High-latitude oceanic variability associated with the 186 year nodal tide Journal of Geophysical Research 98 4639-4644
- Royer, T C 1998 Coastal processes in the northern North Pacific Pages 395-414 in Robinson, A R and K H Brink, editors The sea John Wiley and Sons, New York
- Royer, TC, DV Hansen, and DJ Pashinski 1979 Coastal flow in the northern Gulf of Alaska as observed by dynamic topography and satellite-tracked drogued drift buoys Journal of Physical Oceanography 9 785-801
- Rugh, DJ, KEW Shelden, and BA Mahoney in press Distribution of beluga whales in Cook Inlet, Alaska, during June and July, 1993-1998 Marine Fisheries Review
- Rutherford, S and S D'Hondt 2000 Early onset and tropical forcing of 100,000-year Pleistocene glacial cycles Nature 408 72-75
- SAI 1980 Environmental assessment of the Alaskan Continental Shelf Northeast Gulf of Alaska interim synthesis report Boulder, Science Applications, Inc
- SAI 1980a Environmental assessment of the Alaskan Continental Shelf Kodiak interim synthesis report - 1980 Boulder, Science Applications, Inc
- SAI 1980b Environmental assessment of the Alaskan Continental Shelf Northeast Gulf of Alaska interim synthesis report Boulder, Science Applications, Inc
- Sambrotto, R N and C J Lorenzen 1986 Phytoplankton and primary production Pages 249-282 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C
- Sandegren, F E 1970 Breeding and maternal behavior of the Steller sea lion (*Eumetopias jubata*) in Alaska University of Alaska, Fairbanks
- Sanger, G A 1987 Trophic levels and trophic relationships of seabirds in the Gulf of Alaska Pages 229-257 in Croxall J P, editor Seabirds feeding ecology and role in marine ecosystems
- Saulitis, E L 1993 The vocalizations and behavior of the "AT"-group of killer whales (*Orcinus orca*) in Prince William Sound, Alaska University of Alaska, Fairbanks

- Schiel, D R and M S Foster 1986 The structure of subtidal algal stands in temperate waters Oceanography and Marine Biology Annual Review 24 265-307
- Schlitz, R submitted The interaction of shelf water with warm core rings Journal of Geophysical Research
- Schmidt, G M 1977 The exchange of water between Prince William Sound and the Gulf of Alaska University of Alaska, Fairbanks
- Schneider, D and Hunt Jr, G L 1982 A comparison of seabird diets and foraging distribution around the Pribilof Islands, Alaska Pages 86-95 in Nettleship, D N, G A Sanger, and P F Springer, editors Marine birds their feeding ecology and commercial fisheries relationships Minister of Supply and Services, Canada
- Schumacher, J D and Kendall Jr, A W 1991 Some interactions between young walleye pollock and their environment in the western Gulf of Alaska La Jolla, California Cooperative Oceanic Fisheries Investigations
- Schumacher, J D , C A Pearson, and R K Reed 1982 An exchange of water between the Gulf of Alaska and the Bering Sea through Unimak Pass Journal of Geophysical Research 87 5785-5795
- Schumacher, J D and T Royer 1993 Review of the physics of the subarctic gyre PICES Scientific Report No 1 37-40
- Schumacher, J D , P J Stabeno, and S J Bogard 1993 Characteristics of an eddy over the continental shelf Shelikof Strait, Alaska Journal of Geophysical Research 98 8395-8404
- Schumacher, J D, P J Stabeno, and A T Roach 1990 Volume transport in the Alaska Coastal Current Continental Shelf Research 9 1071-1083
- Scribner, K T , J Bodkin, B Ballachey, S R Fain, M A Cronin, and M Sanchez 1997 Population genetic studies of the sea otter (Enhydra lutris) a review and interpretation of available data Pages 197-208 in Dizon, A E , S J Chivers, and W F Perrin, editors Molecular genetics of marine mammals Society for Marine Mammalogy, Lawrence
- Seaman, G A , K J Frost, and L F Lowry 1985 Investigations of belukha whales in coastal waters of western and northern Alaska Part I Distribution, abundance and movements U S Department of Commerce, National Oceanic and Atmospheric Administration
- Sease, J L 1992 Status review, harbor seals (*Phoca vitulina*) in Alaska National Marine Fisheries Service
- Sease, J L and T R Loughlin 1999 Aerial and land-based surveys of Steller sea lions (*Eumetopias jubatus*) in Alaska, June and July 1997 and 1998
- Seiser, P E 2000 Mechanism of impact and potential recovery of pigeon guillemots (*Cepplus columba*) after the Exxon Valdez oil spill Fairbanks, University of Alaska
- Sergeant, D E and P F Brodie 1969 Body size in white whales, *Delphinapterus leucas* Journal of the Fisheries Research Board of Canada 26 2561-2580

- Shaughnessy, P D and F H Fay 1977 A review of the taxonomy and nomenclature of North Pacific harbour seals Journal of Zoology (London) 182 385-419
- Shigenaka, G, D A Coates, A K Fukuyama, and P D Roberts 1999 Effects and trends in littleneck clams (*Protothaca staminea*) impacted by the *Exxon Valdez* oil spill Proceedings of the 1999 international oil spill conference, Seattle American Petroleum Institute, Washington, D C
- Sigman, D M and E A Boyle 2000 Glacial/interglacial variations in atmospheric carbon dioxide Nature 407 859-869
- Simenstad, CA, JA Estes, and KW Kenyon 1978 Aleuts, sea otters, and alternate stable state communities 200 403-411
- Siniff, D B and K Ralls 1991 Reproduction, survival and tag loss in California sea otters Marine Mammal Science 7 7 211-229
- Siruff, D B , T D Williams, A M Johnson, and D L Garshelis 1982 Experiments on the response of sea otters, Enhydra lutris, to oil Biological Conservation 23 261-272
- Small, R 2001 personal communication Alaska Department of Fish and Game, Juneau, Alaska
- Small, R J 1998 Harbor seal investigations in Alaska Juneau, Alaska, National Marine Fisheries Service Annual Report Award Number NA57FX0367
- Small, R J , K Hastings, and L A Jemison 1999 Harbor seal investigations in Alaska Juneau, Alaska, National Marine Fisheries Service Annual Report Award Number NA87FX0300
- Small, R J and G W Pendleton 2001 Harbor seal population trends in the Ketchikan, Sitka, and Kodiak areas of Alaska, 1983-1999 Marine Mammal Science
- Small, R J, G W Pendleton, and K M Wynne 1997 Harbor seal population trends in the Ketchikan, Sitka, and Kodiak Island areas of Alaska Pages 7-32 in Annual report harbor seal investigations in Alaska Alaska Department of Fish and Game, Anchorage
- Smith, D R, S Niemeyer, J A Estes, and A R Flegal 1990 Stable lead isotopes evidence of anthropogenic contamination in Alaskan sea otters Environmental Science and Technology 24 1517-1521
- Smith, TG, DJ St Aubin, and MO Hammill 1992 Rubbing behaviour of belugas, Delphinapterus leucas, in a high arctic estuary Canadian Journal of Zoology 70 2405-2409
- Snarskı, D 1971 Kıttıwake ecology, Tuxednı National Wildlife Refuge Alaska Cooperative Wildlife Research Unit, quarterly report Fairbanks, University of Alaska
- Sobolevsky, Y I, T G Sokolovshaya, A A Balanov, and I A Senchenko 1996 Distribution and trophic relationships of abundant mesopelagic fishes of the Bering Sea Pages 159-167 in Mathisen, O A and K O Coyle, editors Ecology of the Bering Sea a review of Russian literature Alaska Sea Grant College Program, Fairbanks

- Sogard, S M and B L Olla in press Endurance of simulated winter conditions by age-0 walleye pollock (Theragra chalcogramma) effects of body size, water temperature and energy stores Journal of Fish Biology
- Sousa, W P 1979 Experimental investigations of disturbance and ecological succession in a rocky intertidal community Ecological Monographs 49 227-254
- Southward, A J and E C Southward 1978 Recolonization of rocky shores in Cornwall after the use of toxic dispersants to clean up the Torrey Canyon spill Journal of the Fisheries Research Board of Canada 35 682-706
- Spraker, T R, L F Lowry, and K J Fiost 1994 Gross necropsy and histopathological lesions found in harbor seals Pages 281-312 in Loughlin, T R, editor Marine mammals and the *Euron Valdez* Academic Press, Inc, San Diego
- Springer, A M 1991 Seabird relationships to food webs and the environment examples from the North Pacific Ocean Pages 39-48 in Montevecchi, W A and A J Gaston, editors Studies of high-latitude seabirds 1 Behavioral, energetic, and oceanographic aspects of seabird feeding ecology Canadian Wildlife Service, Ottawa
- Springer, A M 1998 Is it all climate change? Why marine bird and mammal populations fluctuate in the North Pacific? Pages 109-119 in Holloway, G, P Muller, and D Henderson, editors Biotic impacts of extratropical climate variability in the Pacific proceedings'Aha Huliko'a Hawaiian winter workshop University of Hawaii, Hawaii
- Springer, A M, A Y Kondratyev, H Ogi, Y V Shibaev, and G B Van Vliet 1993 Status, ecology, and conservation of *Synthliboi amphus* murrelets and auklets Pages 187-201 in Vermeer, K, K T Briggs, K H Morgan, and D Siegel-Causey, editors The status, ecology, and conservation of marine birds of the North Pacific Canadian Wildlife Service, Ottawa
- Springer, A M, C P McRoy, and M V Flint 1996 The Bering Sea Green Belt shelf edge processes and ecosystem production Fisheries Oceanography 5 205-223
- Springer, A M, J F Piatt, and G Van Vliet 1996 Sea birds as proxies of marine habitats and food webs in the western Aleutian arc Fisheries Oceanography 5 45-55
- Springer, A M and S G Speckman 1997 A forage fish is what? Summary of the symposium Pages 773-805 in Forage fishes in marine ecosystems proceedings of the international symposium on the role of forage fishes in marine ecosystems Alaska Sea Grant College Program, University of Alaska, Fairbanks
- St Aubin, D J, TG Smith, and J R Geraci 1990 Seasonal epidermal molt in beluga whales, *Delphinapterus leucas* Canadian Journal of Zoology 68 359-367
- Stabeno, PJ, RK Reed, and JD Schumacher 1995 The Alaska coastal current continuity of transport and forcing Journal of Geophysical Research 100 2477-2485

- Stephen R Braund & Associates 1995 Whittier access project subsistence technical report Prepared for HDR Engineeringas part of the Whittier access project, environmental impact statement
- Stewart, B S 1997 Ontogeny of differential migration and sexual segregation in northern elephant seals Journal of Mammalogy 78 1101-1116
- Stockmar, E J 1994 Diel and seasonal variability of macrozooplankton and micronekton in the near-surface of the Gulf of Alaska University of Alaska, Fairbanks
- Stockwell, D 2000 personal communication Institute of Marine Sciences, School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, Alaska
- Stommel, H and A B Arons 1960a On the abyssal circulation of the world ocean -I Stationary planetary flow patterns on a sphere Deep-Sea Research 6 140-154
- Stommel, H and A B Arons 1960b On the abyssal circulation of the world ocean -II An idealized model of the circulation pattern and amplitude in oceanic basins Deep-Sea Research 6 217-233
- Sturdevant, MV, AC Wertheimer, and JL Lum 1996 Diets of juvenile pink and chum salmon in oiled and non-oiled nearshore habitats in Prince William Sound, 1989 and 1990 American Fisheries Society Symposium 18 578-592
- Suchanek, T H 1985 Mussels and their role in structuring rocky shore communities Pages 70-89 in Moore, P G and R Seed, editors Ecology of rocky coasts Chapter VI Hodder and Stoughton Educational Press, Kent
- Sugimoto, T 1993 Subarctic gyre gross structure and decadal scale variations in basin scale climate and oceanic conditions PICES Scientific Report No 1 35-37
- Sugimoto, T and K Tadokoro 1997 Interannual-interdecadal variations in zooplankton biomass, chlorophyll concentration, and physical environment of the subarctic Pacific and Bering Sea Fisheries Oceanography 6 74-92
- Sundberg, K, L Deysher, and L McDonald 1996 Intertidal and supratidal site selection using a geographical information system American Fisheries Society Symposium 18 167-176
- Suryan, R M, D B Irons, and J Benson 2000 Prey switching and variable foraging strategies of black-legged kittiwake and the effect on reproductive success Condor 102 374-384
- Szepanski, M M, M Ben-David, and V Van Ballenberghe 1999 Assessment of anadromous salmon resources in the diet of the Alexander Archipelago wolf using stable isotope analysis Oecologia 120 327-335
- Tabata, S 1982 The anticyclonic, baroclinic eddy of Sitka, Alaska, in the Northeast Pacific Ocean Journal of Physical Oceanography 12 1260-1282
- Taylor, C, LK Duffy, RT Bowyer, and GM Blundell 2000 Profiles of fecal porphyrins in river otters following the *Exxon Valdez* oil spill Marine Pollution Bulletin 40 1132-1138

- Tetreau, M 2001 personal communication Kenai Fjords National Park Service, Seward, Alaska
- Thompson, RORY and TJ Golding 1981 Tidally induced upwelling by the Great Barrier Reef Journal of Geophysical Research 86 6517-6521
- Thomson, R E 1972 On the Alaskan Stream Journal of Physical Oceanography 2 363-371
- Thomson, R E, Hickey, and LeBlond 1989 The Vancouver Island Coastal Current fisheries barrier and conduit Pages 265-296 in Beamish, R J and G A McFarlane, editors Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models Canadian Special Publication of Fisheries and Aquatic Sciences
- Thomson, R E , P H LeBlond, and W J Emery 1990 Analysis of deep-drogued satellite-tracked drifter measurements in the Northeast Pacific Ocean Atmosphere-Ocean 28 409-443
- Thomson, R E and E Wolanski 1984 Tidal period upwelling with Raine Island Entrance Great Barrier Reef Journal of Marine Research 42 787-808
- Thorsteinson, F V and C J Lensink 1962 Biological observations of Steller sea lions taken during an experimental harvest Journal of Wildlife Management 26 353-359
- Trenberth, K E and J W Hurrell 1994 Decadal atmospheric-ocean variations in the Pacific Climate Dynamics 9 303-319
- Trenberth, K E and D A Paolino 1980 The Northern Hemisphere sea-level pressure data set trends, errors, and discontinuities Monthly Weather Review 108 855-872
- Trillmich, F and K Ono 1991 Pinnipeds and El Niño responses to environmental stress Springer Verlag Berlin
- Trites, A W 1990 Thermal budgets and climate spaces the impact of weather on the survival of Galapagos (*Ai ctocephalus galapagoensis Heller*) and northern fur seal pups (*Callorhinus ursinus L*) Functional Ecology 4 753-768
- Trowbridge, C 1995 Prince William Sound management area 1994 shellfish annual management report Anchorage, Alaska, Alaska Department of Fish and Game
- Tully, J P and F G Barber 1960 An estuarine analogy in the sub-arctic Pacific Ocean Journal of Fisheries Research Board of Canada 17 91-112
- Tyler, A V and G H Kruse 1996 Conceptual modeling of brood strength of red king crabs in the Bristol Bay region of the Bering Sea High latitude crabs biology, management, and economics Alaska Sea Grant College Program, University of Alaska Alaska Sea Grant College Program, AK-SG-96-02
- Tyler, A V and G H Kruse 1997 Modeling workshop on year-class strength of Tanner crab, *Chuonoecetes ban dı* Juneau, Alaska Department of Fish and Game Regional Information Report No 5J97-02

- U S Bureau of Economic Analysis 2002 CA1-3 personal income summary estimates, Alaska, 1969-1999 U S Department of Commerce
- U S Bureau of the Census 2001 Profiles of general demographic characteristics, 2000 census of population and housing Alaska
- Underwood, A J and E J Denley 1984 Paradigms, explanations and generalizations in models for the structure of intertidal communities on rocky shores Pages 151-180 in Simberloff, D and et al, editors Ecological communities conceptual issues and the evidence Princeton University Press, Princeton
- USDA Forest Service and State of Alaska 2000 Forest health management report forest insect and disease conditions in Alaska 1999 U.S. Department of Agriculture, Forest Service, Alaska Region and Alaska Department of Natural Resources, Division of Forestry R10-TP-82, February 2000a
- USDA Forest Service, Chugach National Forest 2000b Chugach National Forest, proposed revised land management plan and environmental impact statement US Forest Service

USEPA 1998 Climate change and Alaska

USFWS unpublished data US Fish and Wildlife Service, Anchorage, Alaska

- USGS unpublished data Anchorage, Alaska
- USGS 2000 National Water Quality Assessment Program http //AK water usgus gov/Projects/NAWQA

Valdez Chamber of Commerce 2001 personal communication Valdez, Alaska

Valdez Convention & Visitors Bureau 2001 personal communication Valdez, Alaska

- Valiela, I 1995 Marine ecological processes, Second ed Springer-Verlag New York
- Van Pelt, T I, J F Piatt, B K Lance, and D D Roby 1997 Proximate composition and energy density of some North Pacific forage fishes Comparative Biochemistry and Physiology A118 1393-1398
- Van Scoy, K A , D B Olson, and R A Fine 1991 Ventilation of North Pacific intermediate water the role of the Alaskan gyre Journal of Geophysical Research 96 16801-16810
- van Tamelen, PG, MS Stekoll, and L Deysher 1997 Recovery processes of the brown alga, *Fucus gardneri* (Silva), following the *Exxon Valdez* oil spill settlement and recruitment Marine Ecology Progress Series 160 265-277
- VanBlaricom, G R 1987 Regulation of mussel population structure in Prince William Sound, Alaska National Geographic Research 3 501-510
- VanBlaricom, G R 1988 Effects of foraging by sea otters on mussel-dominated intertidal communities Pages 48-91 in VanBlaricom, G R and J A Estes, editors The community ecology of sea otters Springer Verlag, Berlin

- Vastano, A C , L S Incze, and J D Schumacher 1992 Environmental and larval pollock observations in Shelikof Strait, Alaska Fisheries Oceanography 1 20-31
- Vaughan, S L , C N K Moores, and Gay III, S M 2001 Physical variability in Prince William Sound during the SEA study (1994-1998) Fisheries Oceanography 10 (Suppl 1) 58-80
- Vermeer, K, SG Sealy, and GA Sanger 1987 Feeding ecology of Alcidae in the eastern North Pacific Ocean Pages 189-227 in Croxall, JP, editor Seabirds feeding ecology and role in marine ecosystems Cambridge University Press, Cambridge
- Vermeer, K and S J Westrheim 1984 Fish changes in diets of nestling rhinoceros auklets and their implications Pages 96-105 in Nettleship, D N, G A Sanger, and P F Springer, editors Marine birds their feeding ecology and commercial fisheries relationships Canadian Wildlife Service, Ottawa
- von Huene, R W, Shor Jr, G G, and R J Malloy 1972 Offshore tectonic features in the affected region Pages 266-289 in The great Alaska earthquake of 1964, Vol 6 oceanography and coastal engineering National Research Council, National Academy of Sciences, Washington, D C
- von Ziegesar, O, G Ellis, CO Matkin, and B Goodwin 1986 Repeated sightings of identifiable killer whales (*Orcinus orca*) in Prince William Sound, Alaska, 1977-1983 Cetus 6 9-13
- Wang, J 1992 Interaction of an eddy with the continental slope WHOI-92-40
- Ward, A E 1997 A temporal study of the phytoplankton spring bloom in Prince William Sound, Alaska University of Alaska, Fairbanks
- Ware, D M 1991 Climate, predators and prey behavior of a linked oscillating system Pages 279-291 in Kawasaki, T, S Tanaka, Y Toba, and A Tanaguchi, editors Long-term variability of pelagic fish populations and their environments Pergamon Press, Tokyo
- Warren, B A 1983 Why is no deep water formed in the North Pacific? Journal of Marine Research 41 327-347
- Warren, B A and W B Owens 1985 Some preliminary results concerning deep northern-boundary in the North Pacific Progress in Oceanography 14 537-551
- Warwick, R M 1993 Environmental impact studies in marine communities pragmatical considerations Australian Journal of Ecology 18 63-80
- Warwick, R M and K R Clarke 1993 Comparing the severity of disturbance a meta-analysis of marine macrobenthic community data Marine Ecology Progress Series 92 221-231
- Weingartner, T 2000 Institute of Marine Sciences, School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, Alaska Notes University's GLOBEC project
- Weingartner, T 2001 personal communication Institute of Marine Sciences, School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, Alaska

- Welch, D 2001 personal communication Canada Department of Fisheries, Pacific Biological Station
- Welch, DW, BR Ward, BD Smith, and P Eveson 1998 Influence of the 1990 ocean climate shift on British Columbia steelhead (*O mykiss*) and coho (*O kisutch*) populations in Holloway, G, P Muller, and D Henderson, editors Biotic impacts of extratropical climate variability in the Pacific proceedings 'Aha Huliko'a Hawaiian winter workshop University of Hawaii, Honolulu
- Welschmeyer, NA, S Strom, R Goerjcke, G DiTullio, L Belvin, and W Petersen 1993 Primary production in the subarctic Pacific Ocean project SUPER Progress in Oceanography 32 101-135
- Wendell, FE, RA Hardy, and JA Ames 1986 An assessment of the accidental take of sea otters, Enhydra lutris, in gill and trammel nets Marine Resources Technical Report 54 California Department of Fish and Game, Long Beach
- Western Native Trout Campaign 2001 Imperiled western trout and the importance of roadless areas
- Westlake, R L and G O'Corry-Crowe 1997 Genetic investigation of Alaskan harbor seal stock stricture using mtDNA Pages 205-234 Annual report harbor seal investigations in Alaska Alaska Department of Fish and Game, Anchorage
- Wheeler, P A and S A Kokkinakis 1990 Ammonium recycling limits nitrate use in the oceanic Subarctic Pacific Limnology and Oceanography 35 1267-1278
- Whitehead, J C and T J Hoban 1999 Testing for temporal reliability in contingent valuation with time for changes in factors affecting demand Land Economics 75
- Whitledge, T 2000 personal communication Institute of Marine Sciences, School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, Alaska
- Whitney, FA, CS Wong, and PW Boyd 1998 Interannual variability in nitrate supply to surface waters of the northeast Pacific Ocean Marine Ecology Progress Series 170 15-23
- Whittaker, L M and L H Horn 1982 Atlas of Northern Hemisphere extratropical cyclonicactivity, 1958-1977 Madison, Department of Meteorology, University of Wisconsin
- Willette, M, M Sturdevant, and S Jewett 1997 Prey resource partitioning among several species of forage fishes in Prince William Sound, Alaska Pages 11-29 in Forage fishes in marine ecosystems proceedings of the international symposium on the role of forage fishes in marine ecosystems Alaska Sea Grant College Program, University of Alaska, Fairbanks
- Willette, T M, R T Cooney, and K Hyer 1999 Predator foraging-mode shifts affecting mortality of juvenile fishes during the subarctic spring bloom Canadian Journal of Fisheries and Aquatic Sciences 56 364-376
- Willette, T M, R T Cooney, V Patrick, D M Mason, G L Thomas, and D Scheel 2001 Ecological processes influencing mortalities of juvenile pink salmon (*Oncor hynchus gor bascha*) in Prince William Sound, Alaska Fisheries Oceanography 10 (Suppl 1) 14-42

Q

Williams, G J 2000 Juneau, Alaska, Alaska Department of Labor

Williams, G J 2002 Juneau, Alaska

- Willis, J.M., W.G. Pearcy, and N.V. Parin. 1988. Zoogeography of midwater fishes in the subarctic Pacific Pages 79-142 in Nemoto, T. and W.G. Pearcy, editors The biology of the subarctic Pacific Tokyo
- Willmott, A J and L A Mysak 1980 Atmospherically forced eddies in the northeast Pacific Journal of Physical Oceanography 10 1769-1791
- Wilson, D E , M A Bogan, Brownell Jr , R L , A M Burdin, and M K Maminov 1991 Geographic variation in sea otters, Enhydra lutris Journal of Mammalogy 72 22-36
- Wilson, J G and J E Overland 1986 Meteorology Pages 31-54 in Hood, D W and S T Zimmerman, editors The Gulf of Alaska physical environment and biological resources Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U S Department of Commerce, Washington, D C
- Winston, J 1955 Physical aspects of rapid cyclogenesis in the Gulf of Alaska Tellus 7 481-500
- W1pfli, M S , J Hudson, and J Caouette 1998 Influence of salmon carcasses on stream productivity response of biofilm and benthic macroinvertebrates in southeastern Alaska, U S A Canadian Journal of Fisheries and Aquatic Sciences 66 1503-1511
- W1pfli, M S , J P Hudson, D T Chaloner, and J P Caouette 1999 Influence of salmon spawner densities on steam productivity in Southeast Alaska Canadian Journal of Fisheries and Aquatic Sciences 56 1600-1611
- Witherell, D 1999 Status and trends of principal groundfish and shellfish stocks in the Alaska exclusive economic zone, 1999 Anchorage, North Pacific Fishery Management Council
- Witherell, D and N Kimball 2000 Status and trends of principal groundfish and shellfish stocks in the Alaska EEZ, 2000 Anchorage, North Pacific Fishery Management Council
- Wolfe, R J and L B Hutchinson-Scarbrough 1999 The subsistence harvest of harbor seal and sea lion by Alaska Natives in 1998 Alaska Department of Fish and Game Juneau
- Wootton, J T 1994 The nature and consequences of indirect effects in ecological communities Annual Review of Ecology and Systematics 25 443-466
- Xie, L and W W Hsieh 1995 The global distribution of wind-induced upwelling Fisheries Oceanography 4 52-67
- Xiong, Q and T C Royer 1984 Coastal temperature and salinity observations in the northern Gulf of Alaska, 1970-1982 Journal of Geophysical Research 8061-8068
- Yankovsky, A E and D C Chapman 1997 A simple theory for the fate of buoyant coastal discharges Journal of Physical Oceanography 27 1386-1401

Yeardley Jr, R B 2000 Use of forage fish for regional streams wildlife risk assessment relative bioaccumulation of contaminants Environmental Monitoring and Assessments 65 559-585

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- York, A E 1994 The population dynamics of northern sea lions, 1975-1985 Marine Mammal Science 10 38-51
- York, A E, R L. Merrick, and T R. Loughlin 1996 An analysis of the Steller sea lion metapopulation in Alaska Pages 259-292 in McCullough, D R, editor Metapopulations and wildlife conservation Island Press, Washington, DC
- Zador, SG and JF Piatt 1999 Time-budgets of common murres at a declining and increasing colony in Alaska Condor 101 149-152
- Zheng, J and G H Kruse 2000 Recruitment patterns of Alaskan crabs and relationships to decadal shifts in climate and physical oceanography ICES Journal of Marine Science 57 438-451

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8. MODELING

In This Chapter

- > A Survey of North Pacific Models Relevant to GEM
- > Goals and Purposes of Gathering and Analyzing Data with Models
- > Use of a Hierarchical Strategy in Decision-making
- Modeling Strategies and Methods

8.1 Introduction

Modeling and observing systems designed to support modeling efforts have been established in the GOA and North Pacific As a regional

monitoring and research program, GEM seeks to build on the strengths of past and existing programs In this chapter, modeling strategies of established programs are reviewed to provide a starting point for the modeling component of the GEM Program Identification of core variables used in these existing efforts provides an important contribution to developing the GEM monitoring program

Following the review of modeling efforts, the background necessary to implement a modeling program for GEM is developed. This background includes presentation of explanations and discussion of the purposes of modeling, a hierarchical framework for organizing different types of models, options available in modeling strategies and methods, and the means of evaluating modeling proposals

8.2 Survey of Modeling

8 2.1 Modeling Strategies of Established Programs

This subsection provides statements summarizing modeling strategies The information is extracted from web sites as noted

GOOS (Global Ocean Observing System)

Linking user needs to measurements requires a managed, interactive flow of data and information among three essential subsystems of the IOOS (Integrated Ocean Observing System) (1) the observing subsystem (measurement of core variables and the

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transmission of data), (2) the communications network and data management subsystem (organizing, cataloging, and disseminating data), and (3) the modeling and applications subsystem (translating data into products in response to user needs) Thus, the observing system consists of the infrastructure and expertise required for each of these subsystems as well as that needed to insure the continued and routine flow of data and information among them (U S GOOS Steering Committee 2000)

PICES (North Pacific Marine Science Organization)/NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography)

Models serve to extrapolate retrospective and new observations through space and time, assist with the design of observational programs, and test our understanding of the integration and functioning of ecosystem components Clear differences were identified in the level of advancement of the various disciplinary models Atmosphere-ocean and physical circulation models are the most advanced, to the extent that existing models are generally useful now for CCCC (climate change and carrying capacity) objectives, at least on the Basin scale Circulation models in territorial and regional seas are presently more varied in their level of development, and may need some coordination from PICES Lower trophic level models are advancing, and examples of their application coupled with large-scale circulation models are beginning to appear There is a need for comparisons of specific physiological models, and for grafting of detailed mixed layer models into the general circulation models With upper trophic level models, there are several well-developed models for specific applications, but workshop participants felt there were as yet no leading models available for general use within the CCCC program This is an area that needs particular attention and encouragement from PICES (Perry et al 1997)

GLOBEC (GLOBal Ocean ECosystems Dynamics)

The physical models can be coupled with a suite of biological, biophysical and ecosystems models Development of biological models should occur concurrently with development of the physical model Four types of biological or biophysical models are recommended Linking outputs from each of these models will allow the examination of ecosystem level questions regarding top down or bottom up controls in determining pelagic production in the Bering Sea

From http //globec oce orst edu/groups/nep/reports/rep16/ rep16 bs model html)

8 2 2 Core Variables for Modeling

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Table 8.1 shows spatial domains, currencies, inputs, and outputs for several of the most relevant North Pacific models

Model Name/			
Model Region	Model Spatial Domain	Inputs	Outputs/Currency
Single-species stock assessment models that include predation i	Across EBS and GOA Pollock distributions	Fisheries data and predator biomass	Pollock population and mortality trends—number at age (and biomass at age)
Bering Sea MSVPA	The modeled region is the EBS shelf and slope north to about 61°N	Fisheries predator biomass, and food habits data This model requires estimates of other food abundance supplied by species outside the model	Age-structured population dynamics for key species—numbers at age
BORMICON for the Eastern Bering Sea	The model is spatially explicit with 7 defined geographic regions that have pollock abundance and size distribution information	Temperature is included and influences growth and consumption	Spatial size distribution of pollock
Evaluating Alternative Fishing Strategies	U S Exclusive Economic Zone	Gear-specific fishing effort, including bycatch	Biomass of managed fish species
Advection on larval pollock recruitment	Southeast Bering Sea Shelf	OSCURS surface currents (wind-driven)	Index of pollock recruitment
Shelikof Pollock IBM	Western GOA from just southwest of Kodiak Island to the Shumagin Islands shelf, water column to 100 m	From physical model	Individual larval characteristics such as age, size, weight, location, life stage, hatch date, consumption, respiration
		Water velocities, wind field mixed-layer depth water temperature, and salinity,	
		Pseudocalanus field (from NPZ model)	
GLOBEC NPZ 1-D and 3-D Models	Water column (0-100 m) Coastal GOA from Dixon Entrance to Unimak Pass 100 m of water column over depths < 2000 m	Irradiance MLD	Diffusivity, ammonium, nitrate detritus small and large phytoplankton dinoflagellates tintinnids small coastal copepods neocalanus and euphausiids
		Temperature, diffusivity, bottom depths water velocities (u, v, w) sma neod eupl	
	5-m depth bins x 20 km horizontal grid		
			nitrate and ammonium mmol/m ³
			all else mg carbon/m ³

Table 8 1 Model Spatial Domains, Currencies, Inputs, and Outputs

Model Name/				
Model Region	Model Spatial Domain	Inputs	Outputs/Currency	
Steller Sea Lion IBM	Should be applicable to any domain surrounding a specific sea lion rookery or haul-out in the Bering Sea Aleutian Islands or GOA	The main input will be a 3-D field of prey (fish) distribution derived either from hypothetical scenarios or (later) modeled based on acoustic data	Individual sea lion characteristics such as age location life stage and birth date are recorded Caloric balance is the main variable followed for each individual	
Shelikof NPZ Model 1-D and 3-D Versions	Water column (0-100 m) GOA from southwest of Kodiak Island to Shumagin Islands 1-m depth bins for 1-D version 1 m depth x 20 km for 3-D version	Irradiance MLD temperature bottom depths water velocities (u v w)	Nitrogen phytoplankton Neocalanus densities Pseudocalanus numbers/m-3 for each of the 13 stages (egg 6 naupliar 6 copepodite)s	
GOA Pollock Stochastic Switch Model	Shelikof Strait Gulf of Alaska	Number of eggs to seed the model Base mortality additive and multiplicative mort Adjustment parameters for each mort Factor	Number of 90-day old pollock larvae through time	
NEMURO	Ocean Station P (50°N 145°W) Bering Sea (57 5°N 175°W) and Station A7 off the east of Hokkaido island Japan (41 3°N 145 3°W)	15 state variables and parameters, including 2 phytoplankton 3 zooplankton and multiple nutrient groups	Ecosystem fluxes are tracked in units of nitrogen and silicon	
Eastern Bering Sea Shelf Model 1 Ecopath	500 000 km ² in EBS south of 61°N	Biomass, production consumption, and diet composition for all major species in each ecosystem	Balance between produced and consumed per area biomass (t/km ²) Future work will explore energy (kcal/km ²) and nutrient dynamics	
Eastern Bering Sea Shelf Model 2 Ecopath	500 000 km ² in eastern Bering Sea south of 61°N			
Western Bering Sea Shelf Ecopath	300 000 km ² on western Bering Sea shelf			
Gulf of Alaska Shelf Ecopath	NPFMC management areas 610, 620 630, and part of 640			
Aleutian Islands Pribilof Islands Ecopath	Not determined			
Prince William Sound Ecopath	Whole Prince William Sound			
Ecopath Source Table 2 in Appendix E prepared by Kerim Aydin Units of Measure Boreal Migration and Consumption Model Eastern Bering Sea Global Ocean Ecosystem				

Units of Measure Boreal Migration and Consumption Model Eastern Bering Sea Global Ocean Ecosystem Dynamics Gulf of Alaska kilometer kilo calorie meter mixed layer depth millimolar, Multispecies Virtual Population Analysis North Pacific Ecosystem Model for Understanding Regional Oceanography North Pacific Fisheries Management Council, nutrient-phytoplankton-zooplankton Ocean Surface Current Simulations metric ton days of year

8.3 Purposes of Modeling

The ultimate goal of both gathering data and developing models is to increase understanding Pickett et al (1994) ([Pace 2001] p 69) define this goal, in the realm of science, as "an objectively

determined, empirical match between some set of confirmable, observable phenomena in the natural world and a conceptual construct "

A model—Pickett's "conceptual construct"—is useful if it helps people represent, examine, and use hypothetical relationships Data—Pickett's "confirmable, observable phenomena in the natural world"—can be analyzed with statistical tools such as the following

- Analyses of the variance, regressions, and classification and regression trees (CARTs),
- Mathematical tools such as Fourier transforms or differential equations, and
- Qualitative models such as engineering "free body" diagrams, network diagrams, or loop models

Fundamental goals of statistical or mathematical analyses are to develop correlative, and perhaps even causal, relationships and an understanding of patterns and trends In particular, there is a need to distinguish between random variability, noise, and patterns or trends that can be used to explain and predict

In other words, the goal of gathering and analyzing data is to improve our conceptual and analytical models of the world, and the goal of developing models is to represent and examine hypothetical relationships that can be tested with data

One of the most useful applications of even relatively simple statistical and conceptual models is in experimental design that permits investigating the possible roles of various parameters and their interactions, ranking the relative importance of uncertainties that may need to be resolved (Fahrig 1991, Oosterhout 1998), and estimating impacts of sample size and observational error (Botkin et al 2000, Carpenter et al 1994, Ludwig 1999, Meir and Fagan 2000) Statistical models assess how the variability in one or more kinds of data relates to variability of others To answer the "why" and "how" questions, however, mechanistic models can be used to develop and test hypotheses about causes and effects (Gargett et al 2001) (Mechanistic in this use is intended to describe the philosophy of mechanism, especially explaining phenomena through reference to physical or biological causes) For monitoring and modeling to be useful for solving problems, they must contribute to improving decision-making (Botkin et al 2000, Hilborn 1997, Holling 1978, Holling and Clark 1975, Ralls and Taylor 2000)

Toward this end, one goal of the GEM Program is to use models predictively to assist managers in solving problems It is important that expectations be realistic, however The mechanisms that drive ecological systems, particularly those related

to climate and human activities, are not currently well enough understood for predictions about natural systems to be reliably successful It is not unreasonable to expect that predictive models that managers will be able to use to produce at least short-term reliable forecasts will eventually be developed, but advances in decision-support models will require a long-term commitment to advancing understanding on which those decision-support models will ultimately have to be based

Prediction is, however, an important goal of a modeling program even in the short run, because science advances with the development and testing of predictive hypotheses Mechanistic studies are essential to advancing understanding, but carrying out these studies requires defining cause-effect or predictive hypotheses, and then testing those predictions against subsequent data or events with analytical models

The fundamental goal of the GEM Program is to identify and better understand the natural and human forces that cause changes in GOA ecosystems This research goal has a pragmatic purpose that can only be served, in the end, by linking correlative and mechanistic studies with the predictive needs of decision makers Decision-making, prediction, and understanding are inevitably linked, and maintaining that link can help keep a research program focused on its ultimate objectives, and help it to avoid narrow inquiry and the distractions of small temporary problems (Pace 2001)

An often-overlooked benefit provided by the process of developing a model is that it can, and probably should, facilitate communication among researchers, managers, and the public

To summarize, in the GEM Program, the specific purposes of modeling are to

- Inform, communicate, and provide common problem definition,
- Identify key variables and relationships,
- Set priorities,
- Improve and develop experimental designs to attain monitoring objectives, and
- Improve decision-making and risk assessment

8.4 Hierarchical Framework

It is critical that the GEM Program develop a hierarchical modeling strategy to ensure that short-term, smaller-scale decisions about monitoring and modeling studies will be

consistent with the conceptual foundation and GEM Program goals Smaller-scope research studies to test particular hypotheses and develop correlative relationships must fit within a larger synthesis framework connecting the more narrowly focused research disciplines Deductive studies to relate empirical data to synthetic

constructs are just as important as inductive studies to elucidate general principles, and it is important that researchers keep straight whether they are investigating the meaning of the data, given the theory, or the validity of the theory, given the data Neither can be done unless modeling, monitoring, and data management strategies are developed together

As described in Chapter 3, models for the purposes of the GEM Program may be verbal, visual, statistical, or numerical Statistical models are also known as "correlative" and "stochastic," and numerical models are also known as "deterministic" and "mechanistic" Note that "prediction," "analysis," and "simulation" are terms that describe the use of models, and not necessarily their type The modeling hierarchy of the GEM Program will provide links between observations and explanations, development of theory and design of experiments, and advancement of science and the practice of management The "top" of this hierarchy, the conceptual foundation, is the source of questions and hypotheses to be explored Statistical, analytical, and simulation models will be developed explicitly to link the "confirmable, observable phenomena in the natural world" to the "conceptual construct," as Pickett put it ([Pace 2001], p 69)

For example, a visual model of the conceptual foundation is shown in an influence diagram in Figure 8 1, which shows the forces of change on the left and the objects of ultimate interest that are subject to change on the right. In between the two are the intervening elements and relationships on which the human and natural forces act. It is the nature of the connections among these physical and ecological elements that is hypothesized to bring about the changes that the GEM



Figure 8 1 Influence diagram illustrating GEM conceptual foundation

Program seeks to understand Therefore, these connections should provide the overall modeling structure

This conceptual model is linked to the monitoring plan through the variables defined as "essential to monitor" in the conceptual foundation, illustrated in a network diagram in Figure 8.2 The analytical relationships between the monitored variables of Figure 8.2 and the conceptual foundation represented by Figure 8.1, are developed and investigated with statistical and analytical tools, called models

The ultimate goal of GLOBEC's Northeast Pacific modeling appears to be a suite of computer models that represents an entire conceptual foundation The way this is framed in programs like GLOBEC, the North Pacific Marine Science Organization (called PICES), and Global Ocean Observing System (GOOS) (see Section 8 2 of this chapter) is as linked physical and biological models representing the physical and biological worlds over time and space (marine as well as terrestrial) The NRC describes this idealized goal as follows (NRC 2000 p 16)

Develop a whole-ecosystem fishery model as a guide to think about what needs to be monitored Such a model would use current and historical data to relate yields to climate data and contaminant levels and might stress biological and physical endpoints (zooplankton/phytoplankton blooms, macrofauna populations) and climate and physical oceanography endpoints, in conjunction with modeling

Such a conceptual framework can stimulate heated arguments, creative debate, and perhaps synthesis among researchers who have tended to work in somewhat independent fields with different theoretical foundations and languages (Zacharias and Roff 2000) On a pragmatic level, however, it is too general to help decision makers choose to fund one proposal over another



Figure 8.2 Linkages among system attributes that the conceptual foundation identified as essential to monitor

A feasible way to proceed from what can be done now is through an iterative process framed by the conceptual foundation (Figure 8 3) The conceptual foundation should be the explicit source of hypothetical correlative and cause-and-effect relationships Those relationships should be stated as hypotheses, and should be used to determine what needs to be measured and when, where, and how If the monitoring and modeling plans are developed within this framework, the measurements can be compared to model predictions, the results can be used to update the scientific background and the monitoring plan, and the iteration can continue



Feedback control (adaptive) system

Figure 8.3 Feedback control system linking the conceptual foundation, monitoring, and modeling efforts

8.5 Defining and Evaluating Modeling Strategies

Modeling efforts of the GEM Program for the short term will be developed as part of a longterm strategy defined by goals of the GEM Program

To begin with, the modeling strategy must be consistent with GEM implementation tools and

strategies (Chapter 3) and mission goals (Chapter 1) They can be summarized to indicate that GEM modeling should accomplish the following

- Focus on filling gaps, thus avoiding duplication of efforts or "reinventing the wheel",
- Emphasize synthesis,

- Depend as much as possible on already existing piograms,
- Maintain focus on the research questions, and
- Emphasize efficiency

In developing a specific management strategy, it is often useful to think of it as a decision framework (Keeney 1992), and to start by defining an ideal For example, to satisfy GEM Program goals efficiently, an ideal model would arguably require input data that are relatively easy to measure, readily available, and reliable indicators of change The cause-effect theory that drives the modeled system or species behavior would be based not only on statistically valid correlative studies, but also on plausible and well-developed mechanistic studies and their resulting theoretical constructs The model would produce credible predictions under plausible scenarios, and would help answer questions and raise new ones

This ideal model would be easy for other scientists and managers to comprehend, and it would be readily available for others to deconstruct, test, and critique The overarching conceptual model would be modularized so that components of it could be developed and tested relatively quickly by experts from multiple disciplines Ideally, data already available could be used to test and validate the components and their interactions, and could allow quick learning that could be used to redirect the modeling and monitoring strategies Sensitivity analysis of the components, and the interactions between the components, would be a highly productive source for subsequent model and monitoring plan development Model structure would be flexible and have robust mechanisms for assimilating new data and revising model structure As a result, short-term progress toward the long-term goals could be achieved and documented

A modeling strategy is the roadmap that provides the means for achieving the ultimate modeling goals An idealized model like the one described above is a useful step toward defining the attributes of an efficient, workable strategy Development of such an idealized model can produce a useful communication tool Table 8 2 identifies preliminary objectives and attributes derived from this idealized model that could be used to evaluate modeling strategies

Objective or Attribute	Supported by models that help		
Relevance to questions and	Identify variables and relationships		
hypotheses of the GEM Program	Characterize uncertainty and noise impacts of process and observation error		
	Elucidate general principles rather than narrow unique focus driven by short-term perceived crisis		
Contribution to future model	Inform communicate develop common problem definitions		
development	Set priorities clarify relative impacts of variables and relationships		
	Improve and develop experimental (monitoring) designs		
	Prioritize and elucidate impacts of uncertainties in data and in model structure and assumptions		
	Increase utility of using simpler models to identify key variables and relationships to use in future models		
	Advance the state of the art for example increase available methodologies by borrowing from other fields particularly engineering and medicine tools such as neural nets genetic algorithms CARTs other kinds of regression (Jackson et al 2001)		
Efficiency of approach	Synthesize, exploit, and integrate existing data and existing programs whenever possible for example from oceanographic programs such as NOAA OCSEAP GLOBEC, and GOOS		
	Identify and exploit uniqueness of GEM Program opportunity; for example, no one else is doing it because it requires a very long time frame		
	Elucidate links between things that are easy to measure and key indicators of change, whatever they might be		
	Elucidate links between correlations (which are usually easier to develop) and explanatory mechanisms (which are usually more difficult)		
Maintenance and development	Accessibility of models to end users other modelers		
of program support	Contribution to data management, data assimilation effort		
	Contribution to solving problems for resource managers and regulators		

Table 8 2 Potential Objectives and Attributes for Use in Evaluation of Modeling Strategies

8.6 Modeling Methods

The modeling "niche" of the GEM Program will be defined in part by a gap analysis, particularly focused on where it fits with established major regional programs, especially those of GLOBEC,

GOOS, and PICES A very brief summary of the modeling approaches for these programs is provided in Section 8 2 of this chapter

The relationship between monitoring, modeling, and decision-making described here is consistent with the relationships of these programs The purpose of this section is not to define all the other modeling efforts that might be related to
the GEM Program A useful context is provided by a table compiled for GLOBEC by Aydin of the National Oceanic and Atmospheric Administration (Seattle), which summarizes North Pacific models of the Alaska Fisheries Science Center and others (see Section 8 3, Table 8 1, and North Pacific models in Appendix E) Correctly defining the GEM Program niche is important to avoid duplication of effort and to make best use of work already being done by others

Developing a model should be perfectly analogous to designing a controlled experiment A useful model structure will be driven by the questions it needs to help people answer, not by the computer technology and programming expertise of model developers (although technology and expertise may impose constraints) As a general rule, useful models do not tend to be complex, in part because they must be comprehensible to be believed and used by decision makers. That said, models based on laws of physics, which can be validated against those laws and either data or scale physical models, have advanced farther than ecological models in their ability to provide useful output from highly complex models

8 6 1 Linkages Among Models and Among Modelers

One of the most important challenges confronting GEM modelers will be to develop common languages and modeling frameworks that will allow them to resolve the temporal, mathematical, ecological, physical, and spatial sources of disconnects among the various academic paradigms This challenge will require significant commutment to improving communication skills, developing qualitative verbal or visual models, and using intuitive problem-structuring tools that combine different modeling techniques, such as network, systems, or loop models An additional benefit of this kind of approach is that these types of visual, qualitative models should be comprehensible to researchers from any scientific discipline, managers, and the public The attribute of being widely comprehensible will help facilitate the support of stakeholders

The feasibility of managing GEM as a realization of the conceptual foundation will depend in large part on the communication skills of experts in the components and linkages that make up the conceptual foundation Establishing effective communication among experts from different organizations is a widespread problem facing systems modelers (Caddy 1995), and the GEM Program may be in a good position to help advance the cause by making it possible for diverse experts to work together Experts in these fields should bring substantial background capabilities to their work from their common language of mathematics and science learned in graduate school The modelers of the GEM Program also should be required to demonstrate the ability to work with counterparts to develop a shared systems view and conceptual models

8 6 2 Deterministic Versus Stochastic Models

Detecting and understanding change requires that uncertainty and variability play a central role in the analyses (Ralls and Taylor 2000) Two key questions that

must be addressed by anyone trying to detect and understand change are the problems of Type I and Type II error Type I error is "seeing" something that is not really there, and Type II error is concluding something is not there, when it really is Dealing with these types of error in decision-making requires weighing the evidence that suspected change is caused by a (theoretically) definable pattern or trend or is "normal" process error, observation error, or some combination Equally important, and often overlooked, is how real indicators of change may be hidden by process or observation error or by incorrect assumptions about how things work

Dealing with uncertainty and variability in models requires at a minimum carrying out sensitivity analysis on simple deterministic models, with particular emphasis on model structure (Hilborn and Mangel 1997) But it is often more efficient and more useful to incorporate stochasticity into simple models Stochastic models need not necessarily be more data intensive than deterministic models Overlooking the assumptions required in choosing a mean (or median) or geometric mean, as a representative value for a deterministic parameter is one of the most widespread, but overlooked, sources of modeling error (Vose 2000) At least stochastic modeling requires that probability distributions be explicitly defined

Simplistic deterministic models can be every bit as misleading and improper as stochastic models (Schnute and Richards 2001), but because they are more familiar, and their single-number inputs and outputs are easier to think about than uncertainties and ranges, they may lead to false confidence on the part of decision makers Risk assessment in most fields requires analyzing probability distributions and uncertainties, not mean trajectories (Burgman et al 1993, Glickman and Gough 1990, Vose 2000)

One fundamental issue of interest to decision makers is often how best to prioritize research efforts A key part of such an issue is ranking the relative impacts of uncertainties on a decision In this case, it is possible that thoughtful sensitivity analysis carried out on a simple, deterministic model (or multiple models) may be adequate for the job, particularly as a first step in "weeding out" variables that are likely to be extraneous But developing a stochastic version of relatively simple models may be more efficient (Vose 2000) If care is taken to distinguish between environmental or process variation and observational or functional uncertainty, then statistical tools such as analysis of variance or regression can be used to investigate the relative impacts of uncertainties (Fahrig 1991, Law and Kelton 1991, Meyer et al 1986, Mode and Jacobson 1987a, Mode 1987b, Oosterhout 1998, Oosterhout 1996, Ruckelshaus et al 1997, Vose 2000) This approach can be very helpful in developing analytical structures as well as modeling plans It also lends itself well to decision analysis and risk assessment because it is similar to the "value of imperfect information" analyses widely used in risk assessment and decision analysis (Hilborn 1997, Keeney 1992, Punt and Hilborn 1997, von Winterfeldt and Edwards 1986)

8 6 3 Correlative Versus Mechanistic Models

The use of statistics-based tools such as regressions to make deterministic or probabilistic predictions will generally be easier than developing deterministic or stochastic biological models, because of a dearth of predictive "laws" of biology, let alone ecology Because statistics-based models are correlative, cause-and-effect explanations will eventually be needed if change is to be understood and predicted reliably Because some things are easier and more reliable to measure than others, simple models that can help develop correlative relationships between hard-tomeasure parameters and easy-to-measure parameters may be of particular interest

8 6 4 Modeling and Monitoring Interaction

Models should be developed to use and synthesize readily available data whenever possible This approach will also help identify data needs Similarly, whenever possible, monitoring plans should be developed to fit the models that will be used to analyze and interpret them Data management, assimilation, and synthesis should be key considerations for both monitoring and modeling

One useful way to incorporate data into improving an existing statistical or simulation model is with the Bayesian revision methods (Punt and Hilborn 1997, Hilborn 1997, Marmorek et al 1996) Bayesian methods might be useful to consider with respect to the question about how much emphasis should be put on annual forecasts, because Bayesian methods lend themselves well to incorporating incoming data into previous forecasts This entire approach also lends itself well to decision-analysis techniques

The GEM Program shares the view of models as tools for assimilating data and optimizing data collection as expressed for the GOOS program ([Intergovernmental Oceanographic Commission 2000], p 36)

A validated assimilation model can be most useful in optimizing the design of the observing subsystem upon which it depends This underscores the mutual dependence of observing and modeling the ocean, 1 e, observations should not be conducted independently of modeling and vice versa For example the socalled "adjoint method" of assimilation can be used to gauge the sensitivity of model controls (e g , open boundary and initial conditions, mixing parameters) to the addition or deletion of observations at arbitrary locations within the model domain In this regard, Observation System Simulation Experiments are becoming increasingly popular in oceanography as way of assessing various sampling strategies The model is first run with realistic forcing and model parameters The output is then subsampled at times and locations at which the observations were sampled These simulated observations are then assimilated into the model and the inferred field compared against the original field from which the

"observations" were taken This allows the efficacy of the assimilation scheme and sampling strategy to be evaluated (at least to the extent that the model is believed to be a reasonable representation of reality)

8.7 Evaluating Model Proposals

Model proposals should, of course, be evaluated within a decision-structured framework such as that outlined above and detailed in Table 8 2 Proposals must also demonstrate a high

probability of actually producing what they propose to produce andmeeting the objectives of the GEM modeling strategy A set of guidelines for evaluating model proposals will be developed for the GEM Program in conjunction with development of the modeling objectives As a starting point, successful proposals will provide the following:

- Define who will use the model and for what If the proposal is to continue or expand an existing model, it should describe who is currently using it and for what If relevant, the proposal should also identify who could be using it, for what, and why they are not able to use it now
- Define the questions the model is supposed to answer, and directly link those questions to the key questions and hypotheses of the GEM Program
- Argue convincingly that the model structure is adequate for the purpose, and that there is not a better (cheaper, faster, more comprehensible, more direct) way to answer these questions
- Show some kind of schematic (flowchart) that is clear, complete, and concise
- Explain how uncertainty and variability will be represented and analyzed
- Describe the system characteristics that will be left out or simplified and how the analysis will evaluate the impacts
- Define data needs and show how the modeling effort will be coordinated with data assimilation and data management efforts
- Define validation approach
- Define how the modeling efforts will be communicated to other scientists, managers, and the public, and how input from model stakeholders will be incorporated into the effort, if appropriate

8.8 Conclusion

Feasibility and pragmatism in a new program like the GEM Program dictate that walking will have to come before running and that focused, simpler

models will have to come before large-scale, multi-disciplinary models Walking first means developing verbal and statistical models where numerical models cannot be developed because of a lack of data and understanding Learning to run requires developing coupled numerical biophysical models that accurately portray the ecosystem Running means using the biophysical models in a predictive sense The models must adapt to changes in the conceptual foundation (Chapter 2), because the conceptual foundation is designed to change as new information is incorporated Nonetheless, no matter how many improvements are made, it is probably not reasonable to expect consensus on how that conceptual foundation should be used to develop a strategic modeling policy

In a constrained world, "consensus" in practice usually means accepting a strategy that enough decision makers find no more offensive than they can accept, optimization, on the other hand, means figuring out the tradeoffs necessary to achieve as many of the desired objectives as reasonably possible. Adopting a decision-structured approach for the modeling strategy will help ensure that it is driven by the fundamental objectives of the GEM Program, that the modeling questions are defined by the conceptual foundation, and the tradeoffs can be defined, weighed, and justified

8.9 References

- Botkin, D B, Peterson, D L, and Calhoun, J M 2000 The scientific basis for validation monitoring of salmon for conservation and restoration plans University of Washington, Olympic Natural Resources Center Forks
- Burgman, M A, Ferson, S, and Akcakaya, H R 1993 Risk assessment in conservation biology Chapman and Hall United Kingdom
- Caddy, J F 1995 Comment fisheries management science a plea for conceptual change Canadian Journal of Fisheries and Aquatic Sciences 52 2057-2058
- Carpenter, S R, Cottingham, K L, and Stow, C A 1994 Fitting predator-prey models to time series with observation errors Ecology 75 1254-1264
- Fahrig, L 1991 Simulation methods for developing general landscape-level hypotheses of single-species dynamics Pages 417-442 in M G Turner and R H Gardner, editors Quantitative methods in landscape ecology the analysis and interpretation of landscape heterogeneity Springer-Verlag, New York
- Gargett, A E, Li, M, and Brown, R 2001 Testing mechanistic explanations of observed correlations between environmental factors and marine fisheries Canadian Journal of Fisheries and Aquatic Sciences 58 208-219
- Glickman, T S and Gough, M 1990 Readings in risk resources for the future Washington D C
- Hilborn, R 1997 Statistical hypothesis testing an decision theory in fisheries science Fisheries 22 19-20

- Hilborn, R and Mangel, M 1997 The ecological detective confronting models with data Princeton University Press Princeton
- Holling, C S 1978 Adaptive environmental assessment and management John Wiley and Sons Chichester
- Holling, C S and Clark, W C 1975 Notes towards a science of ecological management Pages 247-251 in W H van Dobben and R H Lowe-McConnell, editors First international congress of ecology Dr W Junk B V Publishers, The Hague, Netherlands
- Intergovernmental Oceanographic Commission 2000 Strategic design plan for the coastal component of the Global Ocean Observing System (GOOS) Paris, UNESCO
- Jackson, D A, Peres-Neto, P R, and Olden, J D 2001 What controls who is where in freshwater fish communities - the roles of biotic, abiotic, and spatial factors Canadian Journal of Fisheries and Aquatic Sciences 58 157-170
- Keeney, R 1992 Value-focused thinking Harvard University Press London
- Law, A M and Kelton, W D 1991 Simulation modeling and analysis McGraw-Hill New York
- Ludwig, D 1999 Is it meaningful to estimate a probability of extinction? Ecology 80 298-310
- Marmorek, D R, Anderson, J J, Bashan, L, Bouillon, D, Cooney, T, Derison, R, Dygert, P, Garrett, L, Giorgi, A, Langness, O P, Lee, D, McConnaha, C, Parnell, I, Paulsen, C M, Peters, S, Petrosky, C E, Pinney, C, Schaller, H A, Toole, C, Weber, E, Wilson, P, and Zabel, R W 1996 Plan for analyzing and testing hypotheses (PATH) final report on retrospective analyses for fiscal year 1996 Vancouver, ESSA Technologies
- Meir, E and Fagan, W F 2000 Will observation error and biases run the use of simple extinction models? Conservation Biology 14 148-154
- Meyer, J S, Ingersll, C G, McDonald, L L, and Boyce, M S 1986 Estimating uncertainty in population growth rates jackknife vs bootstrap techniques Ecology 67 1156-1166
- Mode, C J and Jacobson, M E 1987a On estimating critical population size for an endangered species in the presence of environmental stochasticity Mathematical BioSciences 85 185-209
- Mode, C J a M E J 1 1987b A study of the impact of environmental stochasticity on extinction probabilities by Monte Carlo integration Mathematical BioSciences 83 105-125
- NRC 2000 Ecological indicators for the nation National Academy Press Washington, D C

- Oosterhout, G 1998 PasRAS a stochastic simulation of chinook and sockeye life histories Eagle Point, Decision Matrix, Inc
- Oosterhout, G R 1996 An evolutionary simulation of the tragedy of the commons Systems Science Portland State University, Portland
- Pace, M L 2001 Prediction and the aquatic sciences Canadian Journal of Fisheries and Aquatic Sciences 58 63-72
- Perry, R I, Yoo, S, and Terazaki, M 1997 MODEL task team report, workshop on conceptual/theoretical studies and model development Sidney, British Columbia, North Pacific Marine Science Organization (PICES)
- Pickett, S T A, Kolasa, J, and Jones, C G 1994 Ecological understanding Academic Press San Diego
- Punt, A E and Hilborn, R 1997 Fisheries stock assessment and decision analysis the Bayesian approach Reviews in Fish Biology and Fisheries 7 35-63
- Ralls, K and Taylor, B L 2000 Introduction to special section better policy and management decisions through explicit analysis of uncertainty new approaches from marine conservation Conservation Biology 14 1240-1242
- Ruckelshaus, M, Hartway, C, and Jareuva, P 1997 Assessing the data requirements of spatially explicit dispersal models Conservation Biology 11 1298-1306
- Schnute, J T and Richards, L J 2001 Use and abuse of fishery models Canadian Journal of Fisheries and Aquatic Sciences 58 10-17
- US GOOS Steering Committee 2000 A position paper of the US GOOS Steering Committee Toward a national, cost-effective approach to predicting the future of our coastal environment http //wwwocean tamu edu/GOOS/publications/position html
- von Winterfeldt, D and Edwards, W 1986 Decision analysis and behavioral research Cambridge University Press Cambridge
- Vose, D 2000 Risk analysis a quantitative guide John Wiley and Sons Chichester
- Zacharias, M A and Roff, J C 2000 A hierarchical ecological approach to conserving marine biodiversity Conservation Biology 14 1327-1334

9. DATA MANAGEMENT AND INFORMATION TRANSFER

In This Chapter

- > The Role of Data Management
- > Characterizing the Data within GEM
- > Characterizing the GEM User Community
- > The Structure of the GEM Data System

9.1 The Role of Data Management

The data management and information transfer component of GEM includes the following functions data receipt, quality control (QC), storage and maintenance, archiving and retrieval, administrative support, and the systems necessary

to automate as much of these procedures as possible This component also includes programs needed to create the custom data and information products that will be provided to the modeling and applications components, and to the users of this information Therefore, the data management system for GEM fits well into the definition established by the Coastal Committee of the Global Ocean Observing System, C-GOOS (GOOS 2000) as shown in Figure 91



Figure 9 1 GOOS model of data management

The GOOS model is a general description of an end-to-end system that is based on the tripod of observation, data management, and models and applications, with the data management component acting as the intermediary between the observational component and the applications Data flows from observation through the management system to the modeling and applications component In turn, the applications component informs and refines both the design of the observational component and the design of the data management system The monitoring plan may be altered to include new data, regions, or both that are identified during the modeling phase as key to understanding the natural system The interfaces and data products distributed by the data management system will also be refined with feedback from the applications

Scientific data management systems have grown rapidly since the advent of the World Wide Web Initial efforts by projects or groups that collected or archived data provided relatively simple access through the use of navigational links. These supply-oriented systems reflect the structure of the data that was made available by providing links to lists of data sets by years, data set name, or variable name Many of these systems are still in wide use. Newer systems include more sophisticated search options based on selection of spatial and temporal attributes However, these systems make few assumptions about the intended user community, and it becomes the users' responsibility to locate, evaluate, integrate, and pre-process the data into a form that is suitable for their target application.

As the applications that use scientific data become more sophisticated, and the community is able to access and integrate large amounts of data to address a single problem, new data systems that address the data needs of specific user applications will be built. The output of these systems will be higher-order products such as maps, graphs, visualizations, and data in interoperable formats. National Aeronautics and Space Administration (NASA) has funded some projects with a demand-oriented focus (The Federation of Earth Science Information Partners NASA Research Announcement), and in the future, more user communities will find ways to build these types of targeted systems.

The landscape of data product delivery will likely include large archives that supply data in a raw or partially pre-processed form. Application-oriented sites will access data from these archive sites through a high bandwidth connection and may use intermediate sites, which provide value-added services that are not available from the originating archive Common data services available at the archive or through intermediate sites will include subsetting, reformatting, reprojection, regridding, and aggregation

Although predicting the evolution and the impact of the Web on scientific data delivery is speculative at best, the landscape of future data systems will need to be continuously surveyed to understand the role of the data management component during the extended lifespan of GEM Initially, GEM will act as both a data archive and a user-focused delivery system The immediate objective of data management and information transfer is to insure that the data collected by projects under GEM are well documented, safely stored, and accessible to the public within a reasonable period of time after collection An ongoing objective of data management and information transfer in the GEM Program is to achieve to the extent possible the documentation, storage and public access for past data acquired with EVOS funds under Natural Resource Damage Assessment and Restoration GEM will establish coordination among parties as soon as possible by such means as file transfer protocol (ftp) sites, Web sites, and e-mail lists

For data acquired with GEM funds, GEM will define and enforce appropriate data and metadata standards GEM data management staff will ensure that projects are designed so that data and samples are collected in a manner that will yield accuracy and precision sufficient for the objectives of each field program and sufficient for those comparisons and syntheses among programs that can be anticipated It is fundamental to any research program that high-quality data be collected While the primary responsibility for this always belongs to the principal investigator, GEM data management staff will provide guidance, coordination and monitoring, particularly for situations where the level and type of data management appropriate for an individual project may not be the same as that required by an interdisciplinary program of large geographic and temporal extent To provide the opportunity for comparison with historical data, measurement techniques will be consistent with techniques used to collect the existing data unless there is significant scientific justification for change When new techniques are adopted, methods for relating the new data to existing data will be developed

It is just as important that appropriate metadata ("data about data") be created and made available in order to search, identify and retrieve data sets in the GEM data archive Under no circumstances will a data file, data set, data layer, or database be accepted by or made available via the GEM archive without appropriate supporting metadata Metadata usually include, but may not be limited to, location, time, units, accuracy, precision, method of measurement, method of sensor calibration and sensor calibration data, analyst or operator, and data processing methods The metadata format will be compliant with the Federal Geographic Data Committee (FGDC) standards

The Federal Ocean Data Policy requires that appropriate ocean data and related information collected under federal funding be submitted to and archived by designated national data centers, such as the National Ocean Data Center (NODC) Such an archive will be used in addition to the GEM data archive The GEM data management component may not in itself support a "24 hours a day-7 day a week-365 day a year," always on and open system, but could support these types of operations as a partner The GEM Program will continue to maintain metadata and a data search interface to locate and access GEM data that is maintained by the GEM data archive and other data archives in use

The long-term end point for GEM data management and information transfer is a system that manages the rapid and efficient flow of data and information based

on core monitoring projects to end users, and that facilitates the flow of data and information between and among GEM partners and the user community A partnership system of data distribution will be designed to make information products readily available to partners and other user groups The ultimate goal will be an end-to-end system, in which a monitoring network provides data to models and other applications that provide services to a variety of end users, including the ongoing GEM synthesis, research, and modeling

In the long term the GEM Program may turn over the entire archiving task to a center such as NODC that is better equipped to maintain the data for extended periods of time This transition will only be possible after the data flow between the observational component and the applications component has been established and the tools and structures are in place to build the custom data products from a distributed set of data archives The GEM Program would retain the metadata and continue to provide custom data products and services to a set of targeted users

9.2 Characterizing the Data within GEM

Within the data management component, data are classified by the operations that must be applied to them during the archive and retrieval cycle This classification often cuts across the contentbased classifications used during data analysis

Although biologic data are more often collected by observation or laboratory work and physical data are frequently measured by instrument, there are significant exceptions A satellite image of ocean color that contains biologic variables will have more in common, in a data management context, with the physical variables in a Synthetic Aperture Radar image than to the phytoplankton results collected from the settled volume of a bottle sample The settled volume could include both physical and biologic results, but be retained by the data management system as a single data holding The metadata and processing that are associated with the chemical and biologic data from the bottle sample will be nearly identical, as will the processing and metadata associated with both types of satellite imagery

GEM will be collecting and processing a wide range of data from different collection and recording techniques that present different quality control and assurance challenges To classify these differences for the data management component, data can be separated into broad categories that reflect the handling and storage requirements

- Observational data collected or recorded by an individual,
- Measured data collected by an instrument and stored in formatted files,
- Modeled data generated by a running computer model,
- **Geographic** or reference data used by a Geographic Information System, and
- Remotely sensed image data taken from a satellite or aerial platform

The following criteria are used to characterize these data types

- Interoperability how easily the data can be used in alternate applications,
- Consistency the degree of similarity between the data for different points,
- Size of file the size of the data for a single instance,
- Number of files the number of instances that make up the data set,
- **Repeatability** whether or not the same data can be re-sampled,
- Lag time the length of time needed between collection and submission,
- Alternative sources whether the data is maintained at multiple sites, and
- Metadata The content, format, or both of the metadata

921 Observational Data

Observational data are collected by human observation, laboratory results, and manual data entry These data include species counts and locations and can include a large number of ad hoc observations of conditions or unrelated sightings These data are manually entered and capture a person's observations or calculations, which make them less consistent, often complex, generally low volume, and occasionally error prone The observations are not repeatable and the formats are not customarily interoperable. The lag time between collection and submission can be long if extensive lab or manual work is involved. The metadata describe the collection and or processing location and sometimes the conditions These data are often in a database management system or a spreadsheet, which forces a level of consistency that allows automated processing upon retrieval Examples of observational data sets from the GEM habitat types (see Chapter 4) include

Watersheds

- Lab results for stream chemistry
- Plant and animal observations from field study
- Isotopes of nitrogen and levels of phosphorus, silicon, and iron from a lab

Intertidal and Subtidal

- Species counts for substrate classification
- Lab results for chemical and biological oceanography

Alaska Coastal Current

- Lab results for chemical and biological oceanography
- Species counts for zooplankton

- Diet composition for nekton
- Nekton measurements from net tows
- Bird surveys

Offshore

- Lab results for chemical and biological oceanography
- Species counts for zooplankton
- Bird and mammal surveys

9 2 2 Measured Data

These data are mostly measurements of physical variables such as air temperature or salinity, but they may also include biologic variables as in the case of the acoustic measurements of the biomass of nekton or zooplankton. These data are usually stored in files with formats that are set by the collection instrument. The data files are consistent across the data set, but have a low level of interoperability with other systems. Because data collection is automated, the size of the files and the number of the files can be large. Usually, little special processing is involved, therefore, the lag time between collection and submission does not need to be long. The metadata include instrument details and conditions, and the data formats are standard enough to allow customized processing during retrieval. Examples from the GEM habitat types include.

Watersheds

Physical and hydrologic variables

Intertidal and Subtidal

Physical oceanographic variables

Alaska Coastal Current

- Lidar measurements
- Hydroacoustic plankton or nekton surveys
- Fluorescence measurements

Offshore

- Physical oceanography
- Hydroacoustic plankton or nekton surveys
- Fluorescence measurements

923 Modeled Data

Numeric models, and to some degree statistical models, can generate a significant amount of data As an example, the circulation model can provide a snapshot of ocean current vectors across the GEM region, at many depths, for time steps as small as 10 minutes Other models produce smaller result sets, but often these results are used by other models as input and must be cataloged and delivered by the data management component However, unlike most other data sets, these data can be recreated and often are as the model matures. These data are consistent across the data set, can represent a high volume of data, and are not generally interoperable. The lag time between data generation and data submission (and even use) can be very short. The metadata need to describe the classification and version of the model and may need to include relevant input parameters. The metadata may be used to track the lineage of the output data, including the references to the input data and, if relevant, the models that created those input data.

9.2 4 Geographic Data

These data are the reference data used by Geographic Information Systems (GISs) and include base layers such as elevation (bathymetry) and shorelines, but can also include soil types or habitat characterization. These data formats are rarely used to store data collected by a project, but are frequently used to display the information in the spatial context of a map. These data are usually interoperable across different systems and may be stored at several different locations. The metadata are focused on the spatial definition and may include information about the resolution or precision of the data. GEM will not generally be ingesting these data from projects, but the program may store reference information in this format, which is also a prime format for custom data products created by the data management component.

9 2 5 Remotely Sensed Data

Remotely sensed imagery can come from satellite or aerial platforms These are generally large files and may be used on a regular basis by the analysis being conducted by GEM However, images from NASA or NOAA may not need to be archived if they can be retrieved again from the source Aerial photography has also been used by EVOS projects to capture the spatial distribution of nekton in PWS These images, along with satellite images, may in some cases be archived by the GEM Program and provided to the application component. These data will require a large amount of storage and are quite interoperable with GIS and imageanalysis tools. The metadata describe the instrument and platform and often include details of the image quality and the spatial reference system. Examples in the GEM habitat themes could include.

Watersheds

LandSat images of watersheds

- Moderate Resolution Imaging Spectroradiometer (MODIS) imagery
- Aerial photography

Intertidal and Subtidal

- Ocean color imagery from SeaW1FS
- Aerial photography

Alaska Coastal Current

- Ocean color imagery from SeaWiFS
- MODIS ocean products

Offshore

- Ocean color imagery from SeaWiFS
- MODIS ocean products

926 Impact on GEM

Although the data standards set by the GEM Program will be similar across the data sets in a given type, each data set will have its own set of standards and QC and ingest processing As the GEM data management component becomes active, new data sets will be added to the archive For each new data set, GEM will set data standards and create the software to perform the QC against those standards The data management plan will outline what needs to be in place before a new data set can be added to the GEM archive

As each collection effort is funded and organized, a plan that outlines the data inventory and its submission schedule will be established In addition, the plan will include the procedures for performing the QC process and how discrepancies will be resolved

9.3 Characterizing the GEM User Community

During its lifetime, the GEM Program will serve a large and diverse user community with needs that will vary from simple data download, to the creation of tailored data and information products, to administration of projects, reports

and data In most cases meeting the requirements of particular user groups will require detailed analysis and the creation of tailored products, but generalizations can be made about the types of applications for which GEM will provide data

The user groups interested in each application will have different levels of data analysis and reduction capabilities, and each will need to search for GEM data with different criteria Some applications require regular or periodic access to GEM data, and others are irregular or sporadic The largest discriminator between the applications, however, is the type of data products that GEM will create for them and the level of processing that will go into creating those products The following applications are relevant for all four of the main GEM habitat types watersheds, intertidal and subtidal, ACC, and the Offshore

- 1 **Basic research and analysis** is perhaps the most fundamental application of GEM data This activity will be done by researchers who are collecting data for GEM and by other researchers that are investigating the GEM region. In general, this community will have a good understanding of GEM data and will be searching for specific variables within a region of interest. Access is less likely to be irregular, but research applications expect access to data as soon as it can be made available, therefore, file transfer protocol (ftp) or file-download of the original data will generally be sufficient
- 2 **Modeling** is also a critical application of GEM data Verbal and visual models will be drawn from research applications, but statistical and numeric models will require access to customized data products that are tailored to meet the needs of the model as closely as possible Most of the search criteria may be saved by the system and may be reused on a regular basis to execute the model with the most recent set of parameters The types of preprocessing could include reformatting, spatial or temporal aggregation, regridding, and reprojection
- 3 **Resource management applications** will increase in number through time and may become a common use of GEM data These applications will require a set of products separate from the modeling applications Management applications will be both periodic and sporadic, and the products may include reports, graphs, or maps Examples include regular stock analysis reports that are used by fisheries managers to set catch limits and or irregular access to watershed data that would be relevant to permit requests
- 4 **Public outreach** encompasses several different applications that GEM will be supporting to varying degrees These include providing public information about the state of the ecosystems that are being studied by GEM, as well as the general administration of the GEM Program Other outreach activities will include supporting educational programs and possibly emergency response These applications can be supported with maps and graphs that describe various aspects of the central GEM themes Access is likely to be quite irregular and may be accomplished through the creation of a few standard maps and graphs on a regular basis
- 5 GEM programmatic/administrative support will encompass programmatic assistance from original proposal submission to final report publication Development of administrative systems will allow for timelier and well monitored data submission, and provide linkages between data and information only available in the final reports In addition, data management will support continuing gap analysis through a continuously

updated database of current and historical information-gathering projects in the GOA and adjacent areas

931 Supporting GEM Applications with User Interfaces

To support these applications, GEM will initially provide three different modes of access The initial design will include basic search and download, tailored product creation and display, and open map access For the most part, basic search and download will support research applications, tailored products will be used by both modeling and management applications, and open map access will support public outreach applications Together these three modes of access characterize many of the scientific data delivery systems available on the Web

Basic search and download is currently the most common method of accessing data on the Web Many projects have an interface that makes some level of search available and then allows data to be downloaded by clicking through to an ftp site or a Web page containing data links Examples include the following

- CIIMMS (http //info dec state ak us/ciimms/), which has been used successfully to provide basic access to metadata and data relating to Cook Inlet and other areas of Alaska,
- Systems such as GLIMPSE/Webglimpse (http //lternet edu/data/), EMAP (http //www epa gov/emap/), and Beija-flor (http //beijaflor ornl gov/lba/), which provide basic access for the NSF Long Term Ecological Research program, the EPA Environmental Monitoring and Assessment Program, and the Large Scale Biosphere-Atmosphere Experiment in Amazonia sponsored in part by NASA, and
- The GLOBEC program, which provides basic data download through its own database (http //globec whoi edu/globec-dir/data-access html)

Although these systems provide different types of search criteria, and each has a different orientation, they all provide access to metadata and, in most cases, the actual data collected by the program The GEM Program can use one of these systems or something very similar to provide access to data soon after it is submitted to GEM Research applications are often focused on specific variables and regions, and these basic systems meet the majority of those needs In addition, a basic search-and-download tool will provide the minimum access to GEM data and may support the other applications, including modeling, resource management, and public outreach Although budgetary constraints may require that the creation of custom map and data products be limited, the basic search-anddownload functions will be supported as long as data is collected and archived by the GEM Program

The metadata maintained to support the basic search-and-download functions would also support access to remote database services that are funded by or relevant to GEM Remote databases like the EVOS hydrocarbon database and

other databases maintained by the group that is conducting the data collection effort will be included in the GEM metadata for searching purposes The data will then be available through the remote Web site set up to support those data

Map creation systems such as the Open GIS Consortium's Web Mapping Server (WMS) (http //www opengis org/techno/specs/01-047r2 pdf) and the ArcIMS system (http //www esri com/software/arcims/index html) from the Environmental Systems Research Institute make preprocessed maps available to users on the Web Both of these systems provide maps to Web browsers and to freely available viewers Because the WMS protocol is not tied to any particular vendor, it has been enjoying rapid acceptance and use in a wide range of applications In the future, the use of WMS in educational and outreach applications is likely to be very large

Once GEM has identified a set of standard map products that would be useful to the public or to particular educational programs, they will be available through one of these Internet map protocols These products will likely include base maps and general information maps, but might also include regular maps of the Alaska gyre or currents that affect the GEM habitats Web sites designed to support the educational program or the public interests will display these maps and may, in time, support more complicated map viewers that can access and overlay maps from other sites that are relevant to the goal of the Web site

Data products tailored to specific modeling and resource management applications will be the most useful facet of the GEM data distribution and also the most expensive to create It is not possible to create a single data distribution system that meets the wide range of user needs in modeling and resource management Therefore, GEM will need to prioritize the products that are needed by particular groups and create them in sequence These products will be designed with the close involvement of the specific user community to which they are targeted and, initially, they may need to be created with a significant amount of manual effort However, once automated, a separate Web-based interface that will be used by the target user group to create and download these products on a regular (or irregular) basis can be created In the future, after many of these products have been designed and the distribution of them automated, certain common functions will emerge and GEM will begin to build a library of dataprocessing utilities

Examples of modeling products include the reformatting and regridding of data to match the execution grid and time steps of the model Non-GEM data may be pulled from another site and integrated into data products Several different products may be generated at a time to meet the needs of a single modeling application. The creation of a suite of products may be done by hand and may require that GEM start with algorithms that were written by the modeling group itself However, after the modeling group has used the products successfully several times, the process of creating the products could be automated and a simple interface built to allow the group to create and download the product If the requirements for the product are clear enough, the manual step may be bypassed

For resource management applications, a report or spreadsheet used to manage fish stocks may require access to several different data sets and the extraction and integration of different variables Unless the report is already in existence, it may require several attempts before a truly useful product can be created Once this is accomplished, the process could be automated The resource management office could trigger the report through a simple interface created for that product. In this way, the application component of GEM will feedback information and tailor the design of the data management component

In time, GEM will create a wide range of products to meet the specific needs of the GEM modeling and resource management communities The creation of each product will involve GEM staff and interaction with the target user group Depending on the scope of the effort for each product, several tailored products could be created for the modeling and resource management community each year These products, coupled with the basic search and download and the Web-based map delivery services, will support a wide range of both specific and general data distribution needs

9 3 2 GEM Administrative Support

Managing the projects funded by and associated with GEM requires a projectoriented database (see Chapter 5) The administrative information includes the original proposal, comments submitted by the review panel, status reports and notes, and the final report This information will be valuable in the long term as the data collected by the project is evaluated in retrospect. The proposals and reports will contain the original hypotheses, as well as the problems that were encountered during data collection. Future researchers will use this project history to understand the original goals of the project and issues that might affect data quality

Much of these administrative data are in the public record and will be made available over the Web The GEM metadata will include the project specifications so that the data submitted by the project can be displayed along with the administrative details This link between the administration of the project and the data submitted would also allow the GEM Program to evaluate whether all the data for a given project have been submitted

9.4 The Structure of the GEM Data System

The GEM data management system will address the issues related to the data types supplied by the observational component and the demand placed by the applications component As such, the data management system is positioned between the other two components and must develop and maintain an interface to both In addition, modeling and map creation applications will generate new data that will also be archived and delivered by the GEM data system (Figure 9 2)



Figure 9 2 The GEM data system

941 Supply Side Support

To support the ingestion of data from the observational component of the GEM Program, the data management system must provide QC of the metadata (and to some degree the data) and quality assurance of the data and the metadata Quality control will ensure that the metadata comply with GEM standards and that valid values are supplied in formats that can be used to store that data in the GEM archive Values such as station identifier, date, and latitude and longitude need to be valid or fall within a reasonable range. In general, each data type will have unique issues, and the GEM Program will create new QC procedures and programs. Through time however, some of the QC algorithms can be shared across data types. The GEM Program will also need to provide QC on some of the data values, such as species identification, but the submitter will do most of the QC for the data itself. The validation provided by the data management component is done to ensure that data can be found and retrieved with the use of an accepted set of search criteria.

Quality assurance includes the design of the QC processes and documentation of the QC activity The data management component of GEM will not be able to provide QC over most of the data, but it can ensure that the documentation of the submitters' QC is available along with the data The data management system will also provide quality assurance of the metadata

9 4 2 Demand Side Support

On the applications side of the data management system, software modules will create the custom data products and standard maps These routines will not be developed all at once when the system is deployed, but through time, as the archive is populated with data and the user demands become clear Custom

routines will integrate third-party software where possible These external routines may be commercial-off-the-shelf (COTS) software or they may come from the growing library of "open source" software available on the Web These custom routines will pull data sets from the GEM archive and other relevant data sources and provide preprocessing Examples of the types of operations include

- Reformatting Often, raw data may need to be reorganized to be usable by an application For example, an application may need multiple observations pulled into a single output file containing only those variables of interest from a subset of stations This file may also need to be ordered by date or species and written out in a comma-separated file that can be manipulated by a spreadsheet Other output formats may include GIS, image analysis formats or special binary formats for visualization applications
- Aggregation or subsetting Modeling applications often need summary or averaged data These data sets may need to be merged or clipped to capture the temporal or spatial region of interest completely Some file formats support clipping, but many of these routines will be tailored to the input data Aggregation routines may come from the application space or they may simple average or sum calculations
- Projection Data are usually collected with latitude and longitude coordinates Some regional models use a map projection that preserves spatial relationships more accurately for the region Satellite data and other data may need to be projected or reprojected into a specific map projection for the application Software is available to perform some of these reprojection operations from both commercial and freeware sources
- Map creation and visualization Some data products may be best represented in the spatial context of a map or a graph. The generation of these maps or the creation of a multidimensional or graph-oriented visualization requires data-extraction reduction and rendering Many software utilities are available to assist in this process

Most custom data products will require a user interface to allow the entry of parameters and trigger the creation of the product In most cases, these interfaces will be simple Web pages that support various pull-down menus to select input or display parameters Simple interfaces that are designed to support one or two data products are easier to use and maintain Through time, however, GEM will support a large number of custom products, and interfaces may need to be merged to reduce the overall maintenance load

943 Metadata Support

The core of the data system will be metadata and a data-storage component The metadata contains the descriptive information and is used to integrate access to the data by supporting cross-data set searching The ability to search for all data sets within a given spatial of temporal range, or all data sets containing particular variables, requires a single database of metadata. The QC routines will ensure that the metadata submitted to the GEM Program meets the standards necessary to support cross-data set search. No data set will be added to the system unless it can be located with a search of this metadata.

The metadata maintained by the GEM Program will also support access to remote GEM archives that are maintained by individual researchers and their supporting organizations. The GEM Program will also evaluate whether to ingest metadata about data sets that are relevant to the GEM system, but are not directly supported by GEM. The ongoing gap analysis conducted by the GEM Program will continue to reveal data sets and data-collection activities that complement the GEM mission. One of the GEM goals is to integrate with those projects. The data management system will reflect this integration by allowing users to locate relevant data that may not be archived by the GEM Program.

The metadata maintained by the GEM Program could also be available for searching by other data clearinghouse programs In such a situation, the GEM metadata would be a information node for that clearinghouse The GEM Program will identify and work with such programs to ensure that the GEM data is available to a wide and varied audience through a variety of search mechanisms

Most search and download systems include some level of metadata support The GEM Program will evaluate the use of these existing systems, including the structure of the metadata Because the population and use of the metadata will be the central activity of the GEM data system, any existing system will need to be modified before it is used by GEM

9.4 4 Data Storage

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The storage of the data in files or in another storage mechanism is a separate function of the data system that in time will require a significant amount of storage space. The metadata will contain pointers to the data itself, which may physically be in a separate storage facility. The evolution of large archive technology has been rapid in the last few years, but GEM will be able to postpone the use of tape, optical media or a storage area network for several years until the space requirements demand it. The GEM Program will evaluate the use of an external site to store the data as well as the use of GEM computing hardware. Unlike the search of the metadata that places a heavy computational burden on resources while returning a small amount of data, accessing the data itself requires no significant computation, but can return a large amount of data. Therefore, the network connectivity is also an evaluation criterion for the data storage subsystem.

The format of the data files will be defined and standardized in the GEM data management plan Although the QC procedures will not validate the scientific quality of the data, these programs will need to validate the format of the data Routines for creating data product require that input data files are in a recognizable format and contain data in a format that can be processed automatically

9.5 References

GOOS 2000 Strategic design plan for the coastal component of the Global Ocean Observing System (GOOS) UNESCO GOOS Report No 90

APPENDIX A. ACRONYMS AND WEB LINKS

Note Not all of these acronyms and Web links are referenced in the GEM Program document Many are included for general reference purposes

- ABC Acceptable Biological Catch
- ABWC Alaska Beluga Whale Committee
- ABSC (USGS) Alaska Biological Science Center (Biological Resources Division,
 - US Geological Survey)
 - http //www absc usgs gov/research/seabird&foragefish/index html
- AC Alaska Current
- AC Arctic Council
 - http //www arctic-council org/
- ACC Alaska Coastal Current
- ACCE Atlantic Climate and Circulation Experiment
- ACIA Arctic Climate Impact Assessment (Arctic Council) http://www.acia.uaf.edu
- ACRC Alaska Climate Research Center, http://climate.gi.alaska.edu/
- ACT Alliance for Coastal Technologies
- ADCED Alaska Department of Community and Economic Development http://www.dced.state.ak.us
- ADCP Acoustic Doppler Current Profilers
- ADEC Alaska Department of Environmental Conservation http://www.state.ak.us/dec/home.htm
- ADEM Alabama Department of Environmental Management
- ADEOS-II Advanced Earth Observing Satellite-II
- ADFG Alaska Department of Fish and Game
 - http //www state ak us/adfg/adfghome htm
 - Division of Commercial Fisheries http://www.cf.adfg.state.ak.us/cf_home.htm
 - Division of Habitat http //www state ak us/adfg/habitat/hab_home htm

Division of Subsistence http //www state ak us/adfg/subsist/subhome htm Division of Subsistence Whiskers Database

Division of Sport Fish http //www state ak us/adfg/sportf/sf_home htm ADHSS Alaska Department of Health & Social Services

ADNR Alaska Department of Natural Resources http //www dnr state ak us/

Division of Parks and Outdoor Recreation http://www.dnr.state.ak.us/parks

Division of Mining, Land and Water http //www dnr state ak us/mlw

ADOT&PF Alaska Department of Transportation and Public Facilities

http //www dot state ak us

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- AEIDC Artic Environmental Information and Data Center
 - http //www urova fi/home/arktinen/polarweb/polar/lbusaeid htm
- AEPS Arctic Environmental Protection Strategy
- AEWC Alaska Eskimo Whaling Commission
- AFSC Alaska Fisheries Science Center (NOAA/NMFS) http://www.afsc.noaa.gov/generalinfo.htm
- AIS Archival Information System
- ALAMAP-C Alabama's Monitoring and Assessment Program-Coastal
- ALP (aka AL, ALPS) Aleutian low pressure system
- ALPI Aleutian low pressure index
- AMAP Arctic Monitoring and Assessment Programme (Arctic Council) http://www.amap.no/
- AMHS Alaska Marine Highway System
- AMMC Aleut Marine Mammal Commission
- AMMTAP Alaska Marine Mammals Tissue Archival Project
- AMNWR Alaska Maritime National Wildlife Refuge
- AMOS Advanced Modeling and Observing System
- AMSR Advance Microwave Scanning Radiometer
- ANHSC Alaska Native Harbor Seal Commission http://www.ptialaska.net/~aksealmr/
- ANS Alaska North Slope
- ANS Aquatic Nuisance Species (EPA)
- AOC Great Lakes Areas of Concern
- AOSFRF Alaskan Oceans, Seas, and Fisheries Research Foundation http://www.alaskanoceans.org/welcome.html
- APEX Alaska Predator Ecosystem Experiment
- AR Alaska Region, NMFS
- ARC Atlantic Reference Center
- ARCUS Arctic Research Consortium of the United States http://www.arcus.org
- ARGO Array for Real-time Geostrophic Oceanography
- ARGO OPN ARGO Ocean Profiling Network
 - http //www argo ucsd edu
- ARIES Australian Resource Information and Environment Satellite
- ARLIS Alaska Resources Library and Information Service http://www.arlis.org/index.html
- ARMRB Alaska Regional Marine Research Board
- ARMRP Alaska Regional Marine Research Plan
- ARPA Arctic Research and Policy Act (1984)
- ASCC Alaska State Climate Center
 - http //www uaa alaska edu/enri/ascc_web/ascc_home html
- ASF Alaska SAR (Synthetic Aperture Radar) Facility
 - http //www asf alaska edu/
- ASLC Alaska SeaLife Center http://www.alaskasealife.org/

- ASOF Arctic-Subarctic Ocean Flux Array
- ASP Amnesiac Shellfish Poisoning
- ASTF Alaska Science and Technology Foundation http //www astf oig
- ATSDR Agency for Toxic Substances and Disease Registry http://www.atsdr.cdc.gov/
- ATV All Terrain Vehicle
- AUV Autonomous Underwater Vehicle
- AVHRR Advanced Very High Resolution Radiometer
- AVSP Alaska Visitoi Statistics Piogram
- AWC Anchorage Waterway Council
 - http //www anchwaterwayscouncil org
- AWQ Division of Air and Water Quality, ADEC http //www state ak us/dec/dawq/dec_dawq htm
- BAHC Biospheric Aspects of the Hydrological Cycle (IGBP)
- BASS Task Team Basin Scale Studies Task Team (PICES)
- BATS Bermuda Atlantic Time Series
- BBMMC Bristol Bay Marine Mammal Council
- BBNA Bristol Bay Native Association
 - http //www bbna com/
- BCIS Biodiversity Conservation Information System http://www.biodiversity.org/simplify/ev.php
- BDY Beach Dynamics
- BEACH EPA's Beaches Environmental Assessment, Closure, and Health Program
- BIO Biological Oceanography Committee (PICES)
- BOOS Baltic Operational Oceanographic System
 - http //www boos org/
- BORMICON Boreal Migration and Consumption Model
- BRD Biological Resources Division
- C2000 EPA's National Coastal Assessment
- CAAB Codes for Australian Aquatic Biota
- CACGP Commission on Atmospheric Chemistry and Global Pollution
- CAFF Program for the Conservation of Arctic Flora and Fauna (Arctic Council)
- CalCOFI California Co-operative Fisheries Investigation program
- CAOS Co-ordinated Adriatic Observing System
- CARIACO Carbon Retention in a Colored Ocean Program
- CARICOMP Caribbean Coastal Marine Productivity
- CAST Council for Agricultural Science and Technology
 - http //www cast-science org/
- CBMP Chesapeake Bay Monitoring Program
- CCAMLR Commission for the Conservation of Antarctic Marine Living Resources http://www.ccamlr.org
- CCC Cod and Climate Change (ICES/GLOBEC)
- CCCC Climate Change and Carrying Capacity (PICES/GLOBEC)
- CCF One hundred cubic feet

- CCMP NEP Comprehensive Conservation and Management Plan
- CCS California Current System
 - http //globec oce orst edu/groups/nep/index html
- CDFO Canadian Department of Fisheries and Oceans http://www.dfo-mpo.gc.ca/home-accueil_e.htm
- CDOM Coloured Dissolved Organic Matter
- CDQ Community Development Quota
- CEMP Citizens Environmental Monitoring Program (Cook Inlet Keeper)
- CEMP CCAMLR Ecosystem Monitoring Program http://www.ccamli.org/English/e_sci_cttee/e_eco_monit/e_eco_monit_intro.htm
- CENR Committee on Environment and Natural Resources http://www.ostp.gov/NSTC/html/committee/cenr.html
- CEOS Committee on Earth Observation Satellites http://www.ceos.org/
- CGOA Coastal Gulf of Alaska
- C-GOOS Coastal Panel of GOOS
- CHL Chlorophyll
- CHM Clearing-House Mechanism of the Convention on Biological Diversity
- CIFAR Cooperative Institute for Arctic Research
 - http //www cifar uaf edu
 - http //www cifar uaf edu/fisheries html
- CIIMMS Cook Inlet Information Management and Monitoring System
 - http //info dec state ak us/cumms/
- CIK Cook Inlet Keeper
 - http //www inletkeeper org/
- CIMI Computer Interchange of Museum Information
- CIRCAC Cook Inlet Regional Citizens Advisory Council
 - http //www circac org/
- CISeaFFS Cook Inlet Seabird and Forage Fish Study
- CISNet Coastal Intensive Site Network
- CISPRI Cook Inlet Spill Prevention and Response, Inc
- CISWG Circumpolar Seabird Working Group (CAFF, IMCSAP, Arctic Council)
- CLEMAN Check List of European Marine Mollusca
- CLIC Climate and Cryosphere
- CLIVAR Climate Variability and Predictability Program
- C-MAN Coastal Marine Automated Network
- CMED/GMNET Consortium for Marine and Estuarine Disease/Gulf of Mexico Network
- CMI (MMS) Coastal Marine Institute
- CMM Commission for Marine Meteorology (of WMO)
- CNES Centre National d'Etudes Spatiales (France)
- COADS Comprehensive Ocean-Atmosphere Data Set
 - http //www cdc noaa gov/coads
- CODAR Coastal Radar

COLORS COastal region LOng-term measurements for colour Remote Sensing development and validation COMBINE COoperative Monitoring in the Baltic Marine Environment CoML Census of Marine Life http //www.coml.org CONNS Coastal Observing Network for the Near Shore Convention on Biological Diversity http //www biodiv org/ COOP Coastal Ocean Observation Panel http //ioc unesco oig/goos/COOP htm CoOP (NSF) Coastal Ocean Processes http //www skio peachnet edu/coop/ COP Coastal Ocean Program CORE Consortium for Oceanographic Research and Education http //www coreocean org/ Corexit 9500 Brand name of a dispersant from Exxon Corexit 9527 Brand name of a dispersant from Exxon COSESPO Coastal Observing System for the Eastern South Pacific Ocean COTS Commercial off the shelf software CPR Advisory Panel on Continuous Plankton Recorder Survey in the North Pacific (PICES) CPTEC Center for Weather Forecasts and Climate Studies (Brasil) http // www cptec inpe br/Fwelcomei html CRIS Court Registry Investment System CRP Comprehensive Rationalization Program CRRC Chugach Regional Resources Commission CRSA Alaskan coastal resource service areas (CRSAs), see also CIAP http //www ocrm nos noaa gov/czm/ciap/ CRTF US Coral Reef Task Force CSCOR Center for Sponsored Coastal Ocean Research http //www cop noaa gov/ CSIRO Commonwealth Scientific and Industrial Research Organization http //www csiro au/ CTD Conductivity temperature versus depth CTW Coastal Trapped Waves CU cataloging unit CVOA Catcher Vessel Operational Area CWAP Clean Water Action Plan CWPPRA Coastal Wetlands Planning, Protection, and Restoration Act CZCS Coastal Zone Color Scanner CZM Coastal Zone Management DARP Damage Assessment and Restoration Program http //darcnw noaa gov/homepage html DARPA Defense Advanced Research Projects Agency http //www darpa mil/ DBCP Data Buoy Cooperation Panel

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- DBMS Database Management System
- DCE 1,2-dichloroethane
- DDD dichloro bis(p-chlorophenyl)ethane
- DDE Dichlorodiphenyldichloroethylene
- DDT Dichlorodiphenyltrichloroethane
- DEOS Deep Earth Observatories on the Seafloor
- DEOS Dynamics of Earth and Ocean Systems (CORE)
- DFO Department of Fisheries and Oceans, Canada
- DGC Division of Governmental Coordination, State of Alaska, Office of Governor http://www.gov.state.ak.us/dgc/CIAP/CIAPhome.htm
- DIN Dissolved Inoiganic Nitrogen
- DMS Dimethylsulphide
- DNMI Norwegian Meteorological Institute (Det norske meteorologiske institutt) http://met.no/english/
- DO Dissolved Oxygen
- DOC US Department of Commerce
- DoD US Department of Defense
- DODS Distributed Oceanographic Data System http //www unidata ucar edu/packages/dods/ http //dods gso uri edu/
- DOE US Department of Energy
- DOI US Department of the Interior
- DON QUIJOTE Data Observing Network for the QuIJOTe
- DRBC Delaware River Basin Commission
 - http //www state nj us/drbc/drbc htm
- EA/RIR Environmental Assessment/Regulatory Impact Review
- EASy Environmental Analysis System
- EBS Eastern Bering Sea
- EC European Community
- ECDIS Electronic Chart and Display Information Systems
- EC/IP Executive Committee / Implementation Panel for CCCC (PICES)
- ECMWF European Centre for Medium Range Weather Forecasting
 - http //www ecmwf int/
- ECOHAB (NSF) Ecology of Harmful Algal Blooms
- EDOCC Ecological Determinants of Ocean Carbon Cycling
 - http //picasso edu orst edu/ORSOO/EDOCC/EDOCC html
- EDY Estuarine Dynamics
- EEZ Exclusive Economic Zone
- EEZ(A) European Economic Zone (Area)
- EFH Essential Fish Habitat
- EGB (NSF) Environmental Geochemistry and Biogeochemistry
- EIOA European Oceanographic Industry Association
 - http //www eo1a org/
- ELOISE European Land-Ocean Interaction Studies

EMAP Environmental Monitoring and Assessment Program

http //www epa gov/emap/

EMAP-E Environmental Monitoring and Assessment Program-Estuaries

Enersperse Brand name of a dispersant

ENRI Environment and Natural Resources Institute

http //www uaa alaska edu/enri/enri_web/enrihome html

ENSO El Niño Southern Oscillation

EOS NASA's Earth Observing System

EOSDIS NASA'S EOS Data and Information System

http //spsosun gsfc nasa gov/NewEOSDIS_Over html

EPA US Environmental Protection Agency

http //www epa gov/

ERMS European Register of Marine Species

ERL Effects Range Low (concentration of a contaminant potentially having adverse effects)

ERM Effects Range Medium (concentration of a contaminant associated with adverse effects on organisms)

ERS-1 European Remote Sensing satellite-1

ERS-2 European Remote Sensing satallite-2

ESA Endangers Species Act

ESH (NSF) Marine Aspects of Earth System History

ESIP The Federation of Earth Science Information Partners

http //www esipfed org/

ESP Eastern South Pacific

ESRI Environmental Systems Research Institute

ArcIMS system http //www esri com/software/arcims/index html

ETL tools Extraction, Transformation, and Loading tools

EU European Union

EUMETSAT European Organization for the Exploitation of Meteorological Satellites

http //www eumetsat de/en/

EuroGOOS European GOOS

http //www eurogoos org/eurogoosindex html

EuroHAB European Harmful Algae Bloom

EVOS Exxon Valdez Oil Spill http://www.oilspill.state.ak.us/

Bibliography http //www oilspill state ak us/publications html

Final and Annual Reports http://www.oilspill.state.ak.us/pdf/Report_List_5-31-02.pdf

EXDET An Exxon laboratory test for dispersants

F & A Finance and Administration Committee (PICES)

FCCC Framework Convention on Climate Change

Federal Geographic Data Committee metadata requirements

http //www.fgdc gov/metadata/metadata html

Federal Subsistence Fishery Monitoring Program, Federal Subsistence Management Program

http //www r7 fws gov/asm/home html

FDA US Food and Drug Administration

FGDC Federal Geographic Data Committee

FIS Fishery Science Committee (PICES)

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Fishbase, FishGopher, FishNet searchable fish databases managed by multiple organizations

FMP Fishery Management Plan

FOCI Fisheries Oceanography Coordinated Investigations

http //www pmel noaa gov/foc1/

F-R Fundraising Committee (PICES)

FWS US Fish and Wildlife Service

FY Fiscal Year

GAIM Global Analysis, Interpretation and Modelling (IGBP)

GAK Gulf of Alaska

GAK1 Gulf of Alaska station 1 located at the mouth of Resurrection Bay (60 N, 149W)

GAP Gap Analysis Program

GARP Genetic Algorithm for Rule-set Production

GARS Gulf of Alaska Recirculation Study (NSF)

GBIF Global Biodiversity Information Facility

GC Governing Council (PICES)

GCM Global Climate Model

GCN Global Core Network

GCOS Global Climate Observing System

http //193 135 216 2/web/gcos/pub/dim_v1_1.html

GCRMN Global Coral Reef Monitoring Network

GCTE Global Change and Terrestrial Ecosystems (IGBP)

GECaFS Global Environmental Change and Food Systems (IGBP, WCRP, IDHP)

GEF Global Environmental Facility

GEM Gulf Ecosystem Monitoring

GEO Global Eulerian Observations

GEOHAB Global Ecology of Harmful Algal Blooms

GHL Guideline Harvest Level

GIPME Global Investigation of Pollution in the Marine Environment

GIS Geographic Information System

GIWA Global International Water Assessment

GLI Global Imager

GLIFWC Great Lakes Indian Fish and Wildlife Commission

http //www glifwc org/

GLNO Great Lakes National Program Office

GLOBE Global Learning and Observations to Benefit the Environment

http //www globe gov

GLOBEC Global Ocean Ecosystem Dynamics

http //www pml ac uk/globec/

GLOBEC US http //cbl umces edu/fogarty/usglobec/

GLOBEC NEP GLOBEC Northeast Pacific

http //globec oce orst edu/groups/nep/index html

GLORIA Geological Long-Range Inclined Asdic

GLOSS Global Sea Level Observing System (UN)

GLWQA Great Lakes Water Quality Agreement

GMBIS Gulf of Maine Biogeographical Information System

- GMP Joint Gulf States Comprehensive Monitoring Program
- GNP Gross National Pioduct
- GOA Gulf of Alaska
- GODAE Global Ocean Data Assimilation Experiment http://www.bom.gov.au/bmrc/ocean/GODAE/
- GOES Geostationary Operational Environmental Satellite
- GOFS US Global Ocean Flux Study
- COC Clobal Ocean Chapman a Susta
- GOOS Global Ocean Observing System http://ioc.unesco.oig/goos/
- GOSIC Global Observing System Information Center http://www.gos.udel.edu
- GPA/LBA Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities
- GPO GOOS Project Office
- GPS Global Positioning System
- GSC GOOS Steering Committee
- GTOS Global Terrestrial Observing System
- GTS Global Telecommunications System
- GTSPP Global Temperature-Salinity Pilot Project
- GUI Graphical User Interface
- HAB harmful algal bloom
 - http //www redtide whoi edu/hab
- HABSOS Harmful Algal Bloom Observing System
 - http //www habhrca noaa gov
- HAPC Habitat Areas of Particular Concern
- HELCOM Helsinki Commission-Baltic Marine Environment Protection Commission
- HMAP History of Marine Animal Populations
- HMS Hydrometeorological Service
- HNLC high nitrate, low chlorophyll waters
- HOTO Health of the Oceans
- HOTS Hawan Ocean Time Series
- HPLC High Performance Liquid Chromatography
- IABIN Inter-American Biodiversity Information Network http //www iabin org/
- IAI Inter-American Institute
- IARC International Arctic Research Center, University of Alaska http://www.iarc.uaf.edu/
- IARPC Interagency Arctic Research Policy Committee
 - http //www nsf gov/od/opp/arctic/iarpc/start htm
- IBOY International Biodiversity Observation Year
- IBQ Individual Bycatch Quota
- ICAM Integrated Coastal Area Management/ Integrated Coastal Area Management Programme
- ICES International Council for the Exploration of the Sea
 - http //www ices dk/

ICLARM International Center for Living Aquatic Resources Management http //www iclarm org/ ICM Integrated Coastal Management ICSU International Council for Science ICZN International Code of Zoological Nomenclature IFEP Iron Fertilization Experiment Panel (PICES) IFO Intermediate Fuel Oil IFP The French Petroleum Institute http //www ifp fr/ IFQ Individual Fishing Quota IGAC International Global Atmospheric Chemistry Project (IGBP/CACGP) http //www igac unh edu/ IGBP International Geosphere-Biosphere Programme http //www igbp kva se/ IGBP-DIS Data and Information System (IGBP) I-GOOS IOC-WMO-UNEP Committee for the Global Ocean Observing System IGOS (NASA) Integrated Global Observing System http //www igospartners org IGOSS Integrated Global Ocean Services System IGS International GPS Service for Geodynamics IGU International Geographic Union IHDP International Human Dimensions Programme on Global Environmental Change IHDP International Human Dimensions Programme (IGBP et al) http //www uni-bonn de/ihdp/IIP International Ice Patrol IJC International Joint Commission I-LTER International LTER IMCSAP International Murre Conservation Strategy and Action Plan (CAFF, Arctic Council) IMS Institute of Marine Science, University of Alaska http //www ims uaf edu/ InfoBOOS BOOS Information System INPFC International North Pacific Fisheries Commission http //www npafc org/inpfc/inpfc.html IOC Intergovernmental Oceanographic Commission (of UNESCO) http //10c unesco org/1yo/ IOCCG International Ocean Colour Coordinating Group http //www loccg org/ IODE International Oceanographic Data and Information Exchange http //10c unesco org/10de/ IOOS Integrated Ocean Observing System http //core ssc erc msstate edu/oceanobs html IPCC Intergovernmental Panel on Climate Change http //www ipcc ch/ IPHAB Intergovernmental Panel on HABs IPHC International Pacific Halibut Commission http //www iphc washington edu/

IPRC International Pacific Research Center http://iprc soest hawaii edu/

IPSFC International Pacific Salmon Fishing Commission

- IRFA Initial Regulatory Flexibility Analysis
- IRIU Improved Retention/Improved Utilization
- ITAC Initial Total Allowable Catch

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- ITIS Integrated Taxonomic Information System
- ITSU IOC Tsunamı Warning System in the Pacific
- IUCN The World Conservation Union
- IWI EPA's Index of Watershed Indicators
- JCOMM Joint Technical Commission for Oceanography and Marine Meteorology
- JDBC Java Database Connectivity
- JDIMP Joint Data and Information Management Panel
- JGOFS (NSF) Joint Global Ocean Flux Study
 - http //ads smr uib.no/jgofs/jgofs htm
- KBNERR Kachemak Bay National Estuarine Research Reserve http //www state ak us/local/akpages/FISH GAME/habitat/geninfo/nerr/ Kachemak Bay Ecological Characterization study http //www state ak us/adfg/habitat/geninfo/nerr/kbec/index htm
- KRSA Kenai River Sportfishing Association
- LaMP Lakewide Management Plan (EPA)
- LAMP Local Area Management Plan
- LATEX Louisiana-Texas shelf study
- LC50 or LC $_{50}$ Lethal concentration of 50% of the test population
- LEO Long-term Ecosystem Observatory
- LEO-15 Long-term Ecosystem Observatory at 15-m depth
- LExEn (NSF) Life in Extreme Environments
- LIDAR Light Detection and Ranging
- LLP License Limitation Program
- LMR Living Marine Resources
- LOICZ Land-Ocean Interactions in Coastal Zone
- LTER Long-term Ecological Research (NSF) http //lternet edu/
- LTOP Long-Term Observation Program
 - http //globec oce orst edu/groups/nep/index html
- LUCC Land Use/Cover Change (IGBP/IHDP)
- MABNET Man and the Biosphere Network
- MARBID Marine Biodiversity Database
- MARGINS (NSF) Continental Margins
- MarLIN Marine Laboratories Information Network
 - http //www marine csiro au/marlin/
- MAROB Marine Observation
- MAST Marine Science and Technology
- MBARI Monterey Bay Aquarium Research Institute
 - http //www mbari org/about/
- MBF One thousand board feet

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MBMAP Advisory Panel on Marine Birds and Mammals (PICES) MBNMS Monterey Bay National Marine Sanctuary http //bonita mbnms nos noaa gov/research/mb_workshop/index html C MEHRL Marine Environmental Health Research Laboratory www.cofc.edu/~grice/hml MEL Master Environmental Library MEQ Marine Environmental Quality Committee (PICES) MERIS Medium Resolution Imaging Spectrometer MetOp Meteorological Operational MFS Mediterranean Forecasting System MLD Mixed layer depth MLML Moss Landing Marine Laboratories http //www mlml calstate edu/ MMHSRP Marine Mammal Health and Stranding Response Program http //www nmfs noaa gov/prot_res/PR2/Health_and_Stranding_Response_Program/ mmhsrp html MMPA Marine Mammal Protection Act MMRC The North Pacific Universities Marine Mammal Research Consortium http //www zoology ubc ca/~consort/consortm htm MMS Minerals Management Service MMS OCSES Outer Continental Shelf Environmental Studies MNS Mackay, Nadeau, Steelman MODEL Conceptual / Theoretical and Modeling Studies Task Team (PICES) MODIS Moderate Resolution Imaging Spectroradiometer MODMON Neuse Monitoring and Modeling Project MONITOR Monitor Task Team (PICES) MOODS Master Oceanographic Observational Data Set (NMFS) MOOS Ocean Observing System of the Monterey Bay Aquarium Research Institute http //www mbari org/default htm MOS Modular Optoelectronic Scanner MPA Marine Protected Areas (DOC/DOI) http //www mpa gov MPN Most Probable Number MRB Maximum Retainable Bycatch MSFCMA Magnuson-Stevens Fishery Conservation and Management Act MSVPA Multispecies Virtual Population Analysis MSY Maximum Sustainable Yield mt Metric tons MWRA Massachusetts Water Resources Authority http //www mwra state ma us/ NA Northern Adriatic NABIN North American Biodiversity Information Network NABIS National Aquatic Biodiversity Information Strategy NAML National Association of Marine Laboratories http //hermes mbl edu/labs/NAML/

NAO North Atlantic Oscillation NAS Nonindigenous Aquatic Species NASA National Aeronautics and Space Administration http //www nasa gov/ NASA/AMSR Advance Microwave Scanning Radiometer http //www.ghcc msfc nasa gov/AMSR/ Earth Science Enterprise http://www.earth.nasa.gov NASA/GRACE Gravity Recovery and Climate Experiment http //essp gsfc nasa gov/esspmissions html NASA/NASDA Tiopical Rainfall Measurement Mission http //modis gsfc nasa gov/ NASA/Salinity and Sea Ice Working Group http //www esr org/lagerloef/ssiwg/ssiwgrep1 v2 html NASA/SeaW1FS http //seawifs gsfc.nasa gov NASQAN National Stream Quality Accounting Network http //water usgs gov/nasqan/ Naval Oceanographic Office http //128 160 23 51/noframe/select products htm NAWQA National Water Quality Assessment Program http //water usgs gov/nawqa/ NCAR National Center for Atmospheric Research NCDC National Climate Data Center http //www.ncdc noaa gov/ NCDDC National Coastal Data Development Center http //www ncddc noaa gov/ NCEP National Centers for Environmental Protection http //wwwt ncep noaa gov NDBC National Data Buoy Center http //www ndbc noaa gov NDVI Normalized Difference Vegetation Index NEAR-GOOS North East Asian Regional GOOS http //10c unesco org/goos/neargoos/neargoos.htm NEMO Naval Earth Map Observer NEMURO North Pacific Ecosystem Model for Understanding Regional Oceanography NEODAT Inter-Institutional Database of Fish Biodiversity in the Neotrophics NEP National Estuary Program NERR National Estuarine Research Reserve NESDIS National Environmental Satellite, Data, and Information Service http //www nesdis noaa gov/ NGO Non-governmental organization NGOA Northern Gulf of Alaska NGOS North Gulf Oceanic Society http //www whalesalaska org/

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- NIST National Institute of Standards and Technology http://www.nist.gov/
- NIWA National Institute of Water and Atmosphere Research http://www.niwa.cri.nz/index.html
- NLFWA National Listing of Fish and Wildlife Advisories
- NMFS National Marine Fisheries Service
 - http //www nmfs noaa gov/
- NMMHSRP National Marine Mammal Health and Stranding Response Program
 - http //www nmfs noaa gov/piot_ies/overview/mm html
- NMML National Marine Mammal Laboratory
- NMMTB National Marine Mammal Tissue Bank
- NMS National Marine Santuary
- NOAA National Oceanic and Atmospheric Administration
- NOAA HAZMAT Hazardous Materials Program
- NOAA NOS National Ocean Service

http //www nos noaa gov

- NODC National Oceanographic Data Center http://www.nodc.noaa.gov
- NOEL No-Effect Level
- NOLS National Outdoor Leadership School
- NOPP (NASA) National Ocean Partnership Program http://www.NOPP.org
- NOPPO National Oceanographic Partnership Program Office
- NORLC National Ocean Research Leadership Council
- NORPAC North Pacific, an informally organized group of scientists responsible for collating and publishing much of the oceanographic data collected in the North Pacific Ocean during the period of approximately 1930 to 1965 These data were published in several volumes by the University of California Press This data set is collectively known as the NORPAC data
- NOS NOAA's National Ocean Service
 - http //www nos noaa gov
- NO_x Nıtrogen Oxides
- NPAFC North Pacific Anadromous Fish Commission
 - http //www.npafc org
- NPDES National Pollution Discharge Elimination System
- NPFMC North Pacific Fishery Management Council
 - http //ww fakr noaa gov/npfmc/
- NPI North Pacific Index
- NPMRP North Pacific Marine Research Program
 - http //www sfos uaf edu/npmr/index html
- NPO North Pacific Oscillation
- NPOESS National Polar-Orbiting Environmental Satellite System
- NPPSD North Pacific Pelagic Seabird Database

http //www absc usgu gov/research/NPPSD/

- NPS National Park Service
 - http //www nps gov

NPUMMRC North Pacific Universities Marine Mammal Research Consortium http //www.zoology.ubc.ca/~consort/consortm.htm NPZ nutrient-phytoplankton-zooplankton NRA NASA Research Announcement NRC National Research Council http //www nationalacademies org/nrc/ NRDA natural resource damage assessment NRT Near Real Time NS&T National Status and Tiends Program http //ccmaserver nos noaa gov/NSandT/New_NSandT html NSF National Science Foundation NSIPP (NASA) Seasonal-to-Interannual Prediction Program NSTC National Science and Technology Council http //www ostp gov/NSTC/html/NSTC_Home html NURP (NOAA) National Undersea Research Program http //www.nurp.noaa.gov NVODS National Virtual Ocean Data System http //nvods org/ NVP Nearshore Vertebrate Predator project NWI National Wetlands Inventory NWIFC Northwest Indian Fisheries Commission http //www nwifc wa gov NWP numerical weather prediction NWS National Weather Service http //www nws noaa gov OAR Oceanic and Atmospheric Research (NOAA) http //oar noaa gov/ OBIS Ocean Biogeographical Information System www coml org OCC Ocean Carrying Capacity OCRM Office of Coastal Resource Management, NOS, NOAA http //www ocrm nos noaa gov/ OCSEAP Outer Continental Shelf Environmental Assessment Program OCTET Ocean Carbon Transport, Exchanges and Transformations http //www msrc sunysb edu/octet/ OCTS Ocean Color and Temperature Scanner OE (NOAA OAR) Office of Ocean Exploration http //oceanpanel nos noaa gov/ OECD Organization for Economic Co-operation and Development OFP Ocean Flux Program OHMSETT Oil and Hazardous Materials Simulated Environmental Test Tank OMB Office of Management and Budget ONR Office of Naval Research OOPC Ocean Observations Panel for Climate OOSDP Ocean Observing System Development Panel

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OPA 90 Oil Pollution Act of 1990 http //www pwssc-osri org/docs/opa90 html OPR Office of Protected Resources http //www nmfs.noaa gov/prot_res/prot_res html ORAP Ocean Research Advisory Panel ORNL Oak Ridge National Laboratory http //www ornl gov OSCURS = Ocean Surface Current Simulations OSNLR Ocean Science in Relation to Non-Living Resources OSPARCOM Convention for the Protection of the Marine Environment of the North-east Atlantic OSRI Prince William Sound Oil Spill Recovery Institute http //www pwssc-osri org OSSE Observation System Simulation Experiments OST EPA's Office of Science and Technology OSTP Office of Science and Technology Policy OWOW EPA's Office of Wetlands, Oceans, and Watersheds OY Optimum yield PAC Public Advisory Committee PAG Public Advisory Group PAGES Past Global Change (IGBP) P-BECS Pacific Basinwide Extended Climate Study PAH Polycyclic Aromatic Hydrocarbons (EPA) PAH Polynuclear Aromatic Hydrocarbons PAR Phosynthetically Available Radiation PC Publication Committee (PICES) PCAST President's Committee of Advisors on Science and Technology PCB Polychlorinated biphenyls PCC Pollock Conservation Cooperative PDO Pacific Decadal Oscillation PICES North Pacific Marine Science Organization (not an acronym) http //pices ios bc ca/ PIRATA Pilot Research Array in the Tropical Atlantic PISCO Partnership for the Interdisciplinary Study of Coastal Oceans http //www piscoweb org/ PMEL Pacific Marine Environmental Laboratory http //www pmel noaa gov/ PMEL Bering Sea and North Pacific Ocean Theme Page www pmel noaa gov/bering POC Physical Oceanography and Climate Committee (PICES) POLDER Polarization and Directionality of the Earth's Reflectances POM Princeton Ocean Model PORTS Physical Oceanographic Real-Time System PORTS/VTS PORTS/Vessel Traffic Services POST Pacific Ocean Salmon Tracking Project POTW Publicly Owned Treatment Works

PRODAS Prototype Ocean Data Analysis System PROFC Piograma Regional de Oceanografia Fisica y Clima PSAMP Puget Sound Ambient Monitoring Program PSC Pacific Salmon Commission http //www psc org/Index htm PSMFC Pacific States Marine Fisheries Commission http //www.psmfc.org/ PSMFC Regional Mark Processing Center http //www rmis oig/index html PSMSL Permanent Service for Mean Sea Level (UN) PSP Paralytic Shellfish Poisoning PST Pacific Salmon Treaty PWS Prince William Sound PWSAC PWS Aquaculture Corporation http //www ctcak net/~pwsac/ PWSRCAC PWS Regional Citizens Advisory Council PWSSC Prince William Sound Science Center http //www pwssc gen ak us/pwscc/pwscc.html QA/QC Quality Assurance and Quality Control QC Quality Control QUIJOTE Quickly Integrated Joint Observing Team QuikSCAT - quick scatterometer (SeaWinds instrument) R&D Research and Development RACE Resource Assessment and Community Ecology RAMS Regional Atmospheric Modeling System RAP Remedial Action Plan RCAC Regional Citizens Advisory Council RCRA Resource Conservation and Recovery Act RDP Ribosomal Database Project REX Regional Experiments Task Team (PICES) **RFP** Request for Proposals RIDGE (NSF) Ridge Interdisciplinary Global Experiments RLDC Responsible Local Data Center RLDC Responsible Local Data Center RMI Remote Method Invocation RMP Regional Monitoring Program RNODC Responsible National Oceanographic Data Center RSN RedSur Network

- S1 Session 1 Science Board Symposium on Subarctic gyre processes and their interaction with coastal and transition zones physical and biological relationships and ecosystem impacts (PICES)
- S2 Session 2 BIO Topic Session on Prey consumption by higher trophic level predators in PICES regions implications for ecosystem studies (PICES)
- S3 Session 3 Joint BIO / CCCC Topic Session on Recent progress in zooplankton ecology study in PICES regions (PICES)

- S4 Session 4 FIS Topic Session on Short life-span quid and fish as keystone species in North Pacific marine ecosystems (PICES)
- S5 Session 5 POC Topic Session on Large-scale circulation in the North Pacific (PICES)
- S6 Session 6 Joint POC / BIO Topic Session on North Pacific carbon cycling and ecosystem dynamics (PICES)
- S7 Session 7 CCCC Topic Session on Recent findings and comparisons of GLOBEC and GLOBEC-like programs in the North Pacific (PICES)
- S8 Session 8 MEQ Topic Session on Environmental assessment of Vancouver Harbour results of an international workshop (PICES)
- S9 Session 9 MEQ Topic Session on Science and technology for environmentally sustainable mariculture in coastal areas (PICES)
- SAFE Stock Assessment and Fishery Evaluation Document
- SALMON (Sea-Air-Land Monitoring and Observation Network) http://www.ims.uaf.edu.8000/salmon/
- SALSA Semi-arid Land Surface Atmosphere Program
- SAR Synthetic Aperture Radar
- SAV Submerged Aquatic Vegetation
- SB Science Board (PICES)
- SBIA (NSF) Shelf-basin Interactions in the Arctic
- SCAMIT Southern California Association of Marine Invertebrate Taxonomists
- SCB Southern California Bight
- SCBPP Southern California Bight Pilot Project
- SCCWRP Southern California Coastal Water Research Project
- SCDHEC South Carolina Department of Health and Environmental Control
- SCDNR South Carolina Department of Natural Resources
- SCECAP South Carolina Department Estuarine and Coastal Assessment Program
- SC(-IGBP) Scientific Committee for the IGBP
- SCICEX (NSF) Science Ice Exercise
- SCOPE Scientific Committee on Problems of the Environment
- SCOR Scientific Committee on Oceanic Research
 - http //www jhu edu/~scor/
- SCS South China Sea
- SEA Sound Ecosystem Assessment
- SEARCH Study of Environmental Arctic Change
 - http //psc apl washington edu/search/index html
- SEAS Shipboard Environmental Data Acquisition System
- SeaWIFS Sea-viewing Wide Field-of-view Sensor
- SEI Special Events Imager
- SEPOA Southeast Pacific Ocean Array
- SERC Smithsonian Environmental Research Center
 - http //www serc si edu/
- SERVS Ship Escort Response Vessel System
- SFEP San Francisco Estuary Project
- SFOS School of Fisheries and Ocean Sciences

SG Sea Grant http //www nsgo seagrant org/ SGI State of the Gulf Index SHEBA (NSF) Surface Heat Budget of the Arctic Ocean SIMBIOS Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies SIMoN Sanctuary Integrated Monitoring Network http //www mbnms nos noaa gov/Research/simon/simon htm SJBEP San Juan Bay Estuary Program SLFMR Scanning Low Frequency Microwave Radiometers SO-GLOBEC Southern Ocean Programme (GLOBEC) SOIREE Southern Ocean Iron release experiment http //katipo niwa cri nz/~hadfield/gust/iron SOLAS International Convention for Safety of Life at Sea SOLAS Surface Ocean Lower Atmosphere Study (NRC) SOLEC State of the Lakes Ecosystem Conference SPACC Small Pelagic Fish and Climate Change (GLOBEC) Specimen Banking Project http //www nwfsc noaa gov/pubs/tm/tm16/tm16 htm SQuID Structured Query and Information Delivery SSC Scientific and Statistical Committee SSE (NOAA) Sustainable Seas Expedition SSF Storm Surge Forecast System SSH Sea Surface Height SSLRI Steller Sea Lion Research Initiative (NMFS, AR) http //www.fakr noaa gov/omi/grants/sslri SSM/I Special Sensor Microwave/Imager SSS Sea Surface Salunity SST Sea Surface Temperature STAC Scientific and Technical Advisory Committee STAMP Seabird Tissue Archival Monitoring Project START Global Change System for Analysis, Research and Training (IGBP) http //www start org/ STD Salinity Temperature Depth recorder STORET System (EPA) http //www epa gov/storet SVOC Semivolatile Organic Compounds SWAO South Western Atlantic Ocean SWMP NERRS System-Wide Monitoring Program TAC Total Allowable Catch TAO Tropical Atmosphere Ocean (buoy array) TASC Transatlantic Study of Calanus finmarchicus (EU) TCE Tetracholoroethane TCODE Technical Committee on Data Exchange (PICES) TCP Tropical Cyclone Programme

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- TEK Traditional ecological knowledge
- TEMA Training, Education and Mutural Assistance (IOC)
- TMDL Total Maximum Daily Load
- TOGA Tropical Ocean and Global Atmosphere
- TOPEX/Poseiden
 - http //topex-www jpl nasa gov
- T/P TOPEX/Poseidon
- UAA University of Alaska, Anchorage
- UAF University of Alaska, Fairbanks
- UN United Nations
- UNCED The United Nations Conference on Environment and Development
- UNCLOS United National Convention on the Law of the Sea (Montego Bay, 1982)
- UNEP United Nations Environmental Programme
- UNESCO United Nations Educational, Scientific and Cultural Organization http://ioc.unesco.org/iocweb/
- UNFCCC United Nations Framework Convention on Climate Change
- USARC US Arctic Research Commission
- USCG US Coast Guard
- USDA US Department of Agriculture
- USDHHS US Department of Health and Human Services http://www.os.dhhs.gov/
- USFS US Forest Service
- USGCRP (NASA) US Global Climate Research Program
- US GLOBEC (NSF) US Global Ocean Ecosystem Dynamics

http //cbl umces edu/fogarty/usglobec/

- USGS US Geological Survey http://www.usgs.gov
- USNO US Naval Observatory http://www.usno.navy.mul/
- UWA Unified Watershed Assessments
- VBA Vessel Bycatch Accounting
- VENTS (NOAA) Vents Program
- VIP Vessel Incentive Program
- VOC Volatile Organic Compounds
- VOS Volunteer Observing Ships
- W1 Workshop 1 MONITOR Workshop on Progress in monitoring the North Pacific (PICES)
- W2 Workshop 2 REX Workshop on Trends in herring populations and trophodynamics (PICES)
- W3 Workshop 3 MODEL Workshop on Strategies for coupling higher and lower trophic level marine ecosystem models (PICES)
- W4 Workshop 4 BASS Workshop of Development of a conceptual model of the Subarctic Pacific basin ecosystem(s) (PICES)
- W5 Workshop 5 IFEP Planning Workshop on Designing the iron fertilization experiment in the Subarctic Pacific (PICES)

- W6 Workshop 6 (BIO / MBMAP) The basis for estimating the abundance of marine birds and mammals, and the impact of their predation on other organisms (PICES)
- W7 Workshop 7 CO2 Data Synthesis Symposium (PICES)
- WAF Water-Accommodated Fraction
- WAM Wave Model
- WCRP World Climate Research Program (ICSU/IOC/WMO)
- WDFW Washington Department of Fish and Wildlife
- WDOE Washington Department of Ecology
- WES Waterways Experimental Station
- WESTPAC IOC Sub-Commission for the Western Pacific
- WG Working Group (PICES)
- WHOI Woods Hole Oceanographic Institution
- WMO World Meteorological Organization
- WMS Open GIS Consortium's Web Mapping Server
 - http //www opengis org/techno/specs/01-047r2 pdf
- WOCE (NSF) World Ocean Circulation Experiment (WCRP)
 - http //www soc soton ac uk/OTHERS/woceipo/ipo html
- WODC World Oceanographic Data Center
- WOOD World-wide Oceans Optics Database
- WSRI Wild Stock Restoration Initiative
- WWW World Weather Watch
- XBT expendable bathythermograph
- XCDT expendable conductivity, depth and salinity devices

Introduction

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History and Purposes of the List

In November 1994, the *Exam Valdez* Oil Spill Trustee Council adopted an official list of resources and services injured by the spill as part of its *Restoration Plan* This list has served three main purposes in the Restoration Program

- 1 It has highlighted injuries caused by the oil spill and cleanup efforts and helped the Trustees and the public track the status of important fish, wildlife, and other resources and services The fish and wildlife on this list are thought to have suffered population-level or sublethal injuries, but the list does not include every species or resource that suffered some degree of injury For example, carcasses of about 90 different species of oiled birds were recovered in 1989, but only 10 species of birds are on the list of injured species
- 2 It has helped guide the *Restoration Plan* This was especially important in 1994 when the plan was first adopted, but the list still serves to highlight resources that are in need of consideration
- 3 Finally, taken as a whole, the list of injured resources has helped the Trustees and the public track recovery of the overall ecosystem and the functions and human services that it provides

It should be noted that the analysis of these resources and their recovery status only pertains to recovery from the effects of the 1989 oil spill Many of these resources are also experiencing the effects of other natural and human factors resulting in significant population declines Where these species lie on the continuum of recovery from the oil spill should not be taken to reflect their overall status and health In addition, many of the species that may be "recovered" or "recovering" from the effects of the oil spill are vital parts of the oil-impacted ecosystem that will be the focus of the Trustee Council's long-term monitoring program – GEM – the Gulf of Alaska Ecosystem Monitoring and Research Program

The *Restoration Plan* states that the Injured Resources and Services list will be reviewed periodically and updated to reflect results from scientific studies and other information With each review, a resource's progress toward a recovery objective is evaluated The recovery objectives have been set to be as concrete and measurable as possible However, they may be changed to reflect new insights about the nature of the injury and the best – or more accurate - ways to evaluate recovery status

The Injured Resources and Services list was first updated in September 1996 At that time the bald eagle was upgraded from recovering to recovered In March 1999, a major review of recovery objectives and status occurred and several more changes were made River otters were then considered to be recovered, and five resources – black oystercatchers, clams, marbled murrelets, Pacific herring, and sea otters – were upgraded to recovering One resource, the common loon, was moved from recovery unknown to not recovering Five resources remained as recovery unknown All four human services were classified as recovering

In 2002, more than 13 years after the spill, recovery continues to progress and more changes have been made to the list Five more species or resources have been moved to the recovered

category archaeological resources, black oystercatchers, common murres, sockeye salmon and pink salmon In addition, designated wilderness areas have been moved from the recovery unknown to the recovering category, Pacific herring have been moved back from the recovering to the not recovering category, subtidal communities have been moved from the recovering to recovery unknown category, and killer whales have been moved from not recovering to recovering In all, seven resources are considered fully recovered from the effects of the oil spill, 16 resources and all four human services have still not fully recovered, and the recovery of five resources is still considered unknown

The 1994 *Restoration Plan* provides that the Injured Resources and Services list can be updated any time new information becomes available The next major evaluation of changes in recovery status for all injured resources and lost or reduced services likely will be in 2006, 15 years after the 1991 settlement between the governments and Exxon and initiation of the restoration program

How to Interpret this List

The assignment of resources to various categories continues to be based on judgements made after weighing the available evidence, including

- estimates of population sizes and trajectories in the spill area,
- comparisons of population estimates in oiled and unoiled areas of the northern Gulf of Alaska,
- whether there has been continued exposure to residual oil in the spill area, and
- whether sublethal or chronic injuries persist or show improvement

Some of the factors involved in making judgments about recovery status include

- 1 *Uncertainties in population estimates* Because of the variability in animal distributions and the challenges of getting accurate counts, especially of highly mobile fish, birds and marine mammals, most estimates of population size have wide ranges. For example, ranges that are between 40% greater or smaller (or even more) than the true population size will result from many census techniques. This range can be narrowed, but costs escalate with the increasing effort to obtain greater accuracy.
- 2 *Lack of prespill data* Many of the resources affected by the spill had limited or no recent data on their status in 1989 In addition, some of the available pertinent data was the result of limited sampling and had wide ranges in the population estimates Having such patchy data on resources made it difficult to accurately assess initial injury. In turn, any uncertainties in injury inevitably lead to uncertainties in estimating recovery
- 3 *Interaction of spill and natural factors* It is increasingly difficult to separate what may be lingering effects of the spill from changes that are natural or caused by factors unrelated to the oil spill In fact, what is often observed appears to be an interaction between oil effects and natural changes, such as the effects of the 1998 *El Niño* on common murres in the Barren Islands which were recovering from oil spill impacts We now understand much more about long-term changes in climate in the northern Gulf of Alaska and how these changes affect marine species

4 *Emergence of new effects* Since the *Exron Valdez* oil spill affected an area rich in wildlife and was so well studied, it would not be surprising that there are findings without precedent in the scientific literature on oil effects. One example of such an unprecedented effect is the sensitivity of Pacific herring and pink salmon to low concentrations of weathered oil. We cannot discount evidence for an injury just because it had never been encountered in the aftermath of other spills.

Ecosystem Perspective and Recovery

The List of Injured Resources consists mainly of single species and resources, but, as noted above, it provides a basis for evaluating the recovery of the overall ecosystem, its functions, and the services that it provides to people In fact, through the *Reston ation Plan*, the Trustee Council adopted an ecological approach to restoration, and the studies and projects the Trustee Council sponsors have been ecological in character

Page 35 of the Restoration Plan defines ecosystem recovery as follows

Full ecological recovery will have been achieved when the population of flor a and fauna are again present at former or prespill abundances, healthy and productive, and there is a full complement of age classes at the level that would have been present had the spill not occurred. A recovered ecosystem provides the same functions and services as would have been provided had the spill not occurred.

Using this definition, the coastal and marine ecosystems in the oil spill region have not fully recovered at this time from the effects of the oil spill. For example, harlequin ducks and sea otters still show signs of oil exposure and may be negatively affected by such exposure. A number of other species and communities are showing signs of recovery, but are still not fully recovered from the effects of the oil spill. Although full ecological recovery has not been achieved, the spill area ecosystem is still largely intact and functioning and on its way to recovery 13 years after the *Exxon Valdez* oil spill.

It is desirable to have injured resources obtain a state that would have occurred in the absence of the spill However, it also is important to understand that ecosystems are dynamic and would have changed even in the absence of the oil spill Given our present ability to predict multi-year changes in marine ecosystems—which is extremely limited—it is very difficult to know how the ecosystem would have changed in the absence of the spill For that reason, it is also sometimes necessary to consider other measures (return to prespill status or attaining equivalent status in oiled and unoiled areas) in order to have more concrete objectives Also, as mentioned above, baseline data describing fish and wildlife populations, to say nothing of complex intertidal and subtidal communities, were generally poor in 1989 Therefore, in revising this list judgements have been made in the face of increasing knowledge—but also, great uncertainty—of how natural changes have occurred in the northern Gulf of Alaska

The following goals and objectives are used in assessing the status of the resources and services injured by the oil spill

Restoration Goal Recovery of all injured resources and services, including the ecosystem as a whole

Recovery Goal of Injured Resources and Services A return to conditions that would have existed had the spill not occurred

Recovery Objective A specific, measurable parameter that is used to signal the recovery status of an injured resource or service. In most cases the recovery objective reflects the type of injury that occurred from the spill

Since it is difficult to predict conditions that would have existed in the absence of the spill, recovery objectives use measurable and biologically substantive parameters as proxies for these conditions. For some species, multiple objectives are used to assess recovery

Comparisons of these parameters between oiled and unoiled areas are sometimes used where little or no prespill data exist Geographic comparisons of this nature should take into account differences, such as those that may exist naturally between eastern and western Prince William Sound, if these can be determined For some resources, so little is known about the original or current injury or status, that identifying a recovery objective is not possible

The following objectives are used

Return to prespill levels Used where population estimates or indices were available prior to 1989 For species that are highly variable, these numbers could reflect a range of values These numbers do not account for the effects of other influences on injured populations, such as from climate change, although thee other effects may interact with oil spill effects

Hydrocarbon exposure Used where hydrocarbon exposure itself was part of the original basis for injury, where hydrocarbon exposure may limit recovery, or where hydrocarbon exposure in an injured resource may be a pathway to injury in other resources. Oil exposure may refer to background concentrations, which takes into account hydrocarbon exposure from natural oil seeps, natural coal deposits, and oil released from the Valdez petroleum plant as a result of the 1964 earthquake

Stable or increasing population Used where resources were in decline before the spill or there are ongoing declines that may be unrelated to the spill

Measures of Productivity Used in lieu of or to supplement data on population sizes Includes such indicators as eggs produced or young successfully reared, returns-per-spawner, or growth rates These include measures of reproductive success and demographics

- Productivity means an increase in the biomass of a species, or the number of individuals of one species, as a function of time and geographic unit
- Reproductive success means the reproduction of viable individuals, and may not be related to overall biomass For seabirds however, productivity and reproductive success are used interchangeably by biologists and usually refer to eggs hatched or chicks per nest
- Demographics refer to the distribution of individuals in a population or in some geographic area with respect to age and sex or other characteristics of a population

RESOURCES

ARCHAEOLOGICAL RESOURCES

Injury

The oil spill area is believed to contain more than 3,000 sites of archaeological and historical significance. Twenty-four archaeological sites on public lands are known to have been adversely affected by cleanup activities or looting and vandalism linked to the oil spill. Additional sites on both public and private lands were probably injured, but damage assessment studies were limited to public land and not designed to identify all such sites.

Documented injuries included theft of surface artifacts, masking of subtle clues used to identify and classify sites, violation of ancient burial sites, and destruction of evidence in layered sediments In addition, residual oil may have contaminated sites

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Archaeological resources are nonrenewable they cannot recover in the same sense as biological resources Archaeological resources will be considered to have recovered when spillrelated injury ends, looting and vandalism are at or below prespill levels, and the artifacts and scientific data remaining in vandalized sites are preserved (e g, through excavation, site stabilization, or other forms of documentation)

Recovery Status

Assessments of 14 sites in 1993 suggested that most of the archaeological vandalism that can be linked to the spill occurred early in 1989, before adequate constraints were put into place over the activities of oil spill cleanup personnel. Most vandalism took the form of "prospecting" for high yield sites. Once these problems were recognized, protective measures were implemented and successfully limited additional injury. Although some cases of vandalism were documented in the 1990s, there appears to be no spill-related vandalism at the present time.

From 1994-1997, two sites in Prince William Sound were partly documented, excavated, and stabilized by professional archaeologists because they had been so badly damaged by oiling and erosion. The presence of oil in sediment samples taken from four sites in 1995 did not appear to have been the result of re-oiling by *Exron Valdez* oil Residual oil does not appear to be contaminating any known archaeological sites

In 1993, the Trustee Council provided part of the construction costs for the Alutiq Archaeological Repository in Kodiak This facility now houses Kodiak area artifacts that were collected during spill response In 1999, the Trustee Council approved funding for an archaeological repository and local display facilities for artifacts from Prince William Sound and lower Cook Inlet These are currently in various stages of contruction

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Based on the apparent absence or extremely low rate of spill-related vandalism and the preservation of artifacts and scientific data on archaeological sites and artifacts, archaeological resources are considered to be recovered

BALD EAGLES

Injury

The bald eagle is an abundant resident of marine and riverine shoreline throughout the oil spill area Following the oil spill, a total of 151 eagle carcasses were recovered from the spill area Prince William Sound provides year-round and seasonal habitat for about 6,000 bald eagles, and within the sound it is estimated that about 250 bald eagles died as a result of the spill There were no estimates of mortality outside the sound, but there were deaths throughout the spill area In addition to direct mortalities, productivity was reduced in oiled areas of Prince William Sound in 1989

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Bald eagles will have recovered when their population and productivity (reproductive success) have returned to prespill levels

Recovery Status

Productivity (or reproductive success as measured by chicks per nest) was back to normal in 1990 and 1991, and an aerial survey of adults in 1995 indicated that the population had returned to or exceeded its prespill level in the sound **In September 1996, the Trustee Council classified the bald eagle as recovered from the effects of the oil spill**

BLACK OYSTERCATCHERS

Injury

Black oystercatchers spend their entire lives in or near intertidal habitats and are highly vulnerable to oil pollution. It is estimated that 1,500-2,000 oystercatchers breed in south-central Alaska. Only nine carcasses of adult oystercatchers were recovered following the spill, but the actual number of mortalities may have been several times higher.

In addition to direct mortalities, breeding activities were disrupted by the oil and cleanup activities When comparing 1989 with 1991, significantly fewer pairs occupied and maintained nests on oiled Green Island, while during the same two years the number of pairs and nests remained similar on unoiled Montague Island Nest success on Green Island was significantly lower in 1989 than in 1991, but Green Island nest success in 1989 was not lower than on Montague Island In 1989, chicks disappeared from nests at a significantly greater rate on Green Island than from nests on Montague Island Disturbance associated with cleanup operations also reduced productivity on Green Island in 1990 In general, the overt effects of the spill and cleanup had dissipated by 1991, and in that year productivity on Green Island exceeded that on Montague Island

Recovery Goal

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A return to conditions that would have existed had the spill not occurred

Recovery Objective

Black oystercatchers will have recovered when the population returns to prespill levels and reproduction and productivity are within normal bounds An increasing population trend and comparable hatching success and growth rates of chicks in oiled and unoiled areas, after taking into account geographic differences, will indicate that recovery is underway

Recovery Status

Boat-based surveys of marine birds in Prince William Sound indicate that there are increases in numbers of oystercatchers in both the oiled and unoiled areas through 2000 (Stephenson et al, 2001) Given the fact that only 9 carcasses of this species were recovered in 1989 after the spill, it is likely that the population of the sound is probably as large or larger than previous to the spill

In 1998 the Trustee Council sponsored a study to reassess the status of this species in Prince William Sound The data indicated that oystercatchers have fully reoccupied and are nesting at oiled sites in the sound The breeding phenology of nesting birds was relatively synchronous in oiled and unoiled areas, and no oil-related differences in clutch size, egg volume, or chick growth rates were detected A high rate of nest failures on Green Island are likely attributed to predation, not lingering effects of oil Given general agreement between these results and those of the earlier work, which indicated that the effects of the spill on black oystercatchers had largely dissipated by 1991, black oystercatchers are considered to be recovered from the effects of the oil spill This does not mean that oystercatchers are still not exposed to some oil in the intertidal zone, but the amounts are so insignificant that it would not cause an effect on this species

CLAMS

Injury

The magnitude of immediate impacts on clam populations varied with the species of clam, degree of oiling, and location Some littleneck clams and some butter clams were probably killed and may have suffered slower growth rates as a result of the oil spill and cleanup activities

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

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Clams will have recovered when population and productivity measures (such as size and distribution) at oiled sites are comparable to populations and productivity measures at unoiled sites, taking into account geographic differences

Recovery Status

Studies by the NOAA Hazardous Materials Division and others have been conducted on intertidal and subtidal communities in relation to oiling and shoreline treatments. In general, these studies indicated that intertidal fauna dwelling in soft sediments, including various clam species, had recovered to some extent within one to three years after 1989 on oiled-but-untreated shorelines. As of 1997, full recovery had not been achieved, especially on shorelines that were oiled and treated by hot-water washes. One study found that densities of littleneck and butter clams were depressed through 1997 on oiled, treated mixed-sedimentary shores where fine sediments had been washed downslope during pressured water treatments.

Comparing oiled study sites on Knight Island with unoiled sites on Montague Island, researchers in the Nearshore Vertebrate Predator Project found a full range of size classes of clams at the oiled sites, as well as more large clams However, oiled sites also had fewer juvenile clams and lower numbers of several species **Based on all of the evidence summarized above**, clams continue to be recovering, but are not yet fully recovered from the effects of the oil spill The Trustee Council is sponsoring a study of clam populations in FY02 to determine if the populations of clams on treated beaches have improved since 1997

COMMON LOONS

Injury

Carcasses of 395 loons of four species were recovered following the spill, including at least 216 common loons Current population sizes in the spill area are not known for any of these species Common loons in the spill area may number only a few thousand, including only hundreds in Prince William Sound Common loons injured by the spill probably included a mixture of wintering and migrating birds The specific breeding areas used by the loons affected by the spill are not known

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Common loons will have recovered when their population returns to prespill levels in the oil spill area An increasing population trend in Prince William Sound will indicate that recovery is underway

Recovery Status

Boat-based surveys of marine birds in Prince William Sound give at least some insight into the recovery status of the loons affected by the oil spill Prespill counts of loons exist only for 1972-1973 and 1984-1985 After the spill, contrasts between oiled and unoiled areas of the sound indicate that loons as a group are generally doing better in unoiled areas than in oiled areas Thus, the survey data suggest that the oil spill had a negative effect on numbers of loons (all species combined) in the oiled parts of the sound. It is not known what the populations of loons may have been had the spill not occurred

Based on the surveys carned out through 2000, there are indications of recovery, but only in 2000 In 2000 the highest counts ever recorded for common loons occurred in March surveys of Prince William Sound, however, these counts likely included some early migrants as well as wintering birds. In addition, July counts in 2000 were the third highest of the 11 years since 1972 with data. These increases were limited to the unoiled portion of the sound. Since loons are a highly mobile species with widely variable population numbers and the prespill data were limited, one year of high counts in the unoiled areas is insufficient to indicate that recovery has started. Thus the common loon is considered still not to have recovered from the effects of the spill.

COMMON MURRES

Injury

About 30,000 carcasses of oiled birds were picked up in the first four months following the oil spill, and 74 percent of them were common and thick-billed murres (mostly common murres) Many more murres probably died than actually were recovered Based on surveys of index breeding colonies at such locations as the Barren Islands, Chiswell Islands, Triplet Islands, Puale Bay, and Ugiaushak Island, the spill area population may have declined by about 40 percent following the spill In addition to direct losses of murres, there is evidence that the timing of reproduction was disrupted and productivity reduced Interpretation of the effects of the spill, however, is complicated by incomplete prespill data and by indications that populations at some colonies were in decline before the oil spill

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Common murres will have recovered when populations at index colonies have returned to prespill levels and when reproductive success (productivity is sustained within normal bounds increasing population trends at index colonies will be an indication that recovery is underway

Recovery Status

Postspill monitoring at the breeding colonies in the Barren Islands indicated that reproductive success was within normal bounds by 1993, and it has stayed within these bounds

each breeding season since then During the period 1993-1997, the murres nested progressively earlier by 2-5 days each year, suggesting that the age and experience of nesting birds were increasing, as might be expected after a mass mortality event By 1997, numbers of murres at the Barren Islands had increased, probably because 3-and 4-year old nonbreeding subadult birds that were hatched there in 1993 and 1994 were returning to their natal nesting colony Although there were low counts in 1996, the counts in 1997 through 1999 at this index site bring the colony sizes to prespill levels That, coupled with normal reproductive success (productivity), indicate that recovery has been achieved for common murres

CORMORANTS

Injury

Cormorants are large fish-eating birds that spend much of their time on the water or perched on rocks near the water Three species typically are found within the oil spill area Carcasses of 838 cormorants were recovered following the oil spill, including 418 pelagic, 161 red-faced, 38 double-crested, and 221 unidentified cormorants Many more cormorants probably died as a result of the spill, but their carcasses were not found No regional population estimates are available for any of the cormorant species found in the oil spill area In 1996, the U S Fish and Wildlife Service Alaska Seabird Colony Catalog, however, listed counts of 7,161 pelagic cormorants, 8,967 red-faced cormorants, and 1,558 double-crested cormorants in the oil spill area These are direct counts at colonies, not overall population estimates, but they suggest that population sizes are small In this context, it appears that injury to all three cormorant species was significant

Counts on the outer Kenai Peninsula coast suggested that the direct mortality of cormorants due to oil resulted in fewer birds in this area in 1989 compared to 1986 In addition, there were statistically-significant declines in the estimated numbers of cormorants (all three species combined) in the oiled portion of Prince William Sound based on pre- and postspill boat surveys in July 1984-85 compared to 1989-91 It is not known what the counts and trends of comorants would have been in the absence of the oil spill

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Pelagic, red-faced, and double-crested cormorants will have recovered when their populations return to prespill levels in oiled areas An increasing population trend in Prince William Sound will indicate that recovery is underway

Recovery Status

More recent surveys (through 2000) have not shown a significant increasing population trend since the oil spill, and for that reason **these species are considered to be not recovering**

CUTTHROAT TROUT

Injury

Prince William Sound is at the northwestern limit of the range of cutthroat trout Local cutthroat trout populations are believed to be small, and the fish have small home ranges and are geographically isolated Cutthroat trout, therefore, are highly vulnerable to exploitation, habitat alteration, or pollution Following the oil spill, cutthroat trout in a small number of oiled index streams in Prince William Sound grew more slowly than in unoiled streams

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Cutthroat trout will have recovered when growth rates within oiled areas are similar to those for unoiled areas, after taking into account geographic differences

Recovery Status

The apparent difference in growth rates between trout in oiled versus unoiled streams persisted through 1991 It was hypothesized that the slower rate of growth in oiled streams was the result of reduced food supplies or exposure to oil, and there was concern that reduced growth rates would result in reduced survival However, preliminary data from a Trustee Council sponsored study of resident and anadromous forms of cutthroat trout in Prince William Sound suggest that there is significant genetic variation among trout from different locations across the sound These data are consistent with the idea that cutthroat populations are small and isolated and effects other than oil, such as gentic variations in growth rates and variable water temperatures, could be causing the differences seen in the growth rates. The report on this work has experienced significant delays, but is near completion **Pending the completion and review of this additional work, the recovery status of the cutthroat trout remains unknown**

DESIGNATED WILDERNESS AREAS

Injury

The oil spill delivered oil in varying quantities to the waters and tidelands adjoining eight areas designated as wilderness areas and wilderness study areas by Congress or the Alaska State Legislature. Oil also was deposited above the mean high-tide line at these locations. During the intense cleanup seasons of 1989 and 1990, thousands of workers and hundreds of pieces of equipment were at work in the spill zone. This activity was an unprecedented imposition of people, noise, and activity on the area's undeveloped and normally sparsely occupied landscape Although activity levels on these wilderness shores have returned to normal, at some locations there is still residual oil.

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Designated wilderness areas will have recovered when oil is no longer encountered in them and the public perceives them to be recovered from the spill

Recovery Status

Among the affected areas were designated wilderness in the Katmai National Paik, wilderness study areas in the Chugach National Forest and Kenai Fjords National Park, and Kachemak Bay Wilderness State Park Six moderately to heavily oiled sites on the Kenai and Katmai coasts were last surveyed in 1994, at which time some oil mousse persisted in a remarkably unweathered state on boulder-armored beaches at five sites These sites were visited again in 1999 The data from these sites indicate that there is still oil along park shorelines on the Katmai coast Surveys carried out in 2001 to determine the surface and subsurface distribution of oil in Prince William Sound found significant quantities of oil on shorelines within designated wilderness study areas The amount of oil on shorelines in designated wilderness study areas in Prince William Sound has probably decreased since the early 1990s, and natural processes will lead to further reductions Therefore, designated wilderness areas are recovering but have not recovered from the oil spill

DOLLY VARDEN

Injury

Dolly Varden are widely distributed in the spill area In spring, anadromous forms of Dolly Varden migrate to the sea from the lakes and rivers where they spend the winter Summers are spent feeding in nearshore marine waters Thus, some Dolly Varden in Prince William Sound and perhaps at other locations were exposed to *Exxon Valdez* oil in 1989 and possibly beyond In fact, concentrations of hydrocarbons in the bile of Dolly Varden were some of the highest of any fish sampled in 1989 Like the cutthroat trout, there is evidence from 1989-90 that Dolly Varden in a small number of oiled index streams in Prince William Sound grew more slowly than in unoiled streams It was hypothesized that the slower rate of growth in oiled streams was the result of reduced food supplies or exposure to oil, and there was concern that reduced growth rates would result in reduced survival

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Dolly Varden will have recovered when growth rates within oiled streams are comparable to those in unoiled streams, after taking into account geographic differences

Recovery Status

The growth differences between Dolly Varden in oiled and unoiled streams did not persist into the 1990-91 winter No growth data have been gathered since 1991 In addition, by 1990 the concentrations of hydrocarbons in bile had dropped substantially

In a 1991 restoration study sponsored by the Trustee Council, some tagged Dolly Varden moved considerable distances among streams within Prince William Sound, suggesting that mixing of overwintering stocks takes place during the summer in saltwater. This hypothesis is supported by preliminary data from another Trustee Council sponsored study, which indicates that Dolly Varden from different locations across the sound are genetically similar. The final report on this genetics study has been delayed, but should be completed soon. If this preliminary conclusion is born out, it would suggest that the Dolly Varden population in the sound should have little difficulty in recovering from any initial growth-related effects. **Pending completion and review of the genetics work, however, it is prudent to continue classifying the Dolly Varden as recovery unknown**

HARBOR SEALS

Injury

Harbor seal numbers were declining in the Gulf of Alaska, including in Prince William Sound, before the oil spill *Exxon Valdez* oil affected harbor seal habitats, including key haul-out areas and adjacent waters, in Prince William Sound and as far away as Tugidak Island, near Kodiak Estimated mortality as a direct result of the oil spill was about 300 seals in oiled parts of Prince William Sound Based on aerial surveys conducted at trend-count haulout sites in central Prince William Sound before (1988) and after (1989) the oil spill, seals in oiled areas declined by 43 percent, compared to 11 percent in unoiled areas

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Harbor seals will have recovered from the effects of the oil spill when their population is stable or increasing

Recovery Status

In a declining population deaths exceed births, and harbor seals in both oiled and unoiled parts of Prince William Sound have continued to decline since the spill. It is not known what harbor seal populations would have been had the spill not occurred. Environmental changes in the late 1970s may have reduced the amount or quality of prey resources, including such forage fishes as Pacific herring and capelin, available to harbor seals in the northern Gulf of Alaska ecosystem. These changes may have been responsible for or contributed to the initial prespill harbor seal decline, and the ecosystem may now support fewer seals than it did prior to the late 1970s. Recent studies, however, indicate that the seals in the sound, especially pups and yearlings, are in very good condition and do not show evidence of

nutritional stress Ongoing sources of mortality include killer whale predation, possible shark predation, subsistence hunting, and commercial fishery interactions (e.g., drowning in nets) The relative roles of oil and various natural factors are not known

Satellite tagging studies sponsored by the Trustee Council and genetic studies carried out by the National Marine Fisheries Service indicate that harbor seals in the sound are largely resident throughout the year and have limited movement and interbreeding with other subpopulations in the northern Gulf of Alaska This suggests that recovery must come largely through recruitment and survival within resident populations

For the period 1989-1997, the average estimated annual rate of decline of harbor seals in Prince William Sound was about 4.6 percent The population showed some signs of stabilizing in the 1990s, but surveys in 2000 and 2001 indicate that the decline is continuing Therefore, harbor seals continue to be considered not recovering from the effects of the oil spill

HARLEQUIN DUCKS

Injury

Harlequin ducks feed in intertidal and shallow subtidal habitats where most of the spilled oil was initially stranded. More than 200 harlequin ducks were found dead in 1989, mostly in Prince William Sound. Many more than that number probably died in the sound and perhaps thousands throughout the spill area. Because the spill occurred in early spring before wintering harlequins migrated from the sound to inland breeding sites, the initial effects of the spill likely affected harlequin duck productivity beyond the immediate spill zone. The geographic extent and magnitude of these extended impacts are not known.

Prespill data on harlequin populations and reproductive success are limited and difficult to interpret, but after the spill there was concern about poor reproductive success in the western (oiled) versus eastern (unoiled) parts of Prince William Sound This concern was based on observations of 7-15 broods in the eastern sound and few-to-no reports of broods in the western sound when comparable numbers of streams were surveyed

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Harlequin ducks will have recovered when breeding- and nonbreeding-season demographics return to prespill levels and when biochemical indicators of hydrocarbon exposure in harlequins in oiled areas of Prince William Sound are similar to those in harlequins in unoiled areas

Recovery Status

The current overwintering population of harlequin ducks in Prince William Sound is on the order of 18,000 ducks, while the summer population is about half that number Surveys designed specifically to count harlequin ducks have been carried out in the fall, winter and

spring in various years since the spill Fall boat surveys to monitor molting-wintering harlequin ducks indicate a significant declining trend in the oiled western sound from 1995-1997, but no trend in the unoiled eastern sound. The spring harlequin duck surveys have only two years of data (1999 and 2000) — too little on which to draw conclusions, but increases in all areas of the sound in 2000 are promising. Spring surveys were also conducted in 2001 and 2002, but the results are not yet published. Other boat surveys designed to monitor an entire suite of marine birds in the sound have shown mixed results an increasing trend in March surveys in unoiled areas, no trend in oiled areas between 1997 and 2000, and an increasing trend in both oiled and unoiled areas in July of these same years.

Postspill research shows mixed results with respect to age- and sex-structure of harlequin populations in the eastern and western parts of the sound ADF&G fall surveys from 1995-1997 indicate similar age ratios between the two areas, suggesting that recruitment is similar. In addition, some harlequins remain in the sound to nest in the spring and summer, mostly on the eastern side, but it is now suspected that most harlequins of breeding age and condition probably leave the sound altogether to nest in inland drainages. Thus, conclusions of reproductive failure based on lack of broods in the oiled area do not now seem warranted

Winter surveys from 1995-1998 found that adult female survival was lower in oiled versus unoiled areas, and a similar survival scenario is suggested from data collected in 2000 to 2002 Oil remained in the subsurface of the intertidal zone through 2001, including under some mussel beds where harlequin ducks could be feeding. Biopsies from harlequin and Barrow's goldeneye ducks continue to show differences in an enzyme indicative of exposure to hydrocarbons between birds from oiled versus unoiled parts of the sound. These differences are consistent with the possibility of continued exposure to spill-derived hydrocarbons in the western sound. The biological effect of this possible exposure has not been established, but the declining trend of female survivability in the oiled areas may be continuing. Although this result cannot be attributed unequivocally to oil exposure, there is reason for concern about possible oil exposure and reduced survival for harlequin ducks in the western sound.

Trustee Council sponsored studies give insight into prospects for recovery of harlequin ducks Although some harlequin ducks make major seasonal movements, they exhibit high site fidelity to summer breeding sites and to molting and wintering sites during non-breeding seasons Strong site fidelity may limit population recovery by immigration, but a genetic analysis of harlequin ducks indicates that the spill area population is homogeneous (i e, very similar throughout) Taken together, these data are consistent with a low rate of dispersal, perhaps at the subadult stage, or a rapid expansion of the population in recent geological time To the extent that there is subadult dispersal from adjacent expanding populations, such dispersal would enhance recovery It is likely, however, that recovery will largely depend on recruitment and survival from within injured populations. This recovery may be compromised if exposure to lingering hydrocarbons reduces fitness and survival of harlequin ducks

Although some of the indicators show signs of recovery, the majority of the indicators do not indicate recovery Taken together, the population census trends, survival measures and indicators of exposure suggest that the harlequin duck has not recovered from the effects of the oil spill

INTERTIDAL COMMUNITIES

Injury

Portions of 1,400 miles of coastline were oiled by the spill in Prince William Sound, on the Kenai and Alaska peninsulas, and in the Kodiak Archipelago Both the oil and intensive cleanup activities had significant impacts on the flora and fauna of the intertidal zone Intertidal communities are intrinsically important and are resources for subsistence users, sea and river otters, and a variety of birds, including black oystercatchers, harlequin ducks, and pigeon guillemots

Initial impacts to intertidal organisms occurred at all tidal levels and in all types of habitats throughout the oil spill area Many species of algae and invertebrates were less abundant at oiled sites than at unoiled reference sites Some, more opportunistic species, including a small species of barnacle, oligochaete worms, and filamentous brown algae, colonized shores affected by the oil spill and cleanup activities The abundance and reproductive potential of the common seaweed, *Fucus gardnert* (known as rockweed or popweed), also was reduced following the spill

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Intertidal communities will have recovered when such important species as *Fucus* have been reestablished at sheltered rocky sites, the differences in community composition and organism abundance on oiled and unoiled shorelines are no longer apparent after taking into account geographic differences, and the intertidal and nearshore habitats provide adequate, uncontaminated food supplies for top predators

Recovery Status

In the lower and middle intertidal zones on oiled rocky shores, algal coverage and invertebrate abundances had returned by 1991 to coverages and abundances similar to those observed in unoiled areas However, large fluctuations in the algal coverage have taken place in the oiled areas since the spill This pattern is consistent with continued instability due to the original spill impact and the subsequent cleanup However, instability of *Fucus* populations during the last 12 years probably results from a combination of spill- and naturally-induced changes, with a greater influence of natural events in the later years

On the sheltered, bedrock shores that are common in Prince William Sound, full recovery of *Fucus* is crucial for the recovery of intertidal communities at these sites, since many invertebrate organisms depend on the cover provided by this seaweed As of 1997, *Fucus* had not yet fully recovered in the upper intertidal zone on shores subjected to direct sunlight, but in many locations, recovery of intertidal communities had been substantial. In other habitat types, such as estuaries and cobble beaches, many species did not show signs of recovery when they were last surveyed in 1991. In studies of the effects of cleanup activities on beaches, invertebrate molluscs and annelid worms on oiled and washed beaches were still much less abundant than on comparable unoiled beaches through 1997.

More recent data should soon be available, including results of a study in the summer of 2002 to determine if intertidal clam populations on oiled shorelines are comparable to those on unoiled shorelines Based on substantial progress, but the lack of full recovery of some soft-sediment intertidal invertebrates, as well as the continued presence of residual oil and the role of oil in initiating *Fucus* population instability, the intertidal communites are considered to be recovering, but not fully recovered from the effects of the oil spill

KILLER WHALES

Injury

More than 115 killer whales in eight "resident" pods regularly use Prince William Sound/Kenai Fjords as part of their ranges Other whales in "transient" groups are observed in the sound less frequently There has been particular concern about the resident AB pod, which numbered 36 animals prior to the spill Fourteen whales disappeared from this pod in 1989 and 1990, and no young were recruited into the population. The original link between the AB pod losses and the oil spill was largely circumstantial, although the pod was observed surfacing in an Exxon Valdez oil slick following the spill in 1989. The rate of disappearance and likely mortality of killer whales in this well-studied pod far exceeded rates observed for other pods in British Columbia and Puget Sound over the last 30 years, and in the northern Gulf of Alaska over the last 18 years. Another possible cause for the disappearance of the whales in the AB pod was the shooting of killer whales due to conflicts with long-line fisheries prior to the oil spill. Although the original shootings may not have immediately resulted in death for some animals, it is possible the injuries weakened them over time and contributed to premature mortality. In this way it is possible that the effects from the conflicts in the 1980s were still apparent in the 1990s.

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

The original recovery objective for killer whales was a return to prespill numbers for the AB pod The objective was changed in 1999, but upon further reflection and public comment, the recovery objective is once again a return to prespill numbers for the AB pod – 36 individuals

Recovery Status

By 1993 the AB pod had increased to 26 individuals as births outpaced deaths In 1995 mortalities, including animals orphaned in 1989-90, reduced the pod to 22 whales Since 1995 the pod again has increased steadily in size to 26 individuals in 2001 Thus, social disintegration has not happened and an apparently stable structure has been achieved Overall numbers within the other major resident killer whale pods in Prince William Sound are at or exceed prespill levels **Since AB pod has not regained its prespill size of 36 individuals, killer whales are considered to be recovering, but not fully recovered from the effects of the oil spill**

In addition to the AB pod, there is concern that a decline in resightings of individuals within the AT1 group of transient killer whales has accelerated following the oil spill. Although there is no evidence linking the oil spill to the AT1 group, this update also reports on its status. Recent genetic analyses show that resident and transient killer whales in Prince William Sound are genetically distinct. Since 1990 and 1991, 11 individuals have been missing from the AT1 group and are now almost certainly dead. During that same period there has been no recruitment of calves into this pod of transients. Transient killer whales largely prey on marine mammals, and there has been a 60 percent decline in the harbor seal population in the sound over the last two decades. Changes in the availability of such an important prey species could influence killer whale distribution and reproduction. Trustee Council sponsored research on contaminants in killer whales in Prince William Sound indicates that some transient whales, including the AT1 group, are carrying high concentrations of PCBs, DDT, and DDT metabolites in their blubber. The presence of such contaminants is not related to the oil spill. The high concentrations of contaminants found in the transient whales are comparable to those found to cause reproductive problems in other marine mammals.

KITTLITZ'S MURRELETS

Injury

The Kittlitz's murrelet is found only in Alaska and portions of the Russian Far East A large fraction of the world population, which may number only a few tens of thousands, breeds in Prince William Sound The Kenai Peninsula coast and Kachemak Bay are also important concentration areas for this species Very little is known about Kittlitz's murrelets, but they are known to associate closely with tidewater glaciers and nest on scree slopes and similar sites on the ground

Seventy-two Kittlitz's murrelets were positively identified among the bird carcasses recovered after the oil spill Nearly 450 more *Bi achiji amphus* murrelets were not identified to the species level, and it is reasonable to assume that some of these were Kittlitz's In addition, many more murrelets probably were killed by the oil than were actually recovered. It is likely that about 500 individuals died as an acute effect of the oil spill, which would represent a substantial fraction of the world population.

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

No recovery objective can be identified for Kittlitz's murrelet at this time

Recovery Status

Because so little is known about this species, the Trustee Council funded an exploratory study on the ecology and distribution of the Kittlitiz's murrelet in Prince William Sound starting in 1996 This project found that this species has an affinity for tidewater glaciers in the northern and northwestern parts of the sound It also appears that reproductive output in 1996 and 1997

was extremely low or absent, and some Kittlitz's murrelets were apparently paired with marbled murrelets. There appear to be about 1,200-1,400 Kittlitz's murrelets during summer in the four bays studied in northern and northwestern sound. Another, more extensive marine bird boat survey conducted in 2001 suggests a sound-wide summer population of about 2,500 murrelets. These estimates are consistent with what is believed to be a small Alaska and world population.

The population data, indications of low reproductive success, and affinity to tidewater glaciers (of which the lower elevation glaciers are receding rapidly) are reasons for concern about the long-term conservation of Kittlitz's murielets **Specifically, with reference to the effects of the oil spill, however, the original extent of the injury and its recovery status are still unknown and may never be resolved** Therefore, this species is in the recovery unknown category

MARBLED MURRELETS

Injury

The northern Gulf of Alaska, including Prince William Sound, is a key area of concentration in the distribution of marbled murrelets. The marbled murrelet is federally listed as a threatened species in Washington, Oregon, and California, it also is listed as threatened in British Columbia. The marbled murrelet population in Prince William Sound had declined before the oil spill. The causes of the prespill decline are not known for certain, but environmental changes in the late 1970s probably reduced the availability or quality of prey resources. There is, nonetheless, clear evidence that oil caused injury to marbled murrelets in the sound. Carcasses of nearly 1,100 *Bi achyn amphus* murrelets were found after the spill, and about 90 percent of the murrelets that could be identified to the species level were marbled murrelets. Since they are a small bird and not easily seen, many more murrelets probably were killed by the oil than were found, perhaps as much as 7 percent of the spill area population, based on the 1989-1990 population counts

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Marbled murrelets will have recovered when their populations are stable or increasing Sustained or increasing productivity within normal bounds (based on adults and juveniles on the water) will be an indication that recovery is underway

Recovery Status

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The recovery of the marbled murrelet population in Prince William Sound is assessed primarily through standard marine bird boat-based surveys As a result of boat surveys carried out in July for seven years from 1989-2000, densities of marbled murrelets decreased in both the oiled and unoiled areas of Prince William Sound However, for the March surveys carried out in most years between 1990 and 2000, there have been no significant trends in the population size, although the counts have increased in both oiled and unoiled areas The reason for the summer time declines in both oiled and unoiled areas is probably due to some factor other than the oil spill The Trustee Council's Alaska Predator Ecosystem Experiment (APEX) project has investigated the relationship between marbled murrelet declines and the availability and abundance of forage fish, such as Pacific herring, sand lance, and capelin It appears that there is a direct correlation between the availability of forage fish and production of young murrelets, based on the presence of juvenile murrelets on the water in Prince William Sound

The summer time marbled murrelet population is not stable nor increasing, but the March population is stable over time Marbled murrelet productivity, as measured by surveys of adults and juveniles on the water in Prince William Sound, appears to be within normal bounds **Based** on these results, it appears that the marbled murrelet is at least recovering from the effects of the oil spill, but clearly has not yet recovered

MUSSELS

Injury

Mussels are an important prey species in the nearshore ecosystem throughout the spill area and are locally important for subsistence Beds of mussels provide physical stability and habitat for other organisms in the intertidal zone and were purposely left alone during *Exxon Valdez* cleanup operations In 1991, high concentrations of relatively unweathered oil were found in the mussels and in underlying byssal mats and sediments in certain dense mussel beds The biological significance of oiled mussel beds is not known precisely, but they are potential pathways of oil contamination for bird and mammal populations (e g, harlequin ducks and sea otters) which include mussels and other prey in and around mussel beds in their diets

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Mussels will have recovered when concentrations of oil in the mussels reach background concentrations and mussels do not contaminate their predators

Recovery Status

The Trustee Council's Nearshore Vertebrate Predator project has found evidence of hydrocarbon exposure in sea otters, river otters, harlequin ducks, and Barrow's goldeneyes in oiled parts of Prince William Sound in 1996 and 1997 Again in 2000 both sea otters and harlequin ducks showed evidence of oil exposure, but the pathway of such exposure has not been established Both of these species include mussels in their diets

About 30 mussel beds in Prince William Sound still contained *Exxon Valdez* oil residue when last sampled in 1995 Twelve of these beds had been cleaned on an experimental basis in 1993 and 1994 In 1995, oil hydrocarbon concentrations in mussels at half the treated beds were lower than would have been expected if the beds had not been cleaned In 1996, however, limited sampling indicated that several of the cleaned beds had been recontaminated from surrounding or underlying oil residue

Mussel beds along the outer Kenar Peninsula coast, the Alaska Peninsula, and Kodiak Archipelago were surveyed for the presence of oil in 1992, 1993, and 1995 In 1995, hydrocarbon concentrations in mussels and sediments at these Gulf of Alaska sites were generally lower than for sites in Prince William Sound, but at some sites substantial concentrations persisted While several sites in Prince William Sound still contained high concentrations of oil in 1995, over half the sites surveyed demonstrated significant natural declines that suggest background concentrations should be reached in the next few years Oil contamination in mussels, however, will likely persist for many years at certain sites that are well protected from wave action or where oil penetrated deeply into underlying sediments

The latest available data, taken in 1999, indicates that oil is still being accumulated in mussels, but more data will be available soon on samples taken in the summer of 2001 Since the latest available data indicates that Excon Valdez oil remains in mussels, they are considered to be recovering from the oil spill, but not yet recovered

PACIFIC HERRING

Injury

Pacific herring spawned in intertidal and subtidal habitats in Prince William Sound shortly after the oil spill A significant portion of these spawning habitats, as well as herring staging areas in the sound, were contaminated by oil Field studies conducted in 1989 and 1990 documented increased rates of egg mortality and larval deformities in oiled versus unoiled areas Subsequent laboratory studies confirm that these effects can be caused by exposure to *Exxon Valdez* oil, but the significance of these injuries at a population level is not known

Herring populations are dominated by occasional, very strong year classes that are recruited into the overall population. The 1988 prespill year-class of Pacific herring was very strong in Prince William Sound, and, as a result, the estimated peak biomass of spawning adults in 1992 was very high. Despite the large spawning biomass in 1992, the population exhibited a densitydependent reduction in size of individuals, and in 1993 there was an unprecedented crash of the adult herring population. A viral disease and fungus may have been the immediate agents of mortality or a consequence of other stresses, such as a reduced food supply and increased competition for food. There have been no "very strong" year classes recruited into the Prince William Sound herring population since 1988.

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Pacific herring will have recovered when the next highly successful year class is recruited into the population and when other indicators of population health (such as biomass, size-atage, and disease expression) are within normal bounds in Prince William Sound

Recovery Status

Laboratory investigations since the 1993 population crash have shown that exposure to very low concentrations of *Exam Valdez* oil can compromise the immune systems of adult herring and lead to expression of the viral disease. The extent to which the exposure to oil contributed to the 1993 disease outbreak is uncertain. Using closed pounds in the commercial sac roe fishery may also have increased expression of the disease. There is also evidence that plankton production in the 1990s was less than in the 1980s, and so food limitation at the time of a peaking population may have contributed to the 1993 population crash. In addition, the average size-at-age of herring had been decreasing since the mid-1980s as the population was rising.

The Trustee Council's Sound Ecosystem Assessment has resulted in new understanding of the importance of body condition in determining overwintering survival of herring and in the influences of the Gulf of Alaska on herring productivity within Prince William Sound Ongoing research on herring disease in relation to commercial fishing practices, such as the enclosed "pound" fisheries, have direct implications for management of the herring fishery

Numbers of spawning herring in Prince William Sound remained depressed through the 1995 season In 1997 and 1998 the spawning biomass was about double that of 1994, the season following the crash, and there were limited commercial harvests for herring in the sound The increased biomasses in 1997 and 1998 were signs that recovery had begun For that reason, in 1999, Pacific herring were considered to be recovering from the effects of the oil spill Unfortunately, in the last several years the recovery has stalled and the population has yet to recruit a highly successful year-class, which is fundamental to recovery of this species. There is evidence from limited collections in the spring of 2002 that a large proportion (over 70%) of the Pacific herring population in Prince William Sound is now composed of young, 3-year old fish. If this preliminary trend holds up, it is possible that the next large year class has moved into the population, which would once again signal that recovery is underway. However, until that happens, the Pacific herring can only be considered to be not recovering from the effects of the oil spill.

PIGEON GUILLEMOTS

Injury

Although pigeon guillemots are widely distributed in the north Pacific region, they do not occur anywhere in large concentrations Because guillemots feed in shallow, nearshore waters, guillemots and the fish and invertebrates on which they prey are vulnerable to oil pollution Like the marbled murrelet, there is evidence that the pigeon guillemot population in Prince William Sound declined before the oil spill. The causes of the prespill decline are not known for certain, but environmental changes in the late 1970s probably reduced the availability or quality of prey resources. There is, nonetheless, clear evidence that oil caused injury to the guillemot population in the sound. An estimated 10-15 percent of the spill area population died immediately following the spill. Boat-based surveys of marine birds before (1984-85) and after the oil spill indicated that the guillemot populations would be had the oil spill not occurred.

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Pigeon guillemots will have recovered when their population is stable or increasing Sustained or increasing productivity within normal bounds will be an indication that recovery is underway

Recovery Status

Boat surveys have indicated that numbers of guillemots in the summer time continue to decline along both oiled and unoiled shorelines in the Prince William Sound through 2000 March surveys reveal no significant trends in abundance although the data appear to suggest a decline at this time of year as well For these reasons the pigeon guillemot is still considered to be not recovering from the effects of the oil spill

The Trustee Council's Alaska Predator Ecosystem Experiment (APEX) has investigated the possible link between pigeon guillemot declines and the availability of high-quality forage fish, such as Pacific herring and sand lance This work has revealed a strong connection between the availability of certain prey fishes, especially sand lance, and guillemot chick growth rates, fledging weights, and nesting population size The APEX project and the Nearshore Vertebrate Predator (NVP) project, also sponsored by the Trustee Council, addressed the possibility that exposure to oil is limiting the guillemot's recovery The biochemical data indicated that adult guillemots were experiencing greater hydrocarbon exposures in western Prince William Sound than in the eastern portion of the sound as recently as 1999 However, guillemot chicks, which are restricted to the nest and are fed only fish, are not being exposed to hydrocarbons

PINK SALMON

Injury

Certain features of the life history of pink salmon made this species highly vulnerable to damage from the oil spill As much as 75 percent of wild pink salmon in Prince William Sound spawn in the intertidal portions of streams, where eggs deposited in the gravel and developing embryos were chronically exposed to hydrocarbon contamination in the water column or leaching from oil deposits on adjacent beaches When juvenile pink salmon migrate to saltwater, they spend several weeks foraging for food in nearshore habitats. Thus, juvenile salmon entering seawater from both wild and hatchery sources could have been exposed to oil as they swam through oiled waters and fed along oiled beaches. Trustee Council sponsored studies have documented two primary types of injury due to the exposure of these early life stages 1) growth rates in both wild and hatchery-reared juvenile pink salmon from oiled parts of the sound were reduced, and 2) there was increased embryo mortality in oiled versus unoiled streams

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Pink salmon will have recovered when population indicators, such as juvenile growth and survival, are within normal bounds and when ongoing oil exposure, which may cause injury to pink salmon embryos (eggs), is negligible

In addition to the population indicators, the Trustee Council's recovery objective in 1999 required a sequence of two years each of odd- and even-year runs without differences in embryo mortality Differences were detected in 1990-1993, none in 1994, 1995 and 1996, but in 1997 there was again a difference The cause of this difference could not categorically be attributed to oil exposure A Trustee Council sponsored study showed that hatchery-spawned embryos showed the same effects as those displayed by embryos in their native streams However, the only way to sustain such an injury over time would be a continuing genetic effect from the original injury or continuing exposure of the embryos in the originally oiled streams Laboratory experiments have shown a continuing genetic effect for only one generation of pink salmon (two years) There is also a well-known phenomenon of lethality for most mutations that would lead to extermination of the genetic defects in a generation That leaves continued exposure to oil as the remaining pathway for any continuing embryo mortality For that reason, a more precise way to assess continued embryo mortality is based on hydrocarbon exposure of pink salmon embryos Given the expense of the embryo mortality field studies (\$17 million over four years) and the mability to attribute a direct cause to any potential differences, this data is no longer gathered by the Alaska Department of Fish and Game Accordingly, this objective was modified

Recovery Status

In the years preceding the spill, returns of wild pink salmon in Prince William Sound varied from a maximum of 23 5 million fish in 1984 to a minimum of 2 1 million in 1988 Throughout Alaska there is increasing recognition of the importance of changes in marine ecosystems on the growth and survival of salmon The Sound Ecosystem Assessment (SEA) project explored oceanographic and ecological factors that influence production of pink salmon and Pacific herring in Prince William Sound These factors include such things as the timing of spring plankton blooms and changes in circulation patterns that link the sound to the Gulf of Alaska, and are likely to have the greatest influence on year-to-year returns in both wild and hatchery stocks of pink salmon

Since the spill, returns of wild pinks have varied from a high of about 127 million fish in 1990 to a low of about 19 million in 1992. In 2001 the return of wild stock fish was estimated to be 67 million fish. The decade preceding the oil spill was a time of very high productivity for pink salmon in the sound, and, given the tremendous natural variation in adult returns, it is impractical to measure directly the extent to which wild salmon returns since 1989 were influenced by the oil spill. Based on intensive studies and mathematical models carried out following the spill, wild adult pink salmon returns to the sound's Southwest District in 1991 and 1992 were most likely reduced by a total of 11 percent. However, such an approach is unlikely to produce reliable multi-generational injury estimates. In addition, an analysis of escapement data from 1968-2001 showed no apparent time trends in annual escapements in either the oiled or unoiled parts of the sound. Therefore, there appear to be no observable effect at the population level at this time.

Population levels appear to be within normal bounds In addition, reduced juvenile growth rates in Prince William Sound occurred only in the 1989 season Since then, juvenile growth rates have been within normal bounds

Higher embryo mortality persisted in oiled compared to unoiled streams through 1993 No statistically significant differences in mbryo mortalities in oiled and unoiled streams were detected in 1994 through 1996, but in 1997 there was again a difference. It is not clear whether the 1997 difference was due to the effects of lingering weathered oil, perhaps newly exposed by storm-related disturbance of adjacent beaches, or due to other natural factors such as differences in the physical environment Although patches of weathered oil still persist in or near intertidal spawning habitats in a few of the streams used by pink salmon in southwestern Prince William Sound, the amounts are considered negligible based on 1999 and 2001 studies In 1999 dissolved oil measurements were made in six pink salmon streams in the oil spill area, chosen because they were the most likely to show residual oiling Methods were used that were extremely sensitive Only one of the six streams had clearly measurable concentrations of oil, and that was about a thousand times lower than the concentration established through Trustee Council sponsored studies to be toxic to developing pink salmon embryos In 2001 a Trustee Council study assessed those intertidal areas in western Prince William Sound considered to be most heavily oiled in 1993 There were no pink salmon streams located near any of those sites determined to have the most extensive subsurface oil deposits Based on these results, the biological impact of exposure of pink salmon embryos to lingering oil is negligible and unlikely to limit pink salmon populations It is highly unlikely that oil is now accumulating in pink salmon embryos and having any significant effects. On this basis and given the fact that pink salmon population levels and indicators such as juvenile growth and survival are within normal bounds, pink salmon are considered recovered from the effects of the oil spill

APPENDIX B

RIVER OTTERS

Injury

River otters have a low population density in Prince William Sound Twelve river otter carcasses were found following the spill, but the actual total mortality is not known. Studies conducted during 1989-91 identified several differences between river otters in oiled and unoiled areas in Prince William Sound, including biochemical alterations, reduced diversity in prey species, reduced body size (length-weight), and increased home-range size Because there were few prespill data, it is not certain that these differences are the result of the oil spill

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

The river otter will have recovered when biochemical indicators of hydrocarbon exposure or other stresses and indices of habitat use are similar between oiled and unoiled areas of Prince William Sound, after taking into account any geographic differences

Recovery Status

Although some of the differences (e g, values of blood characteristics) between river otters in oiled and unoiled areas in Prince William Sound persisted through 1996, there were few differences documented in 1997 and 1998 Thus, there are no indications of possible lingering injury from the oil spill, and the Trustee Council's recovery objective has been met River otters were considered to be recovered in 1999

ROCKFISH

Injury

Very little is known about rockfish populations (of several species) in the northern Gulf of Alaska A small number of dead adult rockfish was recovered following the oil spill, and autopsies of five specimens indicated that oil ingestion was the cause of death Analysis of other rockfish showed exposure to hydrocarbons and probable sublethal effects In addition, closures to salmon fisheries apparently had the effect of increasing fishing pressure on rockfish, which, in turn, may have adversely affected local rockfish populations

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

No recovery objective can be identified

Recovery Status

The original extent of injury and the current recovery status of this species are unknown Because little is known about rockfish abundance and species composition in the spill area and because rockfish are harvested commercially, even basic information about these species could provide a basis for improved management or, at least, the identification of priorities for more targeted research

SEA OTTERS

Injury

By the late 1800s, sea otters had been eliminated from most of their historical range in Alaska due to excessive harvesting by Russian and American fur traders Surveys of sea otters in the 1970s and 1980s, however, indicated a healthy and expanding population in most of Alaska, including Prince William Sound Today the only harvests of sea otters are for subsistence purposes About 1,000 sea otter carcasses were recovered following the spill, and additional animals probably died but were not recovered In 1990 and 1991, higher-than-expected proportions of prime-age adult sea otters were found dead in western Prince William Sound, and there was evidence of higher mortality of recently weaned juveniles in oiled areas

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Sea otters will have recovered when the population in oiled areas returns to its prespill levels and distribution, and when biochemical indicators of hydrocarbon exposure in otters in the oiled areas are similar to those in otters in unoiled areas An increasing population trend and normal reproduction and age structure in western Prince William Sound will indicate that recovery is underway

Recovery Status

By 1992-93, overwintering mortality rates for juveniles had decreased, but were still higher in oiled than in unoiled parts of the sound Based on both aerial and boat surveys conducted in western Prince William Sound, there is statistically significant evidence of a population increase following the oil spill (1993-98) Observations by local residents bear out this general increase However, within the most heavily oiled bays in the western sound, such as those on northern Knight Island, the aerial surveys indicate that recovery is not complete

The Trustee Council's Nearshore Vertebrate Predator project addressed the lack of recovery in sea otters in these heavily oiled bays. The lack of recovery may reflect the extended time required for population growth for a long-lived mammal with a low reproductive rate, but it also could reflect the effects of continuing exposure to hydrocarbons, or a combination of both factors. Through 2000, researchers have continued to find biochemical evidence of oil exposure in sea otters around northern Knight Island. Biochemical samples from 2001 are now being
analyzed An additional hypothesis is that food supplies are limiting recovery, but the evidence does not fully support this idea

It is clear that sea otter recovery is underway for much of the spill-affected area, with the exception of populations at the most heavily oiled bays in western Prince William Sound For this reason, sea otters continue to be in the recovering category

SEDIMENTS

Injury

Evron Valdez oil penetrated deeply into cobble and boulder beaches that are common on shorelines throughout the spill area, especially in sheltered habitats. Cleaning and natural degradation removed much of the oil from the intertidal zone, but visually identifiable surface and subsurface oil persists at many locations.

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Sediments will have recovered when there are no longer significant residues of *Exxon Valdez* oil on shorelines (both intertidal and subtidal) in the oil spill area Declining oil residues and diminishing toxicity are indications that recovery is underway

Recovery Status

A comprehensive survey of shorelines in Prince William Sound was conducted in 1993, but that survey has been repeated in the summer of 2001 with revised methods for better quantifying the oil remaining in intertidal sediments. The 2001 surveys indicate that about 20 acres of continuously oiled intertidal habitat now persist in Prince William Sound. While it appears that natural weathering processes are gradually reducing the amount of remaining oil in sediments, the amount estimated in 2001 is about twice the amount estimated to be in the sediments in 1993 (using methods that were designed in 1989 more for cleanup decisions than for quantitative estimates of remaining oil). The shorelines of the outer Kenai and Alaska Peninsula coasts get more wave action than most shorelines within Prince William Sound. These Gulf of Alaska sites tended to be contaminated with oil in the form of mousse, a stable emulsion of oil in water, which can persist for long periods in a largely unweathered state. Five of six index beaches on the gulf coast have a heavy boulder "armor" and were last visited in 1993 and 1994. At that time, surface and subsurface oil mousse persisted in a remarkably unweathered state.

In 1995, a shoreline survey team visited 30 sites in the Kodiak Archipelago that had measurable or reported oiling in 1990 and 1991 The survey carried out in 1995 around Kodiak Island found no oil or only trace amounts, so oiling in the Kodiak area has not persisted as it has in the sound Following the oil spill, chemical analyses of oil in subtidal sediments were conducted at a small number of index sites in Prince William Sound At these sites, oil in subtidal sediments was mostly confined to the uppermost 20 meters water depths (below mean low tide), although elevated levels of hydrocarbon-degrading bacteria (associated with elevated hydrocarbons) were detected at depths of 40 and 100 meters in 1990 in Prince William Sound By 1993 however, there was little evidence of *Exxon Valdez* oil and related elevated microbial activity at most index sites in Prince William Sound, except at those associated with sheltered beaches that were heavily oiled in 1989 These index sites – at Herring, Northwest, and Sleepy bays – are among the few sites at which substantial subsurface oiling is still known to occur

Based on the information above, sediments are considered to be recovering However, the presence of surface and subsurface oil continues to compromise wilderness and recreational values, expose and potentially harm living organisms, and offend visitors and residents, especially those who engage in subsistence activities along still-oiled shorelines

SOCKEYE SALMON

Injury

Commercial salmon fishing was closed in Prince William Sound and in portions of Cook Inlet and near Kodiak in 1989 to avoid any possibility of contaminated salmon being sent to market As a result, there were higher-than-desirable numbers (i e, "overescapement") of spawning sockeye salmon entering the Kenai River and also Red and Akalura lakes on Kodiak Island Research carried out following the spill demonstrated that initially these high escapements produced an overabundance of juvenile sockeye that then overgrazed the zooplankton, thus altering planktonic food webs in the nursery lakes The result was lost sockeye production as shown by reduced growth rates during the freshwater part of the sockeye life history and declines in the returns of adults per spawning sockeye

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Sockeye salmon in the Kenai River system and Red and Akalura lakes will have recovered when adult returns-per-spawner are within normal bounds

Recovery Status

Although sockeye freshwater growth tended to return to normal within two or three years following the overescapement, there are indications that these systems are less stable for several years after an initial overescapement event. The negative effects of the 1989 overescapement on sockeye productivity, as measured by return per spawner, in the Kenai River watershed were readily apparent for returns from the brood years 1989-92. Production of zooplankton in both Red and Akalura lakes on Kodiak Island has rebounded from the effects of the overescapement at the time of the oil spill By 1997, Red Lake had responded favorably in terms of smolt and adult production and was at or near prespill production of adult sockeye. At Akalura Lake there were low juvenile growth rates in freshwater during the period 1989-92, and these years of low growth correspond to low adult escapements during the period 1994-97. Starting in 1993, however, the production of smolts per adult increased sharply and the smolt sizes and age

composition suggested that rearing conditions have improved There also was concern about overescapement effects in lakes on Afognak Island and on the Alaska Peninsula However, analysis of sockeye freshwater growth rates of juveniles from Chignik Lake on the Alaska Peninsula did not identify any impacts associated with a 1989 overescapement event. On the basis of catch data through 2001 and in view of recent analyses of return per spawner estimates presented to the Alaska Board of Fisheries in 2001, the return-per-spawner in the Kenai River system is within historical bounds. Therefore, it is highly unlikely that the effects that reverberated from the overescapements in 1989 continue to affect sockeye salmon (e.g., cause abnormal returns per spawner), and this species is considered to be recovered from the effects of the oil spill

SUBTIDAL COMMUNITIES

Injury

Shallow subtidal habitats of Prince William Sound, from the lower intertidal zone to depths of about 20 meters, typically have dense stands of kelp or eelgrass and contain numerous polychaete worms, snails, clams, sea urchins, and other invertebrate life These subtidal communities provide shelter and food for an array of nearshore fishes, birds, and marine mammals Oil that was transported down to subtidal habitats, as well as subsequent cleanup activities involving extensive vessel traffic, apparently caused changes in the abundance and species composition of plant and animal populations below lower tides

Biologically, negative effects of the oil were most evident for oil-sensitive species of amphipods, which were consistently less abundant at oiled than at unoiled sites Reduced numbers of eelgrass shoots and flowers may have been due to increased turbidity associated with cleanup activities (e g , boat traffic) Two species of sea stars and helmet crabs also were less abundant at oiled sites Some invertebrates living in the sediment, including species in eight families of polychaete worms, two families of snails, and one family of mussels, were greater in numbers at oiled sites These species are more tolerant of oil exposure and may have also responded to the organic enrichment associated with oil Some of the species that showed increased numbers also may have benefited from reduced competition or predation due to the effects of the spill It is also is to be expected that when comparing any two sets of bays that measuring a large number of species will turn up differences just on the basis of chance

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Subtidal communities will have recovered when community composition in oiled areas, especially in association with eelgrass beds, is similar to that in unoiled areas or consistent with natural differences between sites such as proportions of mud and sand

Recovery Status

Different habitats, emphasizing eelgrass beds and adjacent areas of soft sediment, were compared at oiled and unoiled sites from 1990-1995 It is difficult to draw firm conclusions from this study, because it is hard to distinguish between natural site differences (e.g., percent sand and mud) and those differences actually resulting from the oil spill or cleanup Concentrations of hydrocarbons in subtidal sediments were significantly higher at oiled sites than at unoiled reference sites, but never very high by comparison with concentrations known to cause community responses in the scientific literature These oil concentrations dropped sharply by 1991, but evidence of oil contamination due to Erron Valdez oil persisted at some locations through 1995 at very low concentrations By 1995, based on postspill comparisons of oiled and unoiled sites, there was recovery of most constituents of the eelgrass community In 1999 an article was published in the peer reviewed literature that acknowledged the role that natural factors may be playing in the remaining differences in subtidal communities between oiled and unoiled bays Since the study results show that the remaining faunal differences could be due to the influence of natural factors or to oil effects or some combination, and since additional study will not likely bring more certainty to question, the recovery status of subtidal communities is judged to be unknown

HUMAN SERVICES

COMMERCIAL FISHING

Injury

Commercial fishing is a service that was reduced through injury to commercial fish species (see individual resource accounts) and also through fishing closures In 1989, closures affected fisheries in Prince William Sound, Cook Inlet, the outer Kenai coast, Kodiak, and Chignik These closures harmed the livelihoods of persons who fish for a living The period before the oil spill was a time of relative prosperity for many commercial fishermen The years 1987-88 saw some of the highest ever per pound prices for salmon and increased capitalization of the fishery Thus, fishermen's expectations for income in 1989 were very high, making the fishery closures and other spill effects even more disruptive

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Commercial fishing will have recovered when the commercially important fish species have recovered and opportunities to catch these species are not lost or reduced because of the effects of the oil spill

Recovery Status

Although pink salmon and sockeye salmon are considered to be recovered from the oil spill, recovery is still not complete for Pacific herring (see individual resource accounts), one of the injured resources that is commercially fished. The recovery status of rockfish is still unknown and will likely never be known. No spill-related district-wide fishery closures related to oil.

contamination have been in effect since 1989 However, the Prince William Sound heiring fishery was closed from 1993-96 due to a disease outbreak that may be related to the oil spill, was open to limited commercial harvest in 1997 and 1998, and has remained closed since then For these reasons, commercial fishing, as a lost or reduced service, is in the process of recovering from the effects of the oil spill, but full recovery has not been achieved

For a variety of reasons, as discussed below, disruptions to income from commercial fishing continue today, as evidenced by changes in average earnings, ex-vessel prices, and limited entry permit values For example, for the period 1981-2000, fishermen's average earnings in the Prince William Sound salmon seine fishery peaked in 1987 (\$176,500), dropped in 1989 by more than half, rebounded in 1990, hit a new low in 1992-93 (runs in 1992-93 were the lowest in 15 years), then hovered somewhat below the 1989 level until 1999-2000, when average earnings climbed to the \$130,000 level Average per-fisher harvests have varied widely during this period, with the three highest years being 1996, 1999, and 2000 Ex-vessel prices were highest in the period 1987-90, and have been below prices of the early 1980s ever since Limited entry permit prices in this fishery reached a peak in 1989-91, nearly double the price in any earlier year in this period, and have declined since to currently ten percent of their peak price (from \$236,000 in 1989 to \$22,000 in 2000) The number of permits fished, roughly 250 each year 1981-91, had declined to 130 in 2000

Natural variability in fish returns and a number of economic changes in the commercial fishing industry since 1989 probably mean that many of these changes in income are not directly attributable to the spill. However, these factors also make discerning spill-related impacts difficult. Economic changes confronting the industry include the increased world supply of salmon (due primarily to farmed salmonids) and corresponding reduced prices, entry restrictions in certain fisheries (such as Individual Fishing Quotas, IFQs, for halibut and sablefish), allocation changes (e.g., a reduction in the allocation of Cook Inlet sockeye salmon to commercial fishermen), changes in processing capacity (closure of major processors in Cordova and Kenai, and a recently announced closure in Larsen Bay on Kodiak Island), and new measures imposed by the North Pacific Fishery Management Council on offshore groundfish fishing to protect the declining number of Steller sea lions

Although a number of studies aimed at allocating financial impacts to the oil spill versus other factors have been carried out, the federal jury's compensatory award (as opposed to the \$5 billion in punitive damages) in the private lawsuit against Exxon is the current legal determination of the liability and damages regarding commercial fishermen (including permit holders, fishing crew, spotter pilots, and vessel owners) The jury award was less than the damage claimed by commercial fishermen and more than that acknowledged by Exxon In brief, the jury determined that any financial effects on fishermen after 1989, with the exception of the salmon seine fishery in Prince William Sound in 1992-93 and the herring fishery in Prince William Sound in 1993, are not attributable to the spill. The jury considered damage claims for the period 1989-95, including claims related to size of harvest, fish prices, limited entry permit values, and vessel values.

PASSIVE USE

Injury

Passive use encompasses nonuse values, such as the appreciation of the aesthetic and intrinsic values of undisturbed areas and the value derived from simply knowing that a resource exists Injuries to passive use are tied to public perceptions of injured resources Immediately following the oil spill, the State of Alaska, using a contingent valuation approach, measured substantial losses of passive use values resulting from the spill. This approach involved surveying a sample of U.S. households to elicit how much people would be willing to pay in additional taxes to fund a program designed to prevent future spills. Prior to answering the survey questions, respondents were provided information about the spill's impact, including the number of miles of shoreline oiled, an estimate of the number of birds, sea otters, and harbor seals killed, and the conclusion that few fish were harmed, as well as projections of when recovery would occur (typically three to five years)

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Passive uses will have recovered when people perceive that aesthetic and intrinsic values associated with the spill area are no longer diminished by the oil spill

Recovery Status

Because recovery of a number of injured resources is incomplete and in some cases has not begun, the Trustee Council considers passive use, as a lost or reduced service, to be recovering from the spill but not yet recovered In updating the status of passive uses, the Trustee Council has chosen not to repeat the contingent valuation study, which was very expensive and time consuming However, the key to recovery of passive use is knowing that restoration of injured resources has occurred Toward this end, in the years since the settlement between Exxon Corporation and the state and federal governments, the Trustee Council has undertaken a comprehensive program to restore injured resources and has made a deliberate and consistent effort to inform the public about the status of restoration

The two key components of the Trustee Council's restoration effort are the research, monitoring, and general restoration program and the habitat protection and acquisition program. The research, monitoring, and general restoration program, which is funded each year through the annual work plan, focuses mostly on knowledge and stewardship as the best tools for long-term health of the marine ecosystem. It also includes development of tools to benefit fisheries management and some direct enhancement activities, such as improving access to spawning habitat. Projects to monitor the status of injured resources, including resources such as killer whales for which no active restoration may be possible, have also been funded through the annual work plan. The habitat protection program preserves habitat important to injured resources through the acquisition of land or interests in land. As of March 2002, the Council has protected more than 643,600 acres of habitat, including more than 1,400 miles of coastline and over 300 streams valuable for salmon spawning and rearing. A summary of the Council's public information efforts follows.

Each year the Trustee Council prepares a number of documents for distribution to the public including, annual work plans, which describe the work underway to restore the injured resources and services, the *Annual Status Report*, which reports to the public on the progress of restoration, and updates to the Restoration Plan (1996, 1999) The Council's annual restoration workshop, which is open to the public, provides another venue for reporting on the progress of restoration. The Council has also published its Restoration Notebook series, which tells the story of injury and recovery from the spill of select injured species.

In addition, from 1996 through early 1999 the Council aned a weekly radio series, "Alaska Coastal Currents", throughout the state Since 1997, the Trustee Council has had a web site (www oilspill state ak us) that offers detailed information about restoration efforts

Project final reports, are also available to the public through the Alaska Resource Library and Information Services (ARLIS) in Anchorage as well as at several other libraries in the state, at the Library of Congress, and through NTIS (National Technical Information Service) In addition, the Council supports researchers in publishing their project results in the peer-reviewed scientific literature, which expands their audience well beyond Alaska Nearly 500 such papers have been published as of April 2002

The 17-member Public Advisory Group (PAG), is an important means of keeping stakeholders and others informed of the progress of restoration. In addition to holding quarterly meetings with the Trustee Council staff, in many years the PAG has held an open house in one or more communities in the spill area. Additional public meetings have been held throughout the spill area. All meetings of the Council are widely advertised and opportunity for public comment, is always provided.

RECREATION AND TOURISM

Injury

The oil spill disrupted use of the spill area for recreation and tourism In addition, resources important to recreation were injured and beaches used for recreational activities were oiled Recreation was also affected by changes in human use in response to the spill For example, displacement of use from oiled areas to unoiled areas, particularly in the years immediately following the spill, increased management problems and facility use in unoiled areas

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Recreation and tourism will have recovered, in large part, when the fish and wildlife resources on which they depend have recovered and recreation use of oiled beaches is no longer impaired

Recovery Status

In the years since the spill, there has been a marked increase in the number of visitors to Alaska Preliminary data for the summer of 2001 indicate over 1.2 million visitors, compared to approximately 600,000 visitors in the summer of 1989 Visitation to the spill area has experienced a similar increase For example, since 1993 the annual number of visitors to the Kenai Fjords National Park Visitor Center has been nearly double what it was in 1988 In 2000, the number of visitors to the USFS Crooked Creek Visitor Information Center in Valdez was nearly 70 percent greater than in 1989 From 1989 to 1997, the number of sportfishers increased by 65% in Prince William Sound, by 25% in the Kodiak Region, and by 15% in the Kenai Peninsula region In 2000, the numbers were up slightly for Prince William Sound and Kodiak, and had decreased slightly for the Kenai Peninsula region

Even though visitation has increased since the oil spill, however, the Trustee Council's recovery objective requires that the injured resources important to recreation be recovered and recreational use of oiled beaches not be impaired, and this objective has not been met **Therefore, the Council finds recreation to be recovering from the effects of the spill, but not yet recovered**

Several resources important for wildlife viewing still are not recovering from the spill or their recovery is unknown, including harbor seal, common loon, cormorant (three species), Kittlitz's murrelet, and pigeon guillemot Other resources, including sea otter and marbled murrelet, are recovering The bald eagle, another resource important for wildlife viewing, has recovered from the effects of the spill (See individual resource accounts for more information on recovery status)

Telephone interviews were conducted in early 1999 with key informants who recreated extensively in the oil spill area before the spill and currently Contacted again in 2002, nearly all of the informants commented on increased visitation to the area since the spill Informants with experience in Prince William Sound continued to report diminished wildlife sightings in the sound, particularly in heavily oiled areas such as around Knight Island. They reported seeing fewer seabirds, killer whales, sea lions, seals, and sea otters than were generally sighted before the spill, but also reported observing increases in the number of seabirds over the last several years. Key informants with experience along the outer Kenai coast reported diminished sightings of seabirds, seals, and sea lions. Changes in the amount of wildlife observed could be due to the oil spill or to other factors.

Sportfishing resources for which the recovery status is unknown are cutthroat trout, Dolly Varden, and rockfish In 1992-93, in response to evidence of injury to cutthroat trout, emergency closures were put in place in some locations in Prince William Sound In addition, bag limits have been reduced since 1991 and a closure during the April 15-June 15 spawning season has been in effect since 1994 These measures reflect the management goals for a potentially vulnerable species at the edge of its range The salmon species that were injured (pink and sockeye salmon) are recovered from the effects of the spill

Harlequin ducks, which are hunted in the spill area, are still not recovered The Alaska Board of Game restricted sport harvest of harlequin ducks in western Prince William Sound and Kenai Fjords in 1991 Those restrictions were removed in the 1999-2000 hunting season when sea duck limits were changed statewide to have different limits for resident and non-resident hunters There are currently no special restrictions for harlequins in Prince William Sound or Kenai Fjords Trustee Council sponsored surveys of oiled shorelines indicate that residual oil is still present on some beaches The results of the most recent survey in Prince William Sound (2001) indicate approximately 20 acres of shoreline are still contaminated with oil Oil was found at 58 percent of the 91 sites assessed and is estimated to have the linear equivalent of 5 8 kilometers of contaminated shoreline. The most recent survey of the Kenai outer coast and the coast of Katmai National Park (1999) found oil mousse persisting in a remarkably unweathered state on five moderately-to-heavily-oiled boulder-armoied beaches (the oil is chemically similar to 11-day old *Exion Valdez* oil) A survey of 30 oiled sites in the Kodiak Archipelago in 1995 found no oil or only trace amounts

Key informants telephoned in early 1999 indicated that some beaches in Prince William Sound, particularly in the western portion of the sound, continue to be avoided by some recreational users, particularly kayakers and campers, because of the presence of residual oil Contacted again in early 2002, informants commented that visitors to the sound routinely inquire about the existence of oil on beaches, either in planning visits or while on tours. They also commented that experienced users of the sound can readily find oil on certain beaches and continue to avoid those areas. Since 1999, informants have indicated that the possible presence of residual oil has no effect on recreational activities along the outer Kenai coast, the Kodiak Archipelago, and the Lake Clark and Katmai national park coastlines

In 1997, the Trustee Council provided funding for the residents of Chenega Bay, working with the Department of Environmental Conservation, to use PES-51, a citrus-based chemical agent, to clean some of the most heavily-oiled sites near their village One year later, a statistical analysis showed that the cleanup method reduced the amount of oil remaining on these beaches by a factor of three compared with reductions observed on untreated beaches However, considerable subsurface oil remains that was inaccessible at the time of treatment, but was uncovered during storms the following winter NOAA's Auke Bay Lab found no biological injury due to the cleanup

The State of Alaska dedicated over \$10 million of its criminal settlement with Exxon to restoring recreational facilities and use in state parks in the spill area Improvements include trails, cabins, boat launches, interpretive displays, and campsites In addition, the Trustee Council funded U S Forest Service development of a human use model for western Prince William Sound, which is intended to aid planning for and mitigation of human uses so that injured species continue to be protected The model may also assist in planning for future recreation needs in the sound

SUBSISTENCE

Injury

Fifteen predominantly Alaskan Native communities (with a total population of about 2,200 people) in the oil spill area rely heavily on harvests of subsistence resources, such as fish, shellfish, seals, deer, and waterfowl Many families in other communities also rely on the subsistence resources of the spill area

Household interviews conducted with subsistence users in communities throughout the spill area in 1989 indicated that subsistence harvests of fish and wildlife in most of the communities declined substantially following the spill Key factors in the reduced harvests included reduced availability of fish and wildlife, concern about possible health effects of eating oiled fish and wildlife, and disruption of the traditional lifestyle due to cleanup and related activities

Recovery Goal

A return to conditions that would have existed had the spill not occurred

Recovery Objective

Subsistence will have recovered when injured resources used for subsistence are healthy and productive and exist at prespill levels In addition, there is recognition that people must be confident that the resources are safe to eat and that the cultural values provided by gathering, preparing, and sharing food need to be reintegrated into community life

Recovery Status

Household interviews were repeated each year 1990-93 and again in 1998 By 1993, the estimated size of the subsistence harvest and participation in subsistence activities appeared to have returned to prespill levels in some communities, with the harvest rebounding first in the communities of the Alaska Peninsula, Kodiak Island, and the lower Kenai Peninsula and lagging behind a year or more in the Prince William Sound communities

Many subsistence resources injured by the spill, including clams, mussels and harbor seals, have still not recovered from the effects of the spill. In addition, in 1998, household interviews indicated that subsistence users continued to feel the effects of the spill. For these reasons, subsistence continues to recover from the effects of the oil spill, but has not yet recovered. The percentage of those interviewed who reported that subsistence uses are lower than before the spill has declined. Concerns about food safety and effects on the traditional lifestyle have lessened. Concerns about resource availability and greater harvest effort remain, but harvest levels in all communities interviewed are at or approaching prespill levels. Subsistence harvests in 1998 varied among communities from 250-500 pounds per person usable weight, indicating continued strong dependence on subsistence resources.

Regarding resource availability, subsistence users continued to report scarcity of a number of important subsistence resources, including harbor seals, herring, clams, and crab These observations are generally consistent with scientific studies funded by the Trustee Council that continue to find that some subsistence species (e g, harbor seals, Pacific herring, clams) are not recovered from the effects of the spill (see individual resource accounts)

According to those interviewed, the 1998 increase in pounds harvested at a time of continued reduced resource availability reflects greater harvest effort (traveling farther, spending more time and money) than would have been required before the spill to achieve a similar harvest. It also reflects increased reliance on fish in the subsistence diet. Increased fish harvests and decreased marine mammal and shellfish harvests occurred in most communities where interviews were conducted. The cultural and nutritional importance of each resource varies, and these changes in diet composition remain a serious concern to subsistence users.

The decline in shellfish consumption reflects food safety concerns as well as reduced availability of shellfish From 1989-94, subsistence foods were tested for evidence of hydrocarbon contamination, with no or very low concentrations of petroleum hydrocarbons found in most subsistence foods However, because some shellfish can readily accumulate hydrocarbons, subsistence users have been advised not to eat shellfish from beaches where oil can be seen or smelled on the surface or subsurface By 1998, a large majority of those interviewed expressed confidence about most foods except certain shellfish, such as clams, and concerns about the presence of PSP (paralytic shellfish poisoning) in clams outweighed concerns about lingering hydrocarbon contamination from the oil spill

Subsistence users continue to emphasize that the value of subsistence cannot be measured in pounds alone Harvest levels do not encompass the cultural value of traditional and customary use of natural resources Following the oil spill, there was concern that the spill disrupted opportunities for young people to learn cultural subsistence practices and techniques, and that this knowledge may be lost to them in the future In 1998, the number of subsistence users reporting a decline in the influence of elders in teaching subsistence skills and values had decreased and the number reporting that young adults are learning enough subsistence skills had increased Also, the number reporting less sharing of subsistence resources, another integral aspect of subsistence culture, had decreased However, many of those interviewed continue to express concern about these elements of the traditional lifestyle, with more than 50 percent responding that the traditional way of life has not recovered since the spill

In the 1998 household interviews, a number of subsistence users commented that some of the current influences on subsistence may not be attributable to the oil spill Factors such as demographic changes in village populations, ocean warming, increased competition for subsistence resources by other people (e g , sport fishing charters) and predators (e g , sea otters), and increased awareness of PSP and other contaminants may play a role in resource availability, food safety, and participation in traditional practices The Trustee Council will likely repeat the household interviews with subsistence users in communities through the spill area in 2004 or 2005

A. Our Commitment

Since its inception, the *Exam Valdez* Oil Spill Trustee Council has been committed to public participation and local community involvement in all aspects of the restoration

program The Trustee Council recognizes the tremendous loss of livelihood and cultural heritage caused by the 1989 oil spill and has devoted a major portion of the restoration funds to the restoration of natural and archaeological resources that are important culturally and economically This effort has included significant public and community involvement and outreach As the Gulf of Alaska Ecosystem Monitoring and Research (GEM) program develops, the Trustee Council hopes to expand community involvement, use of local and traditional knowledge, public participation, education, and outreach These will be major components of the Trustee Council's long-term effort to restore and better understand the northern Gulf ecosystem

As an organization, the Trustee Council is committed to having community members actively involved in

- Planning and developing the program
- Guiding the goals and topics of research projects
- Collecting data and participating in long-term monitoring efforts
- Providing Traditional Ecological Knowledge
- Interpreting results in a local context
- Educating other community members about ongoing research

Some of this involvement will come in the form of participation in various planning and review committees Other involvement will be in the form of working with scientists to provide quality data and input into the GEM program Portions of GEM monitoring will rely on citizen volunteers based on successful programs throughout North America Requests for proposals will ask proposers to state how communities will be involved and informed about each project Funds for community involvement and/or Traditional and Ecological Knowledge (TEK) components will be provided

The remainder of this report documents the efforts and actions the Trustee Council has taken to date to involve tribes, communities, stakeholders and the general public

	From 1995-2001, the Trustee Council has provided almost \$2
B. Community	million to the Chugach Regional Resources Commission
Involvement Project	

¹ Compiled by Geoff Shester for the Exxon Valdez Oil Spill Trustee Council, March 19, 2002

(CRRC) to hire a community facilitator in each of ten spill area communities as well as a region-wide community involvement coordinator CRRC is a regional organization of several tribal governments in the Chugach region, including Prince William Sound and Lower Cook Inlet Facilitators typically have been employees of the tribal government in each community The communities included Chenega Bay, Tatitlek, Valdez, Cordova, Port Graham, Nanwalek, Seldovia, Ouzinkie, Seward, and Chignik Lake The facilitators had five major purposes

- 1 **Provide results of oil spill restoration projects to the communities** Facilitators were paid to disseminate twice-monthly updates provided by the Community Involvement Coordinator about the restoration effort to members of their local communities They would also attend the Trustee Council's Annual Restoration Workshops where they could talk directly to scientists and obtain answers to their questions in a manner they could understand and share when they returned to their communities
- 2 **Facilitate communication between local communities and the Trustee Council** The project was designed to provide for regular communication between communities, facilitators, and the Trustee Council Each month, the facilitators were to meet with members of their community to request opinions, ideas for restoration projects, and concerns and then submit a monthly report to the Community Involvement Coordinator who would pass the information on to the Trustee Council Facilitators also participated in retreats and workshops to evaluate the program and provide feedback to the Trustee Council
- 3 **Promote community-based projects and involvement throughout the life of the restoration effort** Facilitators worked with the Community Involvement Coordinator and EVOS staff to help spill area communities develop competitive proposals for projects of interest to local community members Many of these projects are described in Section C below
- 4 **Serve as primary contact for EVOS in the Community** Requests for information, assistance, and input were all filtered through the facilitator who served as key contact person Principal investigators were urged to use them as their village contact
- 5 **Provide tribal input into development of GEM** Facilitators have been regularly briefed on the status of GEM planning and consulted about their priorities The project has helped fund development of natural resource management plans in several villages, with an eye towards seeing that these local plans and the GEM plan are complementary

C. Integrating Traditional Ecological Knowledge (TEK)

In 1994, the Trustee Council received its first call from a community resident to incorporate TEK of spill area residents into the restoration program Two years later, the 1996 annual restoration workshop had TEK as its theme and led to a set of protocols for incorporating TEK into restoration

projects developed by a committee of Alaska Natives and others and approved later that year by the Trustee Council The Trustee Council has provided funds each year since 1995 toward the goal of incorporating TEK into the restoration program Efforts have included

- Developing a TEK handbook and reference guide for biologists documenting the sources of TEK in the spill area and incorporating it into a western science approach
- Providing funds for CRRC to contract with TEK expert Henry Huntington He has worked directly with Alaska Native elders and hunters as well as scientists to bridge the gap between these two different approaches to understanding the natural world A result of this process is that several EVOS projects incorporate TEK directly into their data sets and results, including projects on community natural resource management, fish and seabird studies, and a series of films about Alutiiq culture (see examples below)
- Conducting two workshops to develop tribal management programs and bringing several scientists to spill area communities to share information

Examples of projects incorporating TEK as a result of Trustee Council efforts include

- Scientist Jody Seitz conducted an extensive project involving TEK Researchers
 interviewed thirty-nine spill area community members to document the historical
 distribution of forage fish such as juvenile herring, sandlance, capelin, and eulachon
 This information was mapped and provided to the Alaska Predator Ecosystem
 Experiment (APEX) and Sound Ecosystem Assessment (SEA) researchers The results
 were extremely valuable because they could not have been obtained from other
 historical sources or from current data collection efforts
- Scientist Dan Rosenberg solicited local participation from communities and conveyed results of his research on surf scoters, an important subsistence resource The project idea came from local communities Rosenberg worked with them throughout all stages of the project, from project design to writing the final report
- The Trustee Council provided funding support to the Alaska Native Harbor Seal Commission, which uses Alaska Native hunters to conduct biosampling of harbor seal tissues using lab-approved techniques In 1999, the commission reached an agreement with the National Marine Fisheries Service to co-manage harbor seal populations
- Three videos have been produced with Trustee Council funds to provide the public information about TEK and concerns about subsistence use after the oil spill. The first two, *Aluting Pride A Story of Subsistence* and *Changing Tides in Tatitlek* describe subsistence methods, interview Alaska Native people who experienced the spill first hand, show actual subsistence hunts, and illustrate the importance of subsistence in Alutiq culture. The third documents the communities of Chenega Bay and Ouzinkie in relation to the effects of the oil spill, residual oil in the spill region, and concerns about paralytic shellfish poisoning (PSP) toxins, natural toxins found in clams harvested for food. These videos were distributed at no charge to all schools in Alaska via their school districts, all spill area tribal councils, and any other library or school in the U S upon request.
- The Trustee Council funded Elders/Youth Conferences in 1995 and 1998 that brought together Alaska Native elders, youth, other subsistence users, scientists, and managers

to share ideas about subsistence issues and facilitate community involvement The Trustee Council paid for four people from each of twenty spill area communities to attend each conference Participants shared stories, voiced frustration, and asked scientists questions about subsistence issues They also developed ideas for youth to get more involved through spirit camps, internships, and educational opportunities These workshops facilitated collaboration between communities of the spill area, while concerns and ideas generated at the conference were reported to the Trustee Council

D. Use of Criminal Settlement funds on subsistence projects

A total of \$6,219,611 from the criminal settlement with Exxon, Inc was appropriated to the Alaska Department of Community and Economic Development (DCED) to implement a grant program with the purpose of restoring, replacing, or enhancing subsistence resources or other

services damaged or lost as a result of the *Excon Valdez* oil spill The grants were limited to the nine non-incorporated communities of Tatitlek, Chenega Bay, Port Graham, Nanwalek, Karluk, Chignik Lake, Chignik Lagoon, Perryville, and Ivanof Bay The three Alaska state representatives on the Trustee Council must be consulted before grants are awarded As community involvement and subsistence projects were proposed to the Trustee Council, those that could not be funded through the civil settlement were passed to this grant program, which was not as legally constrained in its scope of fundable projects. The Trustee Council funded the planning process that preceded the grant awards and provided peer review for all proposals under this program. The planning process included sending a team to visit all nine communities to brief them about the program and assist them identifying and prioritizing potential projects. To date, the state representatives of the Trustee Council have approved twenty-four projects.

- Spirit camps in Prince William Sound and Kodiak Island
- Mariculture, hatchery, and processing facilities for the villages of Tatitlek, Chenega Bay, Chignik Lake, Chignik Lagoon, Perryville, and Ivanof Bay
- Salmon enhancement projects on major subsistence runs near Nanwalek and Port Graham, and on the Kametolook River
- A weir project on the Chignik River
- A subsistence management education program in Tatitlek
- Cultural education centers and programs in Chignik Lagoon, Chignik Lake, Ivanoff Bay, and Perryville
- A preschool language program in Nanwalek
- Community smoke houses in Karluk
- A floating skiff dock in Port Graham
- Archaeological display equipment in Chignik Lake

A "Subsistence, Stewardship, and Oil Spill Recovery Gathering" in Tatitlek

E. Youth Area Watch

In 1995, the Trustee Council launched the Youth Area Watch (YAW) program with the objective of involving youth from spill area communities in the science behind the restoration

effort Under the direction of the Chugach School District and Kodiak Island Borough School District, teachers are trained annually at the Alaska Sealife Center or Kodiak College Students have participated in YAW from Cordova, Tatitlek, Valdez, Whittier, Chenega Bay, Seward, Nanwalek, Port Graham, Seldovia, Akhiok, Larsen Bay, Old Harbor, Port Lions, Kodiak City, Karluk, Chiniak and Port Lions These students (grades 7-12) work with scientists on oil spill research both in the field and in the laboratory Projects in which students have participated include

- Harbor seal biosampling
- Seabird monitoring

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- Identifying and photographing killer whales
- Analyzing chemicals found in intertidal mussels
- Collecting oceanographic data on cruises
- Sampling juvenile herring in Prince William Sound

In addition to assisting scientists, YAW students develop local restoration projects of their own that directly benefit their communities Examples of these projects include

- Black-legged kittiwake monitoring
- Constructing seal and orca skeletons for museum display
- Constructing a community greenhouse
- Teaching about composting
- Constructing a retrievable marine habitat in the community harbor

The program has also aligned itself with a major oceanographic study called the SALMON project through the University of Alaska, Fairbanks YAW students compare oceanographic forecasts and predictions with their own observations in the field to help scientists refine their computer models Teachers also provide local knowledge about climate change in the marine environment

As of 2002, 168 students have participated in the Prince William Sound and Kodiak YAW programs with total funding from the Trustee Council of over \$885,000

F Other Restoration Projects

The Trustee Council has made a concerted effort to involve local communities affected by the oil spill in the restoration program Projects funded include habitat enhancements of interest to sport and commercial fishermen, restoration of

subsistence resources, food safety testing, and public outreach and participation Here are some highlights that have resulted from the Trustee Council's effort to incorporate meaningful public participation and community involvement into the restoration program

- Chenega residents worked with the National Marine Fisheries Service to clean up twelve local mussel beds
- Local community members helped on a project to clean the Chenega area shoreline from residual *Exron Valdez* oil on five cobble-boulder armored beaches
- Alaska Native community members were paid to help NOAA conduct an extensive survey
 of lingering oil in Prince William Sound Communities identified sites important to them
 that they wanted evaluated for residual oil and participated in the survey work itself
- Waste management projects were funded in lower Cook Inlet, Kodiak Island, and Prince William Sound to address marine pollution in proximity to local communities and make improvements in local waste management infrastructure
- The Trustee Council funded a project to restore coho salmon runs, producing 2,000 to 3,000 adults for harvest in a subsistence fishery near Tatitlek
- With funding support from the Trustee Council, the Qutekcak hatchery in Seward produced over 800,000 clams during each year of a pilot project to seed clam beds for subsistence use near Port Graham, Nanwalek, and Tatitlek
- The Trustee Council contributed partial funding to rebuild the Port Graham salmon hatchery that was destroyed by fire in 1998 The hatchery provides pink, sockeye, and coho salmon for the benefit of subsistence and commercial fishermen
- The Trustee Council funded a project initiated by locals in the Native Village of Perryville to rebuild a declining coho salmon run on the Kametolook River used for subsistence
- The Trustee Council funded a project initiated by the Valdez Native Tribe in conjunction with NMFS to provide information on spot shrimp abundance for subsistence users in Prince William Sound
- The Trustee Council funded restoration and recreation enhancements along several miles of the Kenai River These included access stairs, floating docks, interpretive displays, and streambank restoration for the benefit of sportfishing and tourism
- The Trustee Council funded an assessment and restoration plan for Mariner Park in Homer, which promoted recreationally compatible use of the area by residents and tourists
- Construction of the Aluting Archaeological Repository in Kodiak was funded to protect archaeological resources and educate the public about Aluting culture In addition, the

Trustee Council provided funding to train volunteers to monitor and act as site stewards of archaeological sites on the Kenar Peninsula, Kachemak Bay, Uganik Bay, Uyak Bay, and the Chignik area of the Alaska Peninsula

- The Trustee Council provided grant funds to Chugachmiut, Inc. to develop a regional archaeological repository in Seward, local display facilities in Chenega Bay, Tatitlek, Cordova, Valdez, Port Graham, Nanwalek, and Seldovia, and traveling exhibits
- The Trustee Council funded the Port Graham Corporation to restore some salmon streams near the village of Port Graham
- The Resource Abnormalities Study trained 61 volunteers in 19 spill area communities to take samples of abnormal animals harvested for subsistence Samples were tested for hydrocarbons and human health effects at the National Marine Fisheries Service laboratory in Seattle A Resource Abnormalities Hotline was established and the project communicated information on subsistence food safety to communities

G. Annual Restoration Workshops

Every year in January, the Trustee Council holds its annual workshop free to the public, where EVOS scientists report their findings and future research directions are discussed The Trustee Council pays to bring all its researchers as well as

representatives from each community to the meetings Each year's workshop has a different theme and in 1996, the theme was community involvement Input received at these workshops is invaluable, and many research topics and priorities are developed as a result. For the 10th anniversary of the oil spill, the Trustee Council released a report to the nation and a documentary about the first ten years of oil spill effects and restoration.

H. Public Information and Outreach

The Trustee Council has produced numerous publications that inform the public about the status of injured resources, what the Trustee Council does with its funding, and other EVOS-related issues and activities Except as noted, all

documents are sent to a mailing list of over 3,000 and their availability is noticed in papers throughout the spill region Publications can also be requested from the Anchorage Restoration Office, and many can be downloaded from the Web site Public information and outreach efforts include

- Annual Status Reports document major projects and land purchases as well as results of the restoration program explained in lay terms These reports include an accounting of expenditures from the Trust Fund
- The Restoration Notebook series contains detailed natural history and recovery information written by biologists about eight specific species injured by the spill and one about the damage, recovery, and status of subsistence resources This series was distributed at no charge to all schools in Alaska via their school districts, all spill area tribal councils, and any other library or school in the U S upon request

- Since 1993, the Trustee Council has regularly published Restoration Updates, which are several page newsletters about recent Trustee Council actions, upcoming meetings, ongoing activities, and where to find more information
- Annual work plans, the Restoration Plan, Invitations for Proposals, and other program documents (e g GEM program document) are circulated for public review The Trustee Council considers all public comments on these drafts
- As needed, the Trustee Council also releases publications related to specific projects such as a set of publications about each region of the spill area and the specific projects that have benefited each region
- For three years, the Trustee Council funded a production of "Alaska Coastal Currents" a two-minute program about restoration research that aired several times weekly on public radio, accompanied by columns in several regional newspapers By working through the media, these reports created an avenue for outreach to an even broader community
- The Trustee Council has a Web site easily accessible to anyone with Internet access and designed for a variety of users from scientists to government resource managers to high school students. The site covers facts about the oil spill, restoration projects, habitat acquisition, and the GEM program and has many major publications and documents that can be downloaded. Information on funding and upcoming events is regularly posted. The URL is http://www.oilspill.state.ak.us
- The Public Advisory Group is composed of seventeen representatives of various stakeholder groups including fishermen, subsistence users, and the public at large This group provides direct input to the Trustee Council and has visited many spill area communities on annual field trips
- All Trustee Council and Public Advisory Group meetings are advertised, free, and open to the public Those unable to attend any meeting can listen and participate via teleconference Public comment periods are scheduled at each Trustee Council meeting and Public Advisory Group meeting
- Community meetings have been an important part of the restoration process since the day of the oil spill These meetings have addressed a wide variety of topics including public participation, the Restoration Plan, TEK, waste management, the GEM program, archaeology, community involvement, and science updates Over the years, the Trustee Council has sponsored public meetings in the villages of Cordova, Juneau, Chenega, Kodiak, Homer, Valdez, Seward, Seldovia, Tatitlek, Whittier, Anchorage, Fairbanks, Chignik Lagoon, Chignik Lake, Ouzinkie, Port Lions, Karluk, Larsen Bay, Akhiok, Old Harbor, Port Graham, Nanwalek, Kenai/Soldotna, and Perryville

APPENDIX D. GULF OF ALASKA ECOSYSTEM MONITORING AND RESEARCH (GEM) DATABASE

D 1 Current Information Gathering

1

D.1 1 The Gap Analysis Database Introduction

The conceptual foundation in Chapter 2 has been shaped largely by currently available scientific information Much of this information is derived from the monitoring and research activities conducted in the GOA and adjacent waters during the

past 100 years Information from these activities has been included in a database titled "Ongoing and Historical Monitoring and Research Activities in the Gulf of Alaska and Adjacent Waters" This database is referred to as the "gap analysis database" because it is used as a tool to assess past and current activities, to set priorities, and promote collaboration in filling important "gaps" in information, while avoiding duplication Compiling this comprehensive database is a challenge in itself, given multiple funding sources and the dynamic nature of various appropriations processes, as well as a lack of information about the relationships among various programs and projects

The database includes both ongoing and historical projects concerned with information gathering, processing, and applications in resource management and other areas of marine science. Projects in the database include readily identifiable research and monitoring activities, such as the NMFS biennial (triennial) trawl survey, the International Pacific Halibut Commission longline survey, and the National Weather Service data buoy network. The record for each project includes information on project purpose, types of data, expected project duration, contact information, Web site, and latitude and longitude for field activities. Not all categories of information in each record are complete, but a description of the basic functions of each project is available in each record. Because the "project" was not intended to be a standard unit for defining effort in marine research, the broad analysis below should be considered a qualitative comparison of the relative amounts of effort devoted to each category. The database is available in File Maker Pro, but can be made available in other formats, such as Excel and Access.

D 1 2 The Gap Analysis Database Summary

Projects in the gap analysis database have been categorized as either monitoring or synthesis and research For the purposes of the gap analysis, monitoring is routine data gathering based on assumptions about ecosystem behavior or how the measures capture system behavior Monitoring is not expected to be completed within a fixed time frame Examples of monitoring measurements are salinity, temperature, concentration of DDT, and populations of species at seabird colonies For the purposes of the gap analysis, synthesis and research are defined as time-limited activities that investigate relationships among ecosystem components with the use of data according to a specific experimental design. The synthesis and research category includes retrospective analysis, modeling, ecosystem process studies, and data management and information transfer. Each general activity category is further classified into six areas of study

1 Birds, fish, and shellfish,

APPENDIX D

- 2 Physical and biological oceanography,
- 3 Freshwater water quality,
- 4 Contaminants,
- 5 Multiple topics, and
- 6 Other

D.1 2.1 Monitoring

The majority (58%) of 291 projects in the gap analysis database as of May 2001 are classified as monitoring functions Most of the monitoring functions address commercially, culturally, or socially important large animals, as identified below in percentages of all projects in the database

- 20% fish and shellfish,
- 9% multiple topics,
- 7% mammal, and
- 4% seabird

The balance of the monitoring projects are devoted exclusively to the small plants and animals and the physical and chemical measurements, shown below as percentages of all projects in the database

- 15% physical oceanography with some chemical and biological,
- 1% freshwater,
- 1% biological oceanography,
- 1% contaminants, and
- <1% other</p>

Monitoring projects for fish and shellfish are largely directed at single species or closely related aggregates of species such as salmon, halibut, rockfish, and crab Mixed studies combine large animals, smaller fish, plankton, and sometimes contaminants, although detecting trends in the abundance of large animal species appears to be the primary purpose of the mixed surveys Physical oceanography projects are dominated by satellite telemetry

The Alaska Department of Fish & Game (ADF&G) fields the largest number of fish and shellfish projects in the northern GOA, primarily for salmon and crab and, to a lesser extent, rockfish and other species Long annual time series data collected by ADF&G are available from ADF&G for salmon and crab catches and for salmon spawners (escapements) in most major watersheds Long annual time series exist for trawl survey data for shrimp, groundfish, and crab Other substantial salmon data sets are age, weight, and length of adult salmon in catches Other ADF&G projects record characteristics such as genetics, presence of disease, and other biological data

More detailed information is available in Section D 2 of this appendix and the gap analysis database

D.1.2.2 Synthesis and Research

About 42% of the projects in the gap analysis database are synthesis and research activities These activities are listed below as percentages of all projects in the database

- 22% data management and information transfer,
- 11% retrospective analysis,
- 5% modeling, and
- 3% ecosystem process studies

The synthesis and research activities are further defined below as numbers of projects, because the small number of projects in some categories makes comparison of percentages problematic

Data Management and Transfer

- 21 physical oceanography and atmospheric data,
- 2 benthic intertidal,
- 1 biological oceanography,
- 8 bird,
- 5 contaminant,
- 7 fish,
- 8 mammal,
- 6 mixed tissue archives for large animals and biological and physical data, and
- 2 freshwater and watershed oriented

Retrospective Analysis

- 6 physical oceanography,
- 8 mixed (physical and biological),
- 1 mammal,
- 1 human use (subsistence),
- 9 fish,
- 2 contaminant,
- 2 bird,
- 1 biological oceanography, and

1 benthic intertidal

Modeling

- 1 benthic intertidal,
- 3 mammal,
- 1 mixed (coupled biophysical), and
- 8 physical oceanography

Ecosystem Process Studies Relatively few (nine) ecosystem process studies are currently ongoing in the GOA Four are being conducted in Glacier Bay in the more southern end of the GOA Others are more relevant, looking at oceanographic forcing of primary productivity and productivities of fish

D 1 3 Projects of Interest to GEM

The federal government is the primary funding source for the current information gathering programs of interest to the development of the GEM program, with substantial funding also provided by state government, foreign governments, and non-governmental organizations. The work is conducted within programs and projects too numerous to list here, however, a reference on the specific agencies and programs is provided in Section D 2 of this appendix. Relevant projects cover three broad categories.

- 1 Bird, fish, and mammal data and some human impacts associated with their harvests, collected by the primary fish and wildlife resource management entities,
- 2 Biological and other oceanographic observations, collected as part of major research efforts, and
- 3 Physical and chemical characteristics of waters and habitats collected by the primary state and federal agencies providing environmental monitoring

Information on birds, fish, and mammals in watersheds and the nearshore marine areas is relatively abundant Because data were collected through time for a variety of purposes and with a variety of methods, however, the usefulness for a long-term program such as the GEM program will need to be assessed on a case-by-case basis Ongoing programs collecting animal data of particular interest to the GEM program are continuous, annual time series (in excess of 50 years) on commercial species such as salmon, fur, seals, and halibut, and shorter time series (some discontinuous) of around 30 to 50 years on other species of fish and shellfish, seabirds, and marine mammals Observations on marine-related terrestrial animals and vegetation are available from grid surveys in the Chugach National Forest

The longest continuous-time series of physical oceanographic measurements (temperature and salinity) in the GEM region is located outside the mouth of Resurrection Bay near Seward Shorter time series of other variables have been collected at this location, known as Gulf of Alaska 1 (GAK1), by the Institute of Marine Science (IMS), University of Alaska Fairbanks (UAF), during the last three decades Other ongoing oceanography programs initiated within the last twenty years provide important data sets The Fisheries and Oceanography Coordinated Investigations (FOCI), initiated in the 1980s, was the first program in the western GOA to model physical oceanographic processes to understand changes in annual abundance of a marine fish species, pollock Initiated in the 1990s, the Ocean Carrying Capacity (OCC) program is collecting data on the distribution of juvenile salmon on the continental shelf in the GOA and Bering Sea Also initiated in the 1990s, the Global Ocean Ecosystem Dynamics (GLOBEC) program combines retrospective studies of existing data with observations of plankton, physical and chemical oceanography, and juvenile salmon abundance in PWS and the adjacent continental shelf and shelf break GLOBEC is of particular interest to the GEM program because it seeks to understand how natural forces bring about changes in biological productivity, including that of salmon

Other longer time series of observations of biological and physical oceanography from ongoing programs in the marine environment include the work of the Japan Fisheries Agency, which has been taking oceanographic observations in the GOA since the 1950s Observations of the distributions of North American and Asian stocks of salmon and catches of groundfish species (pollock and cod) in the GOA by the International North Pacific Fisheries Commission and its successor, the North Pacific Anadromous Fish Commission (NPAFC), are extensive, however annual time series are not all complete Although located very far to the south in the GOA, Canada's Ocean Station P continues to provide a continuous record of oceanographic observations now more than five decades long

Daily time series (some discontinuous) of oceanographic and atmospheric data relevant to GEM planning are available, with most of the observations from the past decade An array of buoys in the northern GOA operated by the National Weather Service (NWS) and the National Oceanographic Data Center (NODC) of NOAA provides atmospheric and physical oceanographic measurements of relevance to GEM planning In addition, the satellite remote sensing projects of both NOAA and the National Aeronautics and Space Administration (NASA) provide cloud cover and sea surface observations throughout the GEM region

Of immediate interest to GEM are ongoing projects to characterize the physical and chemical characteristics of waters and habitats collected by the primary environmental monitoring concerns US Geological Survey (USGS), Alaska Department of Environmental Conservation (ADEC), and US Environmental Protection Agency (EPA) Long-time-series measurements of freshwater runoff from stream gauges in major rivers of Southcentral Alaska are available from USGS, although the future of this program appears to be in doubt ADEC has ongoing time series of water quality in the GEM region and is responsible for implementation of the EPA stations for the marine Environmental Monitoring and Assessment Program (EMAP) in the northern GOA

D.2 List of Project Titles by Organization and Record Number Note that projects shared among agencies may be listed more than once

Alaska Department of Environmental Conservation (ADEC)

- 184 Monitoring Programs for Paralytic Shellfish Poison (PSP) in King Crab, Dungeness Crab and Tanner Crab
- 236 Certified Shellfish Beaches
- 239 Contaminated Sites Database
- 240 Leaking Underground Storage Tank (UST) Sites in Alaska

Alaska Department of Fish and Game (ADF&G)

- 153 Sonai Enumeration of Returning Adult Salmon
- 154 Catalog of Waters Important for the Spawning, Rearing, or Migration of Anadromous Fishes
- 155 Groundfish Port Sampling
- 156 Whiskers (Seals and Sea Lions)
- 157 Harbor Seal Survey
- 158 Weirs and Counting Towers for Enumeration of Returning Adult Salmon, Escapement
- 159 Aerial / Foot Surveys of Spawning Streams, Salmon Escapement
- 160 Fry / Smolt Outmigration
- 161 Salmon AWL (Age, Weight, Length)
- 162 Rockfish Assessments Southeast Alaska
- 163 Rockfish Habitat Study Southeast Alaska
- 164 Rockfish Jig Survey Historical Dataset, 1980-1984
- 165 Sablefish Assessments, Southeast Alaska
- 166 Catch Sampling Southeast Alaska (Rockfish, Sablefish, Lingcod), Prince William Sound and Lower Cook Inlet (Rockfish, Sablefish, Pacific Cod, Pollock), Kodiak and Aleutian Islands (Rockfish)
- 167 Fish Tickets for Shoreside Landings
- 168 Limnology Lower Cook Inlet
- 169 Herring Dive Surveys Prince William Sound and Southeast Alaska
- 170 Herring Aerial Surveys Statewide
- 171 Herring Catch Sampling Statewide
- 172 Pot Surveys Southeast Alaska King Crabs
- 173 Trawl Surveys Prince William Sound, Lower Cook Inlet, and Alaska Peninsula for King and Tanner Crabs
- 174 Dive Surveys Southeast Alaska Clams, and Sea Cucumbers
- 175 Shellfish Dockside Sampling Statewide
- 176 Shellfish Catch Enumeration Statewide
- 177 Trident Basin Water Temperature
- 178 Shellfish Onboard Observers
- 179 Kodiak Red King Crab Tags
- 180 Gulf Pot Surveys Crabs
- 181 Shrimp Trawl Surveys
- 183 Subsistence Harvest
- 185 Scallop Dredge Survey Prince William Sound and Cook Inlet
- 186Tanner Crab (Cook Inlet), Kıng Crab (Cook Inlet), Dungeness Crab (Prince William
Sound), and Pot Shrimp (Prince William Sound) Tagging Historical Data Sets

- 187 Fish Pathology Disease History Database
- 188 Coded Wire Tag Database
- 189 Atlas to the Catalog of Waters Important for the Spawning, Rearing, or Migration of Anadromous Fishes
- 190 Sport Fish Weils and Sonars
- 191 Coded Wire Tagging (CWT) of Hatchery and Selected Wild Salmonid Stocks
- 192 Oil Spill Health Task Force
- 193 Sociopolitical Consequences of Offshore Oil Development
- 194 Community Profile Database
- 195 Population Survey of Organochlorine Contaminants in Alaskan Steller Sea Lions
- 196 Steller Sea Lion Surveys
- 197 Su-Hydro Beluga Whale Survey
- 235 Kıtoı Bay Monitoring
- 254 Enumeration and estimation of commercial salmon harvests
- 255 Enumeration and estimation of sports salmon harvests
- 256 Shelikof Strait bottomfish trawl survey
- 276 Community Pattern Assessment
- 282 Abundance and Trend of Harbor Seal Populations Haulout patterns and movement
- 283 Abundance and Trend of Harbor Seal populations Index site counts at Tugidak Island
- 285 Harbor Seal Habitat

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- 286 Health and Condition of Harbor Seal populations
- 287 Food Habits of Harbor Seals
- 288 Life History/General Biology of Harbor Seals
- 289 Vital Rates of Harbor Seals
- 291 Measuring Abundance and Trend of Harbor Seal Populations Glacial Survey Methodology

ADF&G and National Marine Fisheries Service (NMFS)

- 282 Abundance and Trend of Harbor Seal Populations Haulout patterns and movement
- 291 Measuring Abundance and Trend of Harbor Seal Populations Glacial Survey Methodology

ADF&G and National Marine Mammals Lab (NMML)

- 288 Life History/General Biology of Harbor Seals
- 289 Vital Rates of Harbor Seals

Alaska Department of Health and Social Services (ADHSS)

- 182 Use of Traditional Foods in a Healthy Diet in Alaska Risks in Perspective
- 198 Twenty Years of Trace Metal Analysis of Marine Mammals Evaluation and Summation of Data from Alaska and Other Arctic Regions

Alyeska Service Corporation

253 Valdez Arm Environmental Monitoring

Center for Alaskan Coastal Studies

270 Coast Walk program for Kachemak Bay

Cook Inlet Keeper

- 237 Lower Kenar Peninsula Watershed Health Project
- 238 Citizens Environmental Monitoring Program (CEMP)

Faculty of Fisheries Hokkaido University (Japan)

293 Cruise of the T/S Oshoro Marri in the Gulf of Alaska

Fisheries and Oceans Canada

- 225 Line P / Station P
- 228 High Seas Salmon Program
- 229 A continuous plankton recorder monitoring program for the eastern North Pacific & southern Bering Sea (also UAF 257)

International Pacific Halibut Commission (IPHC)

030 Pacific Halibut Stock Assessment

Moss Landing Marine laboratories (MLML)

200 Dissolved Iron Data Set for the World Ocean from Moss Landing Marine Laboratories

National Aeronautics and Space Administration (NASA)

- 031 Sea-viewing Wide Field-of-view Sensor (SeaWiFS)
- 032 Moderate Resolution Imaging Spectroradiometer (MODIS)
- 033 Earth Observing System Data Information System (EODIS)
- 034 Advanced Earth Observation Satellite NASA Scatterometer (ADEOS-NSCAT)
- 035 Sensory Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS)
- 036 Advanced Very High Resolution Radiometer (AVHRR)
- 037 Advanced Earth Observing Satellite (ADEOS) II Sea Winds 1B
- 038 AIRS/AMSU/MHS
- 039 EOS ALT
- 040 Quick Scatterometer (QuikSCAT) SeaWinds Instrument
- 041 TOPEX/Poseidon
- 042 Coastal Zone Color Scanner (CZCS)

National Environmental Satellite, Data and Information Service (NOAA-NESDIS)

- 005 General Circulation and Tide Measurements / Model Output for the Coastal U S
- 007 Advanced Very High Resolution Radiometer (AVHRR)
- 044 Sea Surface Temperature 14 Km Analysis (Local-Scale) from NOAA Series AVHRR Data
- 045 Arctic and Southern Ocean Sea Ice Concentration
- 046 Global Temperature-Salinity Pilot Project (GTSPP) Program Database
- 047 NOAA Marine Environmental Buoy Database
- 048 Sea Surface Temperatures at Gulf of Alaska Light Stations (1959-1967)
- 049 US Coastal Advanced Very High Resolution Radiometer (AVHRR) Data Products

- 050 Robinson-Bauer Numerical Atlas of Monthly Surface Layer
- 051 Intertidal Organisms and Habitats (F030) Data (1974-1980)
- 052 Hering Survey Population Density and Distribution (F057) Data (1976-1977)
- 053 Marine Birds of Coastal Alaska and Puget Sound (F031, F033, F034, F038, F040, F041)
- 054 The 14-km SST Fields from the NOAA TIROS/N Satellite Series
- 231 Sea Level Data, Wind Speed, and Significant Wave Height from Satellite Altimetry

National Institute of Standards and Technology (NOAA---NIST)

- 111 National Biomonitoring Specimen Bank (NBSB)
- 112 Benthic Survey and Mussel Watch
- 279 Marine Monitoring Quality Assurance Program

National Marine Fisheries Service (NOAA--NMFS)

- 008 Fishes of Alaska (book)
- 009 Winter Assessment of Shelikof Strait Spawning Pollock
- 010 North Pacific Domestic Groundfish Observer Database
- 011 Steller Sea Lion Count Database
- 012 Pacific Salmon Genetic Database Development
- 018 NMFS Longline Survey of the Aleutian Region, Bering Sea, and Gulf of Alaska
- 019 Life History Monitoring of Pink Salmon Biology
- 020 North Pacific Ocean Salmon Ecology
- 021 Retrospective Studies
- 022 Monitoring
- 055 Long Term Population Monitoring of Natural Populations of Seven Species of Salmonids
- 056 Comparisons of Walleye Pollock, Theragra chalcogramma, Harvest to Steller Sea Lion, Eumetopias jubatus, Abundance in the Bering Sea and Gulf of Alaska
- 057 Annual Survey of Cook Inlet Beluga Whales
- 058 Biennial Survey of Eastern North Pacific Ocean Gray Whales
- 059 Abundance of Pelagic Delphinids and Harbor Porpoise off the Coast of Alaska
- 060 MMPA Harbor Seals minimum population estimates
- 061 Sablefish Longline Survey
- 062 Ichthyoplankton Database
- 063 West Gulf of Alaska Pacific Cod Survey
- 064 Gulf of Alaska Biennial Survey (formerly Gulf of Alaska Triennial Survey)
- 065 Japan-US Cooperative Longline Survey of the Aleutian Region, Bering Sea, and Gulf of Alaska (also includes the data from the ongoing NMFS longline survey conducted in same general area)
- 066 Bycatch, Utilization, and Discards in the Commercial Groundfish Fisheries of the Gulf of Alaska,m Eastern Bering Sea, and Aleutian Islands
- 067 Shellfish and Groundfish Pathogens
- 068 Shelikof Strait FOCI
- 069 Gulf of Alaska Thornyhead Rockfish Stock Assessment
- 070 Ocean Surface Current Simulator (OSCURS)
- 071 North Pacific Foreign Fishery Groundfish Observer Database
- 072 Marine Mammal Protection/Endangered Species Acts Compliance

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- 073 Cook Inlet Set and Drift Gillnet Marine Mammal Observer Project
- 074 Maime Mammal Health and Stranding Response Piogram (MMHSRP) Data Base
- 075 National Marine Mammal Tissue Bank (NMMTB)
- 077 Alaska Marine Mammal Stock Assessments
- 078 Pacific Marine Mammal Stock Assessments
- 079 Master Oceanographic Observational Data Set (MOODS), Extensive Oceanographic Profile Data, All Oceans
- 080 Genetic Stock Identification (GSI) of Pacific Salmon in Mixed Stock Fisheries
- 081 Manne Invertebrate Pathology
- 082 Marine Mammal Health and Stranding Response Program (MMHSRP) Monitoring and Quality Assurance
- 083 Fin Rot
- 084 Fish Pathology
- 085 U.S. Commercial and Recreational Fisheries Statistical Data from NOAA National Marine Fisheries Service, Fisheries Statistics and Economics Division
- 086 West Coast Upwelling Indices Data Files
- 103 Bering Sea FOCI
- 137 Checklist for Bird Observations from the Eastern North Pacific Ocean, 1955 1967
- 226 Rockfish Genetic Database Development
- 245 Chiniak Bay Current Meter Mooring
- 246 Hatch tuning of Tanner crabs (Chionoecetes bairdi) in Kodiak
- 247 Trident Basin (Kodiak) Extended Water temperature and Secchi Depth
- 248 Womens Bay Dive Logs and Crab Observations
- 249 Eastern Bering Sea Temperature Monitoring
- 268 Pavlof Bay Temperature Recording Mooring
- 269 Pavlof Bay Annual Shrimp Trawl Survey
- 277 Biomonitoring Component of the MMHSRP
- 278 Stranding Network--Marine Mammal Health and Stranding Response Program
- 280 Marine Mammal Analytical Quality Assurance
- 284 Stock Identification of Harbor Seal populations
- 290 Human Interactions with Harbor Seals

National Ocean Service (NOAA-NOS)

- 001 National Status and Trends Data Base
- 023 GLOBEC Northeast Pacific Program Retrospective Analysis of Growth Rate and Recruitment for Sablefish, Anoploma fimbria, from the Gulf of Alaska and the California Current System
- 024 GLOBEC Northeast Pacific Program Analysis of Ichthyoplankton Abundance, Distribution, and Species Associations in the Western Gulf of Alaska
- 025 GLOBEC Northeast Pacific Program Long-term Variability in Salmon Abundance in the Gulf of Alaska and California Current Systems
- 026 GLOBEC Northeast Pacific Program A Retrospective Study of Top Predator Trophic Positions, Productivity, and Growth in the Gulf of Alaska for 1960-75 and 1975-90

- 027 GLOBEC Northeast Pacific Program Patterns, Sources and Mechanisms of Decadal-Scale Environmental Variability in the Northeast Pacific A Retrospective and Modeling Analysis
- 028 GLOBEC Northeast Pacific Program Remote Sensing of the Northeast Pacific Retrospective and Concurrent Time Series Analysis Using Multiple Sensors on Multiple Scales
- 029 GLOBEC Northeast Pacific Program Physical-Chemical Structures, Primary Production and Distribution of Zooplankton and Planktivorous Fish on the Gulf of Alaska Shelf
- 043 Marine Mammals of Coastal Alaska Data (1976-1991) Census (F025), Activity (F026) Pathology (F127)
- 087 Fish Kills in Coastal Waters 1980-1989
- 088 Development of an Ecological Characterization of the Kachemak Bay Watershed
- 089 Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) Algorithms
- 090 National Benthic Surveillance Project
- 091 Mussel Watch Project
- 092 Specimen Banking Project
- 093 Using Cytochrome P450 to Monitor the Aquatic Environment Initial Results from Regional and National Surveys Marine Environmental Research 34 195-
- 094 Advanced Very High Resolution Radiometer (AVHRR) Algorithms
- 199 GLOBEC Northeast Pacific Program Retrospective Analysis of Northeast Pacific Microzooplankton
- 224 GLOBEC Northeast Pacific Program Coupled Bio-Physical Models for the Coastal Gulf of Alaska
- 233 GLOBEC Northeast Pacific Program Coupled Bio-physical Models for the Coastal Gulf of Alaska
- 234 GLOBEC Northeast Pacific Program Retrospective Analysis of Northeast Pacific Microzooplankton A Window on Physical Forcing of Food Web Structure
- 251 Kachemak Bay National Estuarine Research Reserve KBNERR

National Weather Service (NOAA-NWS)

- 004 Buoy Observations
- 095 Coastal-Marine Automated Network (C-MAN)
- 096 Moored Buoys
- 097 SeaBreeze CD-ROM

Ocean and Atmospheric Research (NOAA-OAR)

- 006 The Comprehensive Ocean-Atmosphere Data Set (COADS)
- 098 Distribution and Elemental Composition of Suspended Matter in Alaskan Coastal Waters
- 099 Long-Term Variations in Alaskan Salmon Abundance Determined from Sediment Core Analysis
- 100 On Exchange of Water Between the Gulf of Alaska and the Bering Sea through Unimak Pass
- 101 Gulf of Alaska CTD Data Collected under the Environmental Services Data and Information Management (ESDIM) Data Rescue
- 102 Bering Sea and Gulf of Alaska Winds (1946-1982)

- 104 Revised Analysis of Allozyme Variation in Asian and Alaskan Pink Salmon
- 105 Intra-and Interspecific Genetic Valiation of mtDNA in Rockfish (Sebastes)
- 106 Physical-Chemical Structures, Primary Productivity and Distribution of Zooplankton and Planktivorous Fish on the Gulf of Alaska Shelf A GLOBEC Monitoring Proposal Project Energetics Project
- 107 Historical Analysis of Sockeye Scales
- 108 Retrospective Analysis of the Effects of Trawling on Benthic Communities in the Gulf of Alaska and Aleutian Island Region
- 109 Long-Term Variations in Alaskan Sockeye Salmon Abundance
- 110 Monitoring Transport in the Alaska Coastal Current A Feasibility Study

National Science Foundation

- 113 Improvement in the Curation of the University of Alaska Frozen Tissue Collection
- 114 Flora of the Benthic Marine Algae of Alaska Phase 1, An Inventory of the Existing Collections
- 115 Flux and Fate of Sediment and Water from Small Mountainous Rivers to the Continental Margin the Gulf of Alaska Example
- 116 Gulf of Alaska Recirculation Study (GARS)
- 117 Upper Ocean Circulation in the Subpolar and Northern Subtropical Pacific

Pacific States Marine Fisheries Commission (PSMFC)

232 Salmonid Coded Wire Tag Database

Prince William Sound Regional Citizens' Advisory Council (PWSRCAC)

241 Long-Term Environmental Monitoring Program

Prince William Sound Science Center (PWSSC)

201 Long-term Killer Whale Database

US Department of the Interior (DOI)

- 002 Age and Length Characteristics of Rainbow Trout in Selected Streams
- 003 Alaska Seabird Inventory and Monitoring Plan
- 013 Sea Otter Biomonitoring Program
- 014 Seabird Tissue Archival and Monitoring Project (STAMP)
- 015 Bald Eagle Database
- 016 Coastal Studies
- 017 Hydrologic Data Collection and Investigations
- 076 Alaska Marine Mammal Tissue Archival Project (AMMTAP)
- 118 Forage Fish Assessment of the Cook Inlet Oil and Gas Development-Affected Areas
- 119 Kachemak Bay Experimental and Monitoring Studies
- 120 The Alaskan Frozen Tissue Collection and Associated Electronic Database A Resource for Marine Biotechnology
- 121 Spring Survey of Steller's Eiders in the Gulf of Alaska
- 122 Monitoring and Evaluating Effects on Seabird Colonies in Potential Oil and Gas Development Areas

- 123 Sedument Quality in Depositional Areas of Shelikof Strait and Outermost Lower Cook Inlet
- 124 Mapping of Cook Inlet Tide Rips Using Local Knowledge and Remote-Sensing Imagery Techniques
- 125 Historical Data Sets for Prince William Sound Ecosystem Implications of Changing Climate
- 126 Ecological Processes Underlying the Large Spatial and Temporal Variance in Distribution and Abundance of Species in Glacier Bay Part 1 The Spatial Distribution of Small Schooling Fish and Associated Predators in Glacier Bay, and Their Relationship to Oceanographic and Bathymetric Parameters
- 127 Seabird Population Dynamics and Food Supply Assessing Long-Term Changes in Alaska Marine Ecosystem
- 128 Prince William Sound Ecosystem Initiative
- 129 Harbor Seal Monitoring in Glacier Bay National Park and Preserve
- 130 Pacific Coho Salmon Study
- 131 Marine Mammal Marking, Tagging and Reporting Program
- 132 Sea Otter Stock Assessment
- 133 Alaska Seabird Inventory and Monitoring Plan Annual Monitoring Sites
- 134 Beringian Seabird Colony Catalog
- 135 Wintering Marine Bird and Mammal Surveys
- 136 Nongame Migratory Bird Project Boat Survey Data in Bays and Sounds
- 139 Genetics Research for Characterizing Alaskan Salmonid Populations
- 140 Seasonal Movements and Pelagic Habitat Use of Alaska Seabirds Determined by Satellite Telemetry
- 141 Fishes of Alaska
- 142 Design and Implementation of a Seabird Monitoring Database for the North Pacific
- 143 Assessment of Sea Otter Population Status in Alaska
- Ecological Processes Underlying the Large Spatial and Temporal Variance in Distribution and Abundance of Species in Glacier Bay Part 1 The Spatial Distribution of Small Schooling Fish and Associated Predators in Glacier Bay, and Their Relationship to Oceanographic and Bathymetric Parameters
- 145 Population Status and Ecology of Shorebirds in Alaska
- 146 Using Genetic Markers to Determine Population Status and Management Strategies of Mammals
- 147 Pelagic Seabird Atlas of the North Pacific
- 149 IHN Virus Strain Differentiation and Field Epidemiology in Salmonids
- 150 Watershed Ecosystem Studies
- 151 Marine Geology of Benthic Biohabitats in Glacier Bay, Alaska
- 152 Cook Inlet Basin Study Unit
- 223 Alaska Seabird Inventory and Monitoring Plan Periodic Monitoring Sites
- 227 Population Ecology of Seabirds on Middleton Island, Alaska
- 230 Process Structuring Coastal Marine Communities in Alaska DOI Trust Resources
- 242 National Wetlands Inventory (NWI)
- 243 Pelagic Distribution and Abundance of Seabirds and Marine Mammals

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- 244 Seabild Population Dynamics and Food Supply Assessing Long-Term Changes in Alaska Marine Ecosystem
- 252 Management of Subsistence Resources in Alaska
- 271 Alaska Seabird Colony Catalog Database
- 272 Subsistence Haivest of Migratory Birds
- 273 Distribution and Abundance of Kittlitz's Murrelets and Black Oystercatcher in western PWS
- 274 Harbor seal surveys on the coast of Kenai Fjords National Park, 1979 to 1998
- 275 Human Impacts on Nesting Shorebuds on the Coast of Kenai Fjords National Park
- 281 Assessment of Sea Otter Population Status in Alaska

US Global Change Research Program (USGCRG)

- 214 Repeat Hydrography and Special Analysis Centre
- 215 One-Time Survey Cruise 17N
- 216 Subsurface Floats
- 217 Surface Drifting Buoys
- 218 Joint Archive for Shipboard Acoustic Doppler Current Profilers (ADCP)
- 219 Upper Ocean Thermal Data
- 220 Sea Surface Salurity
- 221 Surface Meteorological Data and Surface Fluxes
- 222 Tide Gauges

United Nations (UN)

- 210 Permanent Service for Mean Sea Level (PSMSL) and Global Sea Level Observing System (GLOSS)
- 211 Ships of Opportunity Program (SOOP) Low Density Expendable Bathythermograph Network (XBT)
- 212 Array for Real-Time Geostrophy (ARGO)
- 213 Pacific Basinwide Extended Climate Study (P-BECS)

University of Alaska Fairbanks (UAF)

- 202 Data set for the NOAA Advanced Very High Resolution Radiometer Satellite (AVHRR)
- 203 Advanced Very High Resolution Radiometer (AVHRR) Imagery From UAF HRPT (High Resolution Picture Transmission) Station
- 204 MSL-622 Satellite Oceanography Project
- 205 Institute of Marine Science, University of Alaska Fairbanks Database, Physical, Chemical, Biological and Geological Data
- 206 Isotope Ratio Studies of Marine Mammals in Prince William Sound
- 207 GAK 1 TIME SERIES
- 257 A continuous plankton recorder monitoring program for the eastern North Pacific & southern Bering Sea
- 258 A basin-wide retrospective analysis of growth and survival patterns in pink and chum salmon
- 259 Pilot study on the use of airborne lidar and digital imagery for surveys of epipelagic fish and associated biological features in the southeastern Bering Sea and North Pacific Ocean

- 260 Assessing the physiological stress of Steller sea lions using fecal hormone analysis
- 261 Determining survival and long-term foraging behavior of juvenile Steller sea lions through implanted, satellite-linked mortality transmitters
- 262 Availability and use of prey by Steller sea lions in the Kodiak area
- 263 Process modeling of the Alaska Coastal Current
- 264 Physical forcing of marine productivity monitoring moorings on the Gulf of Alaska shelf
- 265 Estimating seabird diets using fatty acids protocol development and testing of ReFER hypotheses as tested in the Bering Sea
- 266 A cooperative effort between Alaska Native people & federal agencies on marine mammal & bud stranding
- 267 Harbor seal biological sampling expanding the scope of the subsistence archival project Cook Inlet, Kodiak, Aleutian Islands

University of Miami

208 University of Miami TIROS-N-NOAA AVHRR Level 1b

University of Rhode Island

209 University of Rhode Island Advanced Very High Resolution Radiometer (AVHRR) Level 1b

US Department of Agriculture – Forest Service (USFS)

250 Grid Survey System

US Department of the Navy

292 Rutgers University and the U.S. Navy Hyperspectral Coastal Ocean Dynamics Experiment a prototype ocean observing system

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APPENDIX E. GLOSSARY OF EXISTING AGENCY PROGRAMS AND PROJECTS

Introduction

Most major information-gathering programs of the North Pacific can be divided into three major categories large animals or macrofauna (birds, mammals, fish, shellfish), oceanography

(physical, chemical, geological and biological) and human use (land and water use, water quality, contaminants) The Alaska Department of Fish and Game (ADF&G), the U S Department of the Interior (USDOI) and the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) are the primary monitoring agencies for macrofauna Sampling efforts for macrofauna are typically focused on regional or smaller areas, including PWS, Cook Inlet, Kodiak and the Alaska Peninsula The National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) are the primary sources of oceanographic data, including data on zooplankton, phytoplankton and primary productivity Notably absent are monitoring or assessment programs for large plants, such as kelp and other large marine algae Oceanography programs often include the North Pacific region as part of a larger program The U S Environmental Protection Agency (EPA), U S Forest Service (USFS), Alaska Department of Environmental Conservation (ADEC) and Alaska Department of Natural Resources (ADNR) all monitor certain human uses of lands and waters and the impacts of human use on resources, as do several nongovernmental organizations

A summary of the major programs conducted by the United States, State of Alaska, transboundary organizations and nongovernmental organizations follows and is current as of August 2001 and although extensive, should not be considered complete These programs have been incorporated into a database (see Appendix D), which will include projects that are actively collecting data as well as projects that are no longer active Inactive projects contain considerable valuable historical information relevant to the production of plants and animals in the North Pacific region ' Appendix A contains a reference list of commonly used acronyms and web site links for these programs and others

State of Alaska

Alaska Department of Community and Economic Development (ADCED)

Each year, the department's Division of Tourism publishes Alaska Visitor Arrivals and the Alaska Visitor Industry Economic Impact Study These studies are based on secondary data No field surveys have been conducted since the 1993-1994 Alaska Visitor Statistics Program III

Alaska Department of Environmental Conservation (ADEC)

The Division of Air and Water Quality (AWQ) is concerned with public health and environmental problems throughout Alaska The year 2000 statewide water quality assessment describes the nature, status and health of Alaska's waters, and identifies restoration and
protection needs The AWQ also monitors ambient water quality through the State Water Discharge Permits and Certification program and the Non-Point Source Water Pollution Control program Discharge permits, such as that for the Alyeska Marine Terminal in Valdez, require that the permitee monitor both surface water and ground water for such contaminants as petroleum, PCBs and heavy metals Monitoring data from about 3,000 sites statewide (1,000 of which are in the oil spill region) are stored in the Contaminated Sites Database The Non-Point Source Water Pollution Control program keeps a list of "impaired water bodies," that is, water bodies which do not meet state water quality standards ADEC also funds non-point source water pollution monitoring projects with funds authorized by Congress under Section 319 of the Clean Water Act and administered by the Environmental Protection Agency (EPA)

ADEC has awarded EPA Section 319 funds to several citizen-based monitoring programs, such as the Cook Inlet Keeper's water monitoring program in lower Cook Inlet, the Kenai Watershed Forum, and wetlands studies by the Nature Conservancy In partnership with other agencies, ADEC is developing a bioassessment project in the Cook Inlet bioregion. This project seeks to develop protocols for water sampling that are better suited to conditions in Alaska than the current sampling protocols.

ADEC is a partner in implementing the EPA's Environmental Monitoring and Assessment Program (EMAP) in southcentral Alaska (2001) and southeastern (2002) The purposes of the EMAP program are to provide a comprehensive report card on the status of the ecological resources nationwide and to detect trends in these resources

ADEC and ADNR are partners with the EVOSTC in the development of the regional information system known as The Cook Inlet Information Management and Monitoring System (CIIMMS) CIIMMS is a project, funded by the Trustee Council, to develop a website for finding, contributing, and sharing information for the Cook Inlet watershed region CIIMMS is intended to support monitoring, management, and restoration of natural resources, in addition to data sets and software relevant to understanding the ecological status of this region

The Division of Environmental Health routinely tests and certifies clams from commercially harvested shellfish beaches and shellfish farms for paralytic shellfish poisoning (PSP) The division also monitors PSP in king crab in PWS and in Dungeness crab and Tanner crab in PWS, Cook Inlet and Kodiak Island The Contaminated Sites program monitors superfund sites, abandoned military sites and other contaminated sites throughout the state

Alaska Department of Fish and Game (ADFG)

The Division of Commercial Fisheries does substantial monitoring of salmon and other anadromous fish species, herring, crabs, shrimp, and several other invertebrate species, and some species of mammals ADFG is responsible for the North Pacific region portion of the Coded Wire Tag database, which contributes to understanding ocean distributions of salmon The department's point of sales (fish ticket) information supports understanding of abundance and distribution of salmon, crabs, herring, and other species ADFG has extensive historical information on the distribution of some species of crab and shrimp in the North Pacific region ADFG has archives of scales and size at age from salmon and herring that enable understanding of historical marine growth regimes An extensive archive of genetic data on chum, sockeye and other species of salmon is being assembled by ADFG in cooperation with NMFS and agencies of nations participating in the North Pacific Anadromous Fish Commission (NPAFC) The data enhance understanding of the oceanic distribution of salmon, and thereby contribute to understanding oceanic regime shifts ADFG also conducts genetic research on crabs, some rockfish, herring, and pollock

The ADFG and cooperating regional aquaculture associations also collect some physical and biological oceanographic data, such as Kodiak nearshore sea surface temperatures, Kitoi Bay zooplankton biomass (Kodiak), and PWS zooplankton settled volumes

The ADFG Subsistence Division's Whiskers database on subsistence harvest of marine mammals is part of a larger NOAA sponsored program In addition, the Wildlife Conservation Division monitors harbor seals in cooperation with NMFS

The Sport Fish Division conducts port sampling of groundfish for information about the recreational effort, catch, and harvest of rockfish, lingcod and halibut in the northern North Pacific region. This project consists of catch sampling and angler interviews. The Subsistence Division collects data on subsistence fish and shellfish harvest. The Habitat Division monitors the effect of certain activities on anadromous fish streams. Since 1990, the division has been monitoring compliance with the Alaska Forest Practices regulations on private land. Since 1998, the Habitat Division has been researching the effects of stream crossing structures on fish habitat and fish passage on the Kenai Peninsula. Note that most ADFG marine programs serve to provide information to NOAA programs.

Alaska Department of Health & Social Services (ADHSS)

The Division of Public Health has conducted several retrospective studies of contamination in subsistence foods One study examined twenty years of data on trace metal analysis in marine mammals and another examined the occurrence of contaminants in subsistence foods, with an emphasis on methylmercury, cadmium, and PCB levels

Alaska Science and Technology Foundation (ASTF)

The ASTF was established in 1988 by the Governor and the State of Alaska Legislature Its purpose is "to promote and enhance, through basic and applied research and the development and commercialization of technology, economic development and technological innovation in Alaska, public health, telecommunications, and the sustained growth and development of Alaskan scientific and engineering capabilities "

Alaska Department of Natural Resources (ADNR)

The ADNR monitors certain uses of land and resources on state lands and waters The Division of Oil and Gas performs field inspections of activities on state oil and gas leases The Division of Forestry monitors compliance with the terms of state timber sales The Division of Parks and Outdoor Recreation tracks use of state-owned recreation facilities such as campgrounds, cabins, and parking facilities Periodically, staff members inspect these facilities The Division of Mining, Land, and Water issues aquatic farming permits, shore fishery leases, and other permits and leases for use of state-owned tidelands and uplands The Division

maintains statistics on the number of applications submitted and issued and monitors compliance with terms and conditions of permits and leases

State of Alaska, Division of Governmental Coordination (DGC)

As a part of the Governor's Office of Management and Budget, DGC administers the State of Alaska portion of the Coastal Impact Assistance Program, CIAP, which is administered nationwide by NOAA (see CIAP under US Government, NOAA, NOS, below) Alaska will receive \$12,208,723 in funds for federal FY 2001 The DGC will directly receive \$7,935,670, North Slope Borough will receive \$1,939,680, and the remaining seventeen coastal boroughs and coastal resource service areas (CRSAs) will receive approximately \$20,000 to \$600,000 Collectively, the DGC and local governments will undertake more than seventy-five projects, including enhancing local coastal management plans, data collection and research, habitat conservation and restoration, and education and community outreach, coastal access improvements, and project planning In addition DGC will use nearly \$3 million for a Competitive Grants Program to provide funds to coastal resource districts, state and local government agencies, tribal governments and organizations, non-profit organizations, individuals, private industry and other interested parties The grants will be awarded for projects in such categories as coastal erosion control, mitigation of impacts from off-road vehicles, improving fish passage, marine debris removal, habitat protection (including land acquisition), and coastal resource inventorying, mapping, and monitoring In the GEM region, two boroughs and CRSAs will acquire baseline maps, photography, or other information to improve their coastal management decision-making Matanuska-Susitna Borough will obtain and make available an on-line database of new satellite imagery of the borough, focusing on areas of high coastal resource value, and where significant impacts and hazards to coastal resources exist Kodiak Island Borough will obtain vitally needed aerial photography and digitized maps for identification, conservation, and protection of wetlands and floodplains

University of Alaska

The university has extensive programs that are relevant to the North Pacific region Four federally and state supported programs within the university system are expected to provide the International Arctic Research Center substantial expertise and information of interest the School of Fisheries and Ocean Sciences, the Sea Grant Program, the National Underwater Research Program, and the Institute of Social and Economic Research

Institute of Marine Science (IMS) School of Fisheries and Ocean Sciences Scientists associated with IMS have compiled much of the historical data relevant to the North Pacific region IMS produced the comprehensive review (Rosenberg 1972) in preparation for the extensive and intensive environmental studies sponsored by the Minerals Management Service in the 1970s (Hood and Zimmerman 1986) The IMS maintains a historic database of oceanographic measurements from the North Pacific region, and it currently operates the R/V Alpha Helix, a 133-foot research vessel, for the National Science Foundation

Pollock Conservation Cooperative Research Center (PCC) School of Fisheries and Ocean Sciences (SFOS) The SFOS operates the PCC Research Center that was established in February 2000 and seeks to improve knowledge about the North Pacific Ocean and Bering Sea through

research and education, focusing on the commercial fisheries of the Bering Sea and Aleutian Islands For the 2000 funding cycle, the PCC Research Center is especially interested in trying to improve knowledge through research and education relating to climate regime shifts and interannual variability in the Bering Sea ecosystem, the recovery of the Steller sea lion, including the identification of factors contributing to its decline, bycatch in the fisheries (for example, bycatch of salmon), and the impact of fishing activities on ecosystem dynamics and the diversity and abundance of target and non-target species Funding for the PCC Research Center is provided by members of the PCC, a fishing cooperative of companies that operate catcher/processors in the Bering Sea and Aleutian Islands pollock fishery

International Arctic Research Center (IARC) IARC promotes international collaboration in global change research in the arctic In the science plan for IARC, the key elements are understanding the relative contributions of natural and manmade causes to climate change, understanding what to measure in order to detect changes, and predicting the impacts of change on humans The IARC Research Framework has eight themes, four of which are relevant to the North Pacific region 1) detection of contemporary changes, 2) arctic paleoclimatic and paleoenvironmental reconstructions, 3) impacts, consequences of change and education, and 4) integration of research on a regional scale

Sea-Air-Land Modeling and Observing Network (SALMON) SALMON is a program at the University of Alaska that fosters the implementation and operation of ocean-observing systems in Alaskan coastal waters The SALMON Project, in cooperation with other institutes, will provide continuous real-time or near real-time observations of ocean circulation and ecosystems and link these with models to provide ocean forecasts in much the same way that weather forecasts are made

United States Government

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Federal Partnership Programs

Marine Environmental Health Research Laboratory (MEHRL) MEHRL is an interdisciplinary environmental laboratory operated by NOAA, NIST, the University of

Charleston, the Medical University of South Carolina, and the South Carolina Department of Natural Resources It is a model of state-federal cooperation in marine environmental research dedicated to providing the information needed to sustain the health, productivity, and diversity of marine resources The interdisciplinary program is designed to provide answers to complex problems surrounding the health of coastal marine resources

National Ice Center (NIC) The National Ice Center is a multi-agency operational center partnered by the Department of Defense (Navy--Naval Ice Center), the Department of Commerce (NOAA – National Weather Service and National Environmental Satellite Data Information Service), and the Department of Transportation (US Coast Guard) NIC ice data are a key part of the US contribution to international global climate and ocean observing systems

National Oceanographic Partnership Program (NOPP) NOPP is a legislatively-mandated collaboration of twelve US government agencies designed to promote cooperative activities among government, academia, and industry for the advancement of ocean science, technology, and education The Program is chaired by top-ranking officials from the US Navy, NSF,

Department of Energy, U.S. Coast Guard, Defense Advanced Research Projects Agency, NOAA, NASA, EPA, USGS, MMS, and the Office of Management and Budget NOPP is preparing The Ocean Observations Task Team report "An Integrated Ocean Observing System A Strategy for Implementing the First Steps of a U.S. Plan" NOPP has agreed to be a partner with the Alfred P Sloan Foundation to help implement the Census of Marine Life (CoML) and specific studies that are relevant to the common research interests and goals of the CoML and the U.S. oceanographic agencies

The Kachemak Bay Research Reserve (KBRR) is a federal-state partnership KBRR is mandated to do research and education in the local community and in the larger NERRS program (see NOS under NOAA)

Interagency Federal Programs

The Interagency Arctic Research Policy Committee (IARPC) is the coordinating body for federal agencies charged with implementing arctic research and monitoring, some of which may occur in the northern Gulf of Alaska IARPC is chaired and operated by the National Science Foundation (NSF), the lead federal agency responsible for implementing arctic research policy The IARPC helps set priorities for future arctic research, and it works with the State of Alaska and the Arctic Research Commission to develop and establish an integrated national arctic research policy to guide federal agencies in developing and implementing their research programs in the arctic

Marine Protected Areas (MPAs) are an intergovernmental program designed to strengthen the protection of U S ocean and coastal resources The Departments of Commerce and the Interior, assisted by other federal agencies, are working to strengthen and expand a national system of MPAs by working closely with state, territorial, local, tribal, and other stakeholders An MPA is defined as "any area of the marine environment that has been reserved by Federal, State, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein "

National Aeronautics and Space Administration (NASA)

NASA's Earth Science Enterprise remote sensing missions provide a wealth of information that support ocean programs at a fundamental level The TOPEX/Poseidon and Jason-1 altimetry missions will provide high quality sea level estimates for interpretation in climate studies. Sea surface height (SSH) data provide information about the ocean geostrophic flowfield near surface and, when assimilated into an ocean circulation model, in the interior ocean as well. SSH data also provide a measure of upper ocean heat and saline variability. NASA and CNES have combined forces to build and operate altimetric missions for obtaining high accuracy SSH data since August 1992. Jason-1 will be the follow-on mission to TOPEX/Poseidon and is slated for launch in May 2000.

Seawinds instruments on the QuikSCAT and ADEOS-II satellites provide estimates of vector wind over the ocean Wind stress is the primary mechanical forcing function of the ocean circulation Remote sensing observations of surface winds are the only way to assure a truly global coverage of wind data over the ocean and to assure that meteorological models provide high-quality wind-stress fields NASA launched its Seawinds scatterometer on the QuikSCAT mission in mid-1999 to provide 25-km resolution of vector surface winds over 90 percent of the ice-free ocean each day A second Seawinds instrument is slated for launch in late 2000 on the Japanese ADEOS-2 satellite

Sea surface temperature is now delivered operationally using a combination of AVHRR data from NOAA satellites and in situ data for calibration NASA's new technology for delivering sea surface temperature includes the MODIS instrument on EOS AM and PM platforms and microwave (all-weather) temperatures from the NASA/NASDA Tropical Rainfall Measurement Mission

The concentration of chlorophyll in the upper ocean layer can be deduced from relatively small contrasts in ocean color While absolute calibration of such contrast measurements may be a challenge, easily observable fast space-time variations provide valuable insight into the dynamics of primary production and the processes that control it Such ocean color measurements will be provided more or less systematically by a number of satellite missions and operational programs, including NASA/SeaWiFS, ESA/ENVISAT, NASDA/ADEOS-2, NASA/EOS AM-1 and PM-1, and eventually NPOESS (beginning around 2009)

The Gravity Recovery and Climate Experiment (GRACE) satellite is slated for launch in March 2001 It will provide a high accuracy measurement of the time varying gravity field Knowledge of the marine geoid is fundamental for using altimeter data to study the absolute ocean currents This mission also provides information about variable deep ocean currents which is complimentary to that obtained from altimetry

NASA is currently developing the technology to remotely sense the ocean surface salinity from low earth orbit The scientific issues are discussed in a report of the Salinity and Sea Ice Working Group

Sea-ice concentrations (percent aerial coverages) to a resolution on the order of 30 km have been obtainable from satellites since the early 1970's using passive microwave radiometer technology The record from the early and mid 1970's contains many large data gaps, but is reasonably complete since Oct 1978 in terms of obtaining a consistent global sea ice coverage dataset every one to three days This record demonstrates significant seasonal and interannual variability in the sea-ice cover and its dynamics This dataset is currently being continued with the DMSP Special Sensor Microwave/Imager (SSM/I) and will be further continued with the Advance Microwave Scanning Radiometer (AMSR) on both the EOS-PM platform and the Japanese ADEOS-II platform, both scheduled for launch in the year 2000

National Oceanic and Atmospheric Administration (NOAA)

National Marine Fisheries Service (NMFS)

The National Marine Fisheries Service conducts programs that support the domestic and international conservation and management of living marine resources and the fisheries that depend on them NMFS is organized around Regions that conduct management-operational activities, including some monitoring, and Centers that conduct research in support of regional needs Centers responsible for Pacific Ocean research and monitoring within NMFS are the Alaska Fisheries Science Center, the Northwest Fisheries Science Center (Seattle), and the

Southwest Fisheries Science Center (LaJolla) The research needs of NMFS in the Alaska Region (Juneau) and the North Pacific Fishery Management Council (Anchorage) are served by the Alaska Fisheries Science Center (AFSC) which includes the Sand Point (Seattle) Headquarters, the Auke Bay Laboratory (Juneau), the Kodiak Laboratory, and the Hatfield Marine Science Center (Newport, OR) Major programs include the triennial trawl surveys for groundfish (scheduled to become biennial in 2001), annual longline surveys primarily for sablefish and rockfish, and the Ocean Carrying Capacity program with three cruises a year The Auke Bay Laboratory conducts the salmon and rockfish genetic stock identification programs of the Alaska Fisheries Science Center in Juneau, Alaska The AFSC also conducts fishing vessel observer programs that collect biological information are conducted out of

The National Marine Mammal Laboratory (NMML) is a research organization of the AFSC that conducts research on marine mammals important to the mission of NMFS and NOAA Its geographic focus includes areas off the coasts of Oregon, Washington and Alaska Its activities are information gathering and analysis, including stock assessments, life history determinations, and status and trends NMML provides information to various US governmental and international organizations to assist in developing rational and appropriate management regimes for marine resources under NOAA's jurisdiction NMML also carries out research programs cooperatively with other federal, state and private sector agencies Marine mammal survey programs include the Cook Inlet marine drift and set gillnet observer program and the Cook Inlet beluga population survey. The Southwest Fisheries Science Center conducts offshore killer whale surveys in the North Pacific region as part of a coast-wide program.

NMFS, in conjunction with the states and other federal agencies (USGS and NIST), conducts the National Marine Mammal Health and Stranding Response Program, which collects and analyzes tissue samples from stranded marine mammals for histopathology, contaminants, and disease NMFS also routinely observes fish sampled in resource surveys for the presence of tumors or lesions that may show high levels of contaminants in the environment. Human uses of fisheries are monitored through the Fisheries Statistics and Economics Division, which maintains U S commercial and recreational fisheries statistical data, such as pounds and dollar value of commercial landings. In the southeastern U S coastal states, NMFS cooperates with the Food and Drug Administration to conduct a Seafood Inspection Program that includes monitoring the level of toxic dinoflagellate, *Pfiesteria piscicida*, and related water quality properties that might pose a threat to human health and the ecosystem.

NMFS partners with other federal and state agencies and academic institutions to support ecosystem programs Several of the programs collecting ecosystem information including data on physical and chemical oceanography, phytoplankton, zooplankton, and forage fishes are the California Cooperative Fisheries Investigation (CalCoFI) off Southern California, the Marine Monitoring and Assessment Program (MARMAP) in the Northwest Atlantic, SEAMAP in the Southeast U S , and the Fisheries Oceanography Coordinated Investigations (FOCI, NOAA's OAR is also a partner) in the Gulf of Alaska and Bering Sea These programs furnish fundamental information on abundance and distribution of marine fish and invertebrates, and environmental changes which affect them

Office of Oceanic and Atmospheric Research (OAR)

OAR consists of twelve laboratories nationwide The office's activities include a complex program of geophysical, oceanographic, and macrofauna monitoring and evaluation activities that involve NMFS and other NOAA personnel

The Pacific Marine Environmental Laboratory (PMEL) in Seattle focuses on coastal and open ocean observations and modeling to improving understanding of the physical and geochemical processes operating in the world oceans PMEL's fisheries oceanography program (FOCI), which is a collection of NOAA research programs attempting to understand the influence of envuonment on the abundance of various commercially valuable fish and shellfish stocks in Alaska waters and then role in the ecosystem, has a project in Shelikof Strait between Kodiak and the Alaska Peninsula This and other North Pacific region monitoring projects are partnered with NMFS' Alaska Fisheries Science Center, under its Resource Assessment and Conservation Engineering (RACE) program PMEL also conducts retrospective fisheries and oceanographic studies and the rescue and dissemination of older data collected by PMEL scientists PMEL operates the El Niño-Southern Oscillation (ENSO) Observing System, which supports NOAA's climate prediction mission, primarily on seasonal to interannual time-scales NOAA's environmental satellite systems, with region and basin-wide observations of sea surface temperature and surface wind speed, are supplemented by the ENSO Observing System Seventy moorings in the tropical Pacific (called the Tropical Atmosphere-Ocean or TAO array) provide surface atmospheric and ocean mixed-layer observations Several hundred global Lagrangian drifting buoys in all the major ocean basins, a volunteer observing ships (VOS) expendable bathythermograph (XBT) program of about forty commercial ships, and a network of tide gauges complete the ENSO system The resulting data are used to initialize climate models, verify model results, and monitor the evolution of the upper ocean

Other observing systems maintained by NOAA that are still in the developmental stage, include a shipboard thermosalinograph effort, the Trans-Pacific Profiler Network, consisting of ten profilers in the equatorial Pacific, a Pacific upper-air sounding network on islands and ships in the Pacific, the Pan American Climate Studies Sounding Network of enhanced atmospheric observations, an ocean carbon-ocean tracer hydrographic program to determine global distributions of key chemical, biological, and physical tracers, a submarine cable providing estimates of Florida Current transport, a Voluntary Observing Ship CO2 program of semiautomated systems to monitor CO2, an Atlantic Ocean pilot project (called PIRATA) of twelve buoys in the tropical Atlantic, and an Atlantic profiling float array to study processes important in establishing SST variability

Another of OAR's twelve labs, the Climate Diagnostics Center, holds the Comprehensive Ocean-Atmosphere Data Set (COADS) with surface marine data since 1854 OAR's Arctic Research Office partners with the University of Alaska Fairbanks to run the Cooperative Institute for Arctic Research (CIFAR) in Fairbanks Proposals are being solicited in FY 2001 for research on (1) climate variability and change in the Arctic, and (2) Bering Sea productivity These funds will be made available from the Department of Commerce/NOAA through the Arctic Research Initiative, which started in FY 97 NOAA's Office of Ocean Exploration (OE) was founded in 2001 under the Office of Oceanic and Atmospheric Research (OAR) to meet four challenges 1) Mapping at new scales emphasizing regions not previously observed, 2) Exploring ocean dynamics and interactions at new scales, 3) Developing new technologies, and 4) Reaching out in new ways to stakeholders

National Ocean Service (NOS)

This branch of NOAA is the nation's principal advocate for coastal and ocean stewardship through partnerships, and supports the science and information needed for the proper balance between environment and economics In cooperation with the National Science Foundation, NOS supports oceanographic research in the North Pacific region, providing about half the support for the Northeast Pacific subprogram of the US GLOBEC The substantial projects of the GLOBEC program are retrospective analyses and monitoring studies NOS oversees the newly established Kachemak Bay National Estuarine Research Reserve and its Kachemak Bay Ecological Characterization study The system of twenty-five estuarine reserves nationwide monitors physical, chemical, and biological parameters in order to depict, track, and forecast long-term changes and short-term variability in the resources of these areas

The NOAA NERRS System Wide Monitoring Program includes the Kachemak Bay Research Reserve, KBRR, in Kachemak Bay As part of NERR KBRR has deployed four permanent sensor arrays to measure ocean and meteorological parameters at two sites in Kachemak Bay and Lower Cook Inlet The parameters include salinity, ocean temperature, DO, pH, turbidity, fluorescence, in water PAR, wind speed and direction, air temperature, surface PAR, precipitation, and RH In addition, nutrients and chlorophyll will be measured once per month at the permanent sites As part of that program we have also established CTD transects along and across the axis of Kachemak Bay with monthly measurements

NOS also conducts the National Status and Trends Program which measures levels of toxic contaminants, including trace metals, pesticides, petroleum hydrocarbons, and other toxic organic contaminants and their effects on fish and shellfish This national program currently includes North Pacific region samples in the Mussel Watch contaminants project and formerly included the Benthic Surveillance Project in Alaska Specimens are held in the Specimen Banking Project at the National Institute of Standards and Technology (see NIST, below)

NOS also administers the Coastal Impact Assistance Program (CIAP) Congress authorized the Coastal Impact Assistance Program (CIAP) in fiscal year 2001 by amending Section 31 of the Outer Continental Shelf Lands Act The purpose of the CIAP is to assist states and local communities in mitigating the impacts of Outer Continental Shelf oil and gas development and production Congress appropriated \$150 million under the CIAP to the seven offshore oil and gas producing states of Alabama, Alaska, California, Florida, Louisiana, Mississippi and Texas The CIAP funding allocation formula is set out in the law and based on the following factors revenues derived from offshore oil and gas taken from each state's offshore waters, distance of the offshore oil and gas leases from each state's coastline, length of coastline of each coastal county, and population of each coastal county For example Alaska will receive the smallest allocation of \$12,208,723 in federal fiscal year 2001, while both Louisiana and Texas will receive the maximum amount of \$26,406,064 Thirty-five percent of each state's allocation will be awarded directly to the individual coastal counties, as called for in the CIAP legislation

NOS conducts a number of projects nationally that do not have a presence in Alaska, but may be relevant to Alaska conditions or programs, and could be potential sources of funding for

future efforts One example is NOAA's National Water Level Network along the nation's ocean and Great Lakes shorelines, which includes almost 200 continuously operating water level measurement systems At five extremely busy harbor entrances, NOS operates Physical Oceanographic Real-Time Systems (PORTS) These systems include acoustic Doppler current profilers with anemometers, packet radio transmission equipment, a data acquisition system and an information dissemination system

The Alliance for Coastal Technologies (ACT) is committed to developing an active partnership with state and regional managers and private industry who deal with the need for effective use of sensor technologies in monitoring coastal environmental natural resources

National Environmental Satellite, Data, and Information Service (NESDIS)

NESDIS holds most of the historical information gathered by NOAA agencies and current satellite, oceanographic, and buoy data, global climatological data, and sea ice information Much of the information is stored at the National Oceanographic Data Center (NODC), the National Climate Data Center (NCDC), and the National Geophysical Data Center (NGDC) These three data centers cooperate with NASA, the National Weather Service, and many international agencies to provide global information such as sea surface temperature, wind speeds and vectors, biological productivity, salinity, absolute sea height, and other types of observations NODC is a major partner in the Global Ocean Observing System (GOOS)

NESDIS has a role in ensuring national security, since it serves as the operational and command authority for the Defense Department's Defense Meteorological Satellite Program NOAA's environmental satellite data are shared in near real-time through an agreement with the Department of Defense in support of the Air Force and the Navy's global and regional weather and ocean forecasting model prediction services During national emergencies (both military and natural hazards response), NOAA enhances local environmental satellite coverage through its polar orbiting satellites worldwide For emergencies affecting the western hemisphere, images from NOAA's geostationary satellites are enhanced

National Weather Service (NWS)

NWS collects weather, hydrologic, and climate data for coastal and ocean areas The National Data Buoy Center has over 100 buoys and several Coastal Marine Automated Network (C-MAN) shore-based stations, some of which are based in Alaska The center has real-time weather and oceanographic data and cooperates with NODC to provide historical monitoring data

National Institute of Standards and Technology (NIST)

The NIST cooperates with USGS, NMFS, and NOAA's Office of Protected Resources in maintaining and operating the National Biomonitoring Specimen Bank Archiving of biological samples for future analysis, and creation and maintenance of databases on specimen samples are NIST specialties

National Science Foundation (NSF)

The National Science Foundation is a quasi-independent U S government agency supporting science and engineering programs worth over \$3.3 billion per year Program areas of potential

interest to North Pacific are polar research, geosciences, and biology NSF also contributes funding for GLOBEC, FOCI and other projects of interest to the North Pacific region

NSF has funded technology, instrument development, and infrastructure over the last several years The ALVIN submersible, the best known of many ocean observing instruments sponsored by NSF, is continually upgraded to provide state-of-the-ait, long times-series, deep ocean observations

Three observatories the Hawaii Undersea Geo-Observatory (HUGO)-automated submarine volcano observatory, the Hawaii-2 Observatory (H2O)-broad-band seismometer, and the Long-term Ecosystem Observatory (LEO-15)-broad array of sensing systems are currently involved in technological developments

NSF is pursuing the design concept of a fiber optic cable connecting a series of sea floor nodes capable of supporting real-time transmission of data and images from hundreds of instruments with the National Ocean Partnership Program (NOPP) In 1996, NSF initiated another program, Deep Earth Observatories on the Seafloor (DEOS), for observations beyond the reach of fiber optic cables

The World Ocean Circulation Experiment (WOCE) produced a five-year look at the global density and property field of the ocean Numerous hydrographic sections were repeated during the experiment at regular intervals to address overall structure, meridional overturning, and transport through particularly important "choke points" The Atlantic Climate and Circulation Experiment (ACCE), a study conducted during WOCE between Greenland and latitudes below the equator using independent subsurface profiling floats, is the model for the Array for Real-time Geostrophic Oceanography (ARGO)

The Argo Ocean Profiling Network is an international effort to collect and share information on the temperature, currents, and salinity of the world's oceans Such information may be used to improve predictions of the effects of weather events such as El Niño and La Niña on our seasonal climate Each float is programmed to sink a mile into the ocean, drift at that depth for about ten days, then slowly rise, measuring temperature and salinity through the layers as it makes its way to the surface. At the surface, data is transmitted to a communications satellite and the probe begins another cycle Each float is designed to last four to five years. Argo floats can be deployed from ships or by aircraft NOAA and the Office of Naval Research through the National Oceanographic Partnership Program fund the U S contribution to ARGO NOAA, Scripps Institution of Oceanography, University of Washington, and Woods Hole Oceanographic Institution are implementing ARGO. Scientists have determined that 3,000 floats are needed for the full global observing array. The goal is to have the entire array of floats drifting and bobbing throughout the world's ice-free oceans by 2003.

Early in the next decade ARGO will furnish a major portion of the database for the Global Ocean Data Assimilation Experiment (GODAE) The large number of independent floats released under ARGO, supported by NSF, is planned as a part of the long-term climate research program In addition to ARGO, Global Eulerian Observations (GEO) will provide diagnostic support and verification of the Lagrangian measurements, greatly decreasing their uncertainties, and lead to more accurate portrait of global heat fluxes In 1977, the Oceanic Flux Program (OFP), the first continuous time-series particle flux in the deep ocean, was inaugurated at Hydrostation S The observation that the particulate flux to depth was not constant but seasonally dependent on the plankton production cycle amazed the oceanographic community

In 1988, as a part of US JGOFS, several stations in the North Pacific, North Atlantic and near Bermuda, were funded by NSF to collect oceanic time-series to provide a greater understanding of the oceans' role in global and climate change The stations in the North Pacific and near Bermuda have become prototypes for other national and international oceanic time-series observatories

The principal goal of the Carbon Retention In A Colored Ocean Program (CARIACO), instituted in 1995, was to study the relationship between surface biogeochemical processes and the fluxes of carbon and nutrients in a continental margin setting influenced by seasonal upwelling

The US GLOBEC Northwest Atlantic-Georges Bank Program is intended to assimilate the population dynamics of major species on the Bank in terms of their relationship to the physical environment, predators and prey The ultimate goal is to be able to forecast changes in the distribution and abundance of these species as a result of changes in their physical and biotic environment, as well as to predict how their populations might respond to climate change Continuing observations will be essential in the foreseeable future A similar US GLOBEC Northeast Pacific Program (NEP) has initiated a study of the effects of past and present climate variability on the population ecology and population dynamics of marine biota and living marine resources

NSF has funded studies of existing ocean and coastal data sets, including the Continuous Plankton Recorder Surveys and the California Cooperative Fisheries Investigations (CalCoFI) NSF has also helped to sponsor a series of workshops to gather all the historical data surrounding major fish stock explosions and crashes, subjecting them to extensive modeling exercises in an effort to prove or disprove the many speculative hypotheses established to explain them

For several years, studies in the Great Barrier Reef have focused on coral and algae, as have studies of the ecology of reefs in relation to El Niño events in the eastern tropical Pacific, rocky shore sites along Northern Massachusetts and the outer coast of Washington State These studies were expanded to include Long-Term Ecological Research (LTER) in Land/Ocean Margin Ecosystems The network includes freshwater and tidal forcings and geomorphology, watershed land-use types, and aquatic and terrestrial biogeographic provinces and climatic regions These programs have been useful in measuring coastal ecological system responses to ENSO and other long-term climactic variability

Comprehending the causal linkages and covariations among the physical, chemical, and biological components of mid-ocean ridge volcanic and hydrothermal systems, and the long-term temporal evolution of these systems, is an important aspect in a number of on-going and planned programs Six areas are involved in the programs three on the Juan de Fuca Ridge in the northeast Pacific Ocean, one on the East Pacific Rise off southern Mexico, one on the East Pacific Rise off northern Peru, and one on the Mid-Atlantic Rise south of the Azores The programs involve long-term temporal observations through repeat visits, and could evolve into permanent, real-time observatories in the future

The Earth's climate system varies on time scales greater than the instrumental record, from the major changes of glacial/interglacial cycles to the recently-identified millennial cycles of the North Atlantic and the decadal oscillations of the North Pacific Capturing the full natural variability of the system requires highly-resolved records spanning hundreds or even thousands of years Preservation of these "paleo" time-series are recorded in oceanic sediments and other geo-archives such as massive corals

U S Arctic Research Commission (USARC)

The US Arctic Research Commission was established by Congress under the Arctic Research and Policy Act of 1984 to promote arctic research, develop national research plans, and facilitate interagency coordination within the federal government and state and local governments in Arctic research An important resource for the USARC established by ARPA (P L 98-373 [1984], amended P L 101-609 [1990]) is the Interagency Arctic Research Policy Committee (IARPC) operated by NSF, described separately in this section. The Commission is composed of seven members appointed by the President plus the director of the National Science Foundation USARC has produced its set of research priorities for FY 2001 that includes a renewed emphasis on the Bering Sea and a call for increased efforts dealing with climate change in the arctic. Under the Arctic Council, the U S has taken the lead role in the preparation of an Arctic Climate Impact Assessment (ACIA), to be prepared by experts from all of the arctic countries and other countries with arctic interests

U S Environmental Protection Agency (USEPA)

The mission of the Environmental Protection Agency is to protect human health and to safeguard the air, water, and land of the nation Of particular interest to the North Pacific region is the EPA's Environmental Monitoring and Assessment Program (EMAP), which seeks to fulfill a national mission that may be very similar to some elements of North Pacific's regional charge The purposes of the EMAP program are to provide a comprehensive report card on the status of ecological resources nationwide and to detect trends in these resources. In addition to having common concerns, the review of the design phase of EMAP by the National Research Council (NRC 1995) is also relevant EMAP is a partnership between EPA and NOAA for long-term, integrated monitoring, research, and assessment to ascertain the status of our nation's ecological resources EMAP's purpose is to develop the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of ecological condition and forecasts of the future risks to the sustainability of our natural resources This data supports the National Environmental Monitoring Initiative of the Committee on Environment and Natural Resources EMAP implements monitoring programs that operate on regional scales, highlighting different ecological resource categories, over periods of several years, including five monitoring activities (1) completion of the Mid-Atlantic Integrated Assessment Geographic Initiative, (2) initiation of the Western Pilot Geographic Initiative, (3) planning for a National Coastal Survey, (4) developing probabilistic coastal monitoring in all coastal states, and (5) establishment of an interagency (EPA, NOAA and NASA) effort to develop an intensive coastal site network of monitoring and research locations throughout the United States

EPA also issues National Pollution Discharge Elimination System (NPDES) permits, which typically require that the permittee monitor discharges Permittees include the Alyeska Marine Terminal in Valdez, seafood processors, hatcheries, and logging companies EPA also maintains a list of hazardous waste handlers under the Resource Conservation and Recovery Act (RCRA) and may require that the handlers monitor certain aspects of their activities The RCRA list is based on those who report the handling of hazardous wastes through, for example, storage or transport EPA also monitors Superfund sites

EPA research laboratories and program offices support several coastal ocean observation studies Additionally some federal, state and local governments, and private entities' projects fall under EPA's jurisdiction

EPA maintains observations to ensure compliance with legislative mandates and regulatory requirements. Concern about protection of marine ecosystems from the adverse effects of the disposal of dredged materials and treated wastewater encouraged development of Ocean. Dumping and Ocean Discharge Programs. Possible impacts include problems associated with eutrophication, pathogens, and toxics that result in adverse effect on human health and biological integrity of the coastal waters, as well as habitat modification and loss. Data includes the quality of dredged materials or treated wastewater, and 'the physical, chemical, and biological circumstances of the marine environment surrounding the disposal or discharge area.

States are required by the National Water Quality Inventory to report water quality conditions to EPA for inclusion in the National Water Quality Inventory Reports to Congress The water quality includes physical, chemical, and biological conditions, and is processed according to monitoring results of the quality of waters, including estuarine and coastal waters

The National Estuary Program (NEP) was founded by Congress to restore and preserve estuaries, the program currently includes twenty-eight estuaries that represent 42 percent of the shoreline of the continental U S. These programs are in various stages of development. Each individual estuary program inventories existing federal, state, local and volunteer monitoring programs in their area and combines pertinent details from these on-going activities into their own monitoring plans according to EPA guidance. Each NEP is developing its own database management system.

The Chesapeake Bay Program established in 1984 by the Chesapeake Bay Executive Council, is a Bay-wide EPA/state joint effort. The program is made up of over 165 stations below the fall line, and combines the efforts of Maryland, Pennsylvania, Virginia, the District of Columbia, several federal agencies, ten institutions, and over thirty scientists. Nineteen physical, chemical, and biological characteristics are monitored twenty times a year in the main stem of the bay and its many tributaries. A volunteer citizen monitoring program was started in 1985.

The Great Lakes National Program combines several federal, state, tribal, local, and industry partners in an integrated, ecosystem approach to protect, maintain, and restore the chemical, biological, and physical integrity of the Great Lakes The program monitors Lake ecosystem

data, manages and provides public access to Gieat Lakes data, and helps communities address contaminated sediments in their haibors

The Gulf of Mexico Program is made up of many state and local monitoring projects An integrated coastal monitoring and assessment program for the Gulf of Mexico is currently being designed, with four main focus areas excessive nutrient enrichment, public health associated with seafood consumption and recreational use, habitat loss, and non-indigenous species introduction

The Clean Water Action Plan, a new initiative, is an ambitious multi-agency proposal to speed the restoration of our nation's waterways One important component is development of a Coastal Research Strategy involving integrated studies of coastal waters and a public report on the condition of the nation's coastal waters in 2000

U S Department of Health and Human Services (USDHHS)

Agency for Toxic Substances and Disease Registry (ATSDR)

ATSDR is the principal federal public health agency involved with hazardous waste issues The agency helps prevent or reduce the harmful effects of exposure to hazardous substances on human health ATSDR was created by the Superfund Law in 1980, and is concerned with issues surrounding human health as they may be affected by contaminants associated with exposure to hazardous substances from waste sites, unplanned releases, and other sources of pollution present in the environment

ASTDR is directed by congressional mandate to perform specific functions concerning the effect on public health of hazardous substances in the environment. These functions include public health assessments of waste sites, health consultations concerning specific hazardous substances, health surveillance and registries, response to emergency releases of hazardous substances, applied research in support of public health assessments, information development and dissemination, and education and training concerning hazardous substances

U S Department of the Interior (USDOI)

Fish and Wildlife Service (USFWS)

The Alaska Maritime National Wildlife Refuge (AMNWR) monitors ten seabird colonies annually, four of which are in the North Pacific region The AMNWR also monitors other sites on a periodic basis largely dependent upon availability of funds

The Office of Subsistence Management is entering its second year of the Federal Subsistence Fishery Monitoring Program The program is directly administered by the Fishery Information Services Division, which consists of staff with expertise in both fisheries and social sciences, and which funds studies that gather, analyze and report information needed for subsistence fisheries management on federal lands in Alaska Funded studies focus on three information types Traditional Ecological Knowledge, Subsistence Fishery Harvests, and Fishery Stock Status/Trends Most studies contribute to developing the capability and expertise of agencies, local communities, and rural residents to participate in subsistence fisheries have been For purposes of management and research, Alaska federal subsistence fisheries have been grouped into ten regions Each region has an Advisory Council consisting of local residents who represent the geographic and cultural diversity of that region In addition to providing recommendations on policies, Advisory Councils also identify study needs and make recommendations on project proposals for their region

Minerals Management Service (MMS)

The MMS provides substantial support for projects related to the potential effects of oil and gas exploration and recovery that are largely conducted by other agencies and contractors Studies envelop a wide range of resources such as sediment quality, seabird monitoring, mapping of riptides, Cook Inlet forage fish, and others MMS has funded a varied range of project types for many years The University of Alaska Fairbanks and the MMS have joined to form the Alaskan Coastal Marine Institute (CMI) The purpose of the CMI is to provide matching MMS funding for research in Alaska on coastal, marine and human environmental issues pertaining to offshore mineral exploration and extraction Researchers must secure at least one dollar of non-federal matching funds for every dollar from the CMI Projects should address the Beaufort Sea and secondarily Cook Inlet/Shelikof Strait

U.S. Geological Survey (USGS)

The Biological Research Division's (BRD) Alaska Biological Science Center maintains a seabird database and a pelagic seabird atlas The Alaska Biological Science Center (Biological Resources Division, U.S. Geological Survey) is the lead biological science agency for the Department of the Interior (DOI) in Alaska, where it conducts research on wildlife and their habitats on Federal public lands and waters Federal public lands in Alaska cover a geographic area equivalent to the all of the Eastern seaboard from Maine through Florida and include nearly all of the country's National Wildlife Refuges (88 percent) and most of its National Park lands (65 percent) Clients of ABS include the National Park Service, Fish and Wildlife Service, Bureau of Land Management, and Minerals Management Service The responsibilities of ABS also include providing scientific information essential for resource management decisions for DOI trust species such as migratory birds, marine mammals, and anadromous fish species

BRD cooperates with many other projects from several agencies to obtain the contents of this database. In addition, since the 1970s BRD has had an extensive seabird-monitoring project at Middleton Island, the Marine Biological Station BRD also is in the process of assembling the Pacific Seabird Monitoring Database. The Alaska Marine Mammals Tissue Archival Project (AMMTAP) and the Seabird Tissue Archival Monitoring Project (STAMP) are probably the most significant contaminants studies in Alaska

The Water Resources Division of the USGS in Alaska maintains the Cook Inlet Basin Study Unit, part of the National Water Quality Assessment program (NAWQA), which examines trends in water quality over a nine-year period NAWQA takes measurements to determine water chemistry in streams and aquifers, the quantity of suspended sediment and the quality of bottom sediments in streams, the variety and number of fish, benthic invertebrates and algae in streams, and the presence of contaminants in fish tissues The Water Resources Division also maintains a long time series of measurements of groundwater and freshwater runoff for various stations in Alaska

The Geologic Division has the capability to produce high-resolution maps of the sea floor through its Marine and Coastal Geology Program in Menlo Park, California

U S Department of Agriculture (USDA)

U S Forest Service (USFS) has substantial responsibility for controlling and directing the impacts of human uses The USFS conducts occasional surveys of recreational use in PWS These surveys are not conducted on a regular basis and are therefore not intended to serve as a long-term monitoring instrument The USFS also reports on use of campgrounds, visitor centers, and other facilities operated by the agency in the North Pacific region The Forest Service has extensive experience in watershed analysis and planning for ecosystem-based management Their extensive experience in developing scientific information relevant to balancing multiple uses of public lands and waters is available for planning monitoring and research

US Department of the Navy (USN)

Ocean observations collected by the US Navy were originally developed around two objectives due to national security reasons (1) Up-to-date forecasts for open ocean waves, weather, and ice flow patterns for the safety of fleet operations, and (2) the Cold War requirement for open-ocean temperature, salinity, and sound velocity measurements to support sonar performance in the tracking of Soviet ballistic-missile submarines. The national securitysupported ocean observation system has, therefore, included heavy emphasis on open-ocean temperature, salinity, winds, and ice observations. Several elements included in that system are expendable temperature probes that measure temperature with water depth as the probe falls through the water column, used by navy ships and aircraft to take bathyermograph (XBT) measurements around the globe during fleet operations, and satellite temperatures of the sea surface taken by infrared satellite sensors

National security requires real-time global data and the Navy acts as a national Core Processing Center for sea surface temperature (SST) data from various satellites and disseminates the data to civil and military users worldwide Other types of satellite measurements are used in remote areas where ship and buoy measurements are not readily available Satellite altimetry measures the height of the sea surface roughness to infer winds Products include sea-surface topography, currents, eddies, wave heights, and surface wind-speed and direction

Drifting buoys are deployed yearly by the Navy with hourly feedback via satellite They measure surface atmospheric pressure, air and sea surface temperature, winds and waves, and surface currents, that provide excellent "ground-truth" for satellite observations, as well as water temperature with depth, and "ambient" (background) noise levels that support Nave sonar operations

The National Ice Center receives information from the Navy, NOAA, and the Coast Guard on global, regional, and local sea-ice analyses and forecasts, including ice edge, concentration, drift, and thickness, for military and civil users Ice observations come from US and European satellites, US and Canadian ice reconnaissance flights, and from specially instrumented buoys placed each year through the Arctic ice

A dedicated fleet of Navy ships has collected the following data for years water depth, bottom type, tides and currents or "hydrographic" data in coastal areas worldwide to improve and update nautical charts, deepwater bathymetry (water depth) and gravity measurements to support strategic submarine operations, physical oceanography (temperature, salinity, sound velocity), ambient noise, seafloor structure, and sediment type to support sonar performance and acoustic surveillance arrays, and a wide range of other observations (water clarity, bioluminesence, currents, magnetics) that affect naval operations

The Navy's national security needs for ocean data are now focused not only in the open ocean but also increasingly on the coastal waters of the world The Navy is a significant supporter of a national academic research fleet, funding both worldwide basic ocean observations and applied research projects The Navy requires data from the open ocean through coastal waters, the surf zone, and over the beach to sustain modern naval operations Because of the greater variability, shallow coastal waters require more observations in time and space Of particular interest are water depth, sea surface temperature and temperature at depth, bottom type, waves, tides, currents, and coastal ambient (or background) noise While the main national security requirements for coastal ocean observations are in sensitive areas overseas, the diversity of environments in U.S. coastal waters provides many analogues of coastal systems overseas. For this reason, national security needs must play a significant role in design of the coastal observing system. Navy home-porting, and coastal training, test and exercise functions in U.S. waters require expanded observations

The US Naval Observatory (USNO) is the basic source of information on the effect of astrophysics on climate change The Earth's orbit, its orientation in space, and its angle of inclination toward the sun, as measured by the USNO, all play important roles in determining climatic conditions The USNO is the world's leading authority in the areas of measuring day length, celestial observing, and other fundamental astronomy

US Department of Transportation (USDOT)

U S Coast Guard (USCG)-- USCG ocean data buoys take synoptic meteorological and oceanographic measurements for both the National Data Buoy Center and the National Ice Center They also provide a number of other ocean and lake observations The USCG operates a Vessel Traffic Service (VTS) for nine United States coastal ports Each VTS is a service of active waterways management using advanced technology such as radar, closed circuit TV, differential GPS (DGPS), and VHF-FM radio communications In addition, the VTS also receives information from various sources on predicted vessel movements, hazards to navigation, aids to navigation discrepancies, and other information of interest to VTS users The VTS involves individuals off the vessel that receive, process, and communicate information related to the safe navigation of a waterway with a primary focus of public safety and protection of the environment. This information is communicated in general public advisories or in the form of specific recommendations to assist a vessel in avoiding hazardous conditions early on. VTS does not usually interfere with the vessel's sailing route

Sea ice and icebergs are monitored by the International Ice Patrol (IIP), which is supported by seventeen member nations and operates in the North Atlantic under the provisions of the US Code and the International Convention for Safety of Life at Sea (SOLAS) It monitors iceberg danger near the Grand Banks of Newfoundland during the ice season, and advises ships about safe and efficient navigation routes The USCG International Ice Patrol sets drifting buoys for the use of iceberg/sea ice prediction. The observations of position and sea surface temperature are reported via satellite eight times per day. The IIP obtains water temperature profiles from AXBTs

deployed by Coast Guard aircraft and sea surface temperature data made available by commercial ships These data are sent to the Navy The National Ice Center provides sea-ice analyses and forecasts using data from satellites, aircraft reconnaissance flights, and arctic buoys received from the USCG, NOAA, and the Navy USCG polar icebreakers provide a number of oceanographic observations in the Arctic and Antarctic to Navy, NIMA, and/or NOAA databases The reports include ocean temperature, salinity, bathymetry, and marine mammal data

USCG cutters send weather information to the Navy and NOAA Coast Guard stations also send meteorological data to NOAA for use in analyses and for ecasts

U S Department of Energy (USDOE)

The Department of Energy, Biological, and Environmental Research (DOE-BER) is funding peer-reviewed research in marine biology and oceanography relating to the impact of anthropogenic CO2 on global warming DOE also encourages technological developments that support new global ocean observational capabilities Examples of specific programs include

- Marine Biotechnology the application of the tools of modern molecular biology to linkages of carbon and nitrogen cycles
- Synthesis of Global CO2 Data (with NOAA) development of tools and models to synthesize the existing data set on ocean CO2 and related parameters
- Quality Assurance of CO2 Survey Data QA/QC and dissemination of CO2 data through the Carbon Dioxide Information Analysis Center
- Carbon Sequestration in the Ocean establishment of center(s) of excellence as part of the Climate Change Technology Initiative

Intergovernmental Organizations

Bristol Bay Marine Mammal Council (BBMMC)/Bristol Bay Native Association (BBNA)

The BBMMC was formed in 1995 by the thirty-one member tribes of the BBNA and works closely with marine mammal

organizations to best utilize our resources and avoid redundancy in monitoring efforts The larger body is governed by a seven member Executive Council which consists of one representative from each of the five sub-regions of Bristol Bay and two at-large members The general membership and the Executive Council are a accurate representation of the people from each sub-region The Executive Council can come together and discuss the marine mammal concerns of each sub-region and look for ways to resolve those concerns

The BBMMC recognizes the dynamic nature of the marine ecosystem and the difficulties associated with large scale research efforts To best use limited funding, the BBMMC supports expansion to the Bristol Bay region of successful programs that currently exist in other regions of Alaska

- Harbor seal biosampling program,
- Harbor seal harvest monitoring,

- ArcView mapping of projects, and,
- Consensus building among Bristol Bay area villages

Pacific Coastal Salmon Recovery Program

The US Congress, recognizing the need to assist states and tribes with Pacific Coastal Salmon Recovery, appropriated funds for the states of Alaska, Washington, Oregon and California, as well as the treaty fishing tribes in the Pacific Northwest

This is a cooperative program that assists the states in fulfilling responsibilities under the Pacific Salmon Treaty by providing administrative, management, and applied research support to the states' treaty Indian tribes to meet the needs of the Pacific Salmon Commission and U S international commitments under the treaty

Since implementation of the Pacific Salmon Treaty in 1985, the States of Washington, Oregon, Idaho, and Alaska have provided the necessary support to and have been involved with the Pacific Salmon Commission in accordance with the treaty Alaska has provided and continues to provide technical support necessary for supporting and enhancing the U S position on Yukon River salmon, Taku and Stakine river salmon and salmon fisheries in ongoing negotiations with Canada In fiscal year 1999, four awards were made It is anticipated that eight awards will be made in fiscal years 2000 and 2001 For the Pacific Coast Salmon Recovery Program, it is anticipated that five awards will be made in fiscal years 2000 and 2001

The State of Alaska intends to apply the salmon funds over a five-year period to address salmon issues in Southeast Alaska, east of Cape Suckling The general project areas are

- Research and Monitoring the focus is on important salmon producing streams and systems - uplands through estuaries, wild salmon stocks, transboundary rivers, and identification of habitat stewardship and restoration priorities,
- Habitat Stewardship and Restoration the focus is on on-the-ground fish passage remediation projects on state, local, Native and private lands with initial focus on Coho, Chinook, and sockeye watersheds adversely impacted by human practices, and ensuring important habitat is not degraded,
- Improve Economics of SEAK Fishing the focus is on the broad range of projects to mitigate impacts of Pacific Salmon Treaty on fisherman and fishing communities in SE Alaska, and,
- Cooperative Programs the focus is on cooperative or joint projects with Pacific Northwest tribes, tribal entities, Canada, and/or Pacific Northwest states on salmon habitat or stocks of common concern

Nongovernmental Organizations

Alaska Beluga Whale Committee (ABWC)

The ABWC was formed in 1988 to promote conservation and management of beluga whales, obtain better harvest information, and provide a means of better communication

between beluga hunters, biologists and agencies

The ABWC brought together representatives from beluga hunting communities in Alaska, local, state and federal governments, and beluga researchers to discuss conservation issues, the biology of belugas, and the needs for additional information They initiated a program to obtain reliable harvest data, prepare a beluga management plan, and to encourage beluga research

To date, the ABWC has accomplished the following

- adopted the Alaska Beluga Whale Management Plan,
- signed a Co-management Agreement foi Western Alaska Beluga Whales,
- obtained harvest information from ABWC members since 1988 and supported harvest monitoring and sampling,
- conducted aerial surveys of Norton Sound, Bristol Bay, and the Chukchi Sea,
- funded a genetic stock ID study using samples from hunters, with results that support the genetic discreteness of five stocks,
- supported contaminant studies of belugas in the eastern Chukchi Sea and Cook Inlet,
- produced newsletters informing coastal residents and others about important beluga research and management activities, and
- successfully satellite tagged belugas in the Chukchi Sea in 1998 and 1999 and started a pilot program in Norton Sound

Alaska Center for the Environment (ACE)

This is the largest membership-based environmental organization in Alaska with 7,000 paying members. Their main issue is public lands protection, but they are also active in public water issues, especially watersheds. They are also a member of the Prince William Sound Alliance. They have nine full-time year round employees plus summer interns and volunteers and an annual budget of \$750,000. Major concerns relevant to GEM are watershed interactions with the marine environment and contaminants issues.

Alaska Community Action on Toxics

This organization protects human health from toxic contamination from industry and the military, often focusing on environmental justice Their approach is a blend of advocacy, research, and service They are strong in the area of community involvement and provide technical assistance to rural communities dealing with toxics issues Major programs address issues of Water Quality Protection, Pesticide Right-to-Know, Northern Contaminants and Health, and Military Toxics and Health Their key issues are contaminants, pesticide dispersal, bioaccumulative toxics, an international treaty on POPs, and targeting pollution at its source via the permitting process. The organization has six staff including researchers and community organizers and has a geographic scope of all Alaskan terrestrial, aquatic, and marine environments. They may be able to collaborate with the GEM Program in the following ways

Sharing information about contaminants

- Training local community members how to test for contaminants in the environment
- Training youth to do stream sampling, possibly in conjunction with Youth Area Watch
- Documenting pesticide use in Alaska

http //www akaction net

Alaska Conservation Foundation

This state organization raises funds, gives grants, and creates programs to protect Alaska's ecosystems, both marine and terrestrial, and promote sustainable livelihoods They fund and create other programs and organizations such as Alaska Oceans Network and Alaska Community Action on Toxics, and have an internship program designed to bring college students into the conservation field They have eight office staff and twenty-two Trustees, and grant on the order of \$2.4 million per year on programs ACF is high familiarity with the GEM Program and sees many collaboration opportunities including

- Steering other groups toward GEM that might benefit from the program
- Sponsoring training for other groups to use the GEM database
- Getting other groups to use GEM's info (Data distribution and advertising)

Their Web site is http //www akcf org

Alaska Eskimo Whaling Commission (AEWC)

The mission of the AEWC is to provide leadership, guidance, and coordination in the administration and implementation of policies and programs established by the AEWC Board of Commissioners, and in the successful implementation of the AEWC-NOAA Cooperative Agreement as it relates to the whaling captains and crew members that make up the AEWC in the ten subsistence whaling communities The AEWC was formed in 1977 to represent the whaling communities in an effort to convince the U.S. Government to take action to preserve the Eskimos subsistence hunt of bowhead whales. Its purpose is

- to preserve and enhance a vital marine resource, the bowhead whale, including protection of its habitat,
- protect Eskimo subsistence bowhead whaling,
- protect and enhance the Eskimo culture, traditions, and activities associated with the bowhead whales, and subsistence bowhead whaling, and,
- to undertake research and educational activities related to bowhead whales

The following goals were established to carry out these purposes

 ensure that the hunt of the bowhead whale is conducted according to the AEWC Management Plan in a traditional, non-wasteful manner,

- promote extensive scientific research on the bowhead whale so as to ensure the continued health of the bowhead whale stock, and,
- communicate to the outside world the facts pertaining to the subsistence bowhead whale hunt, the manner in which it is conducted, the Eskimo's knowledge of the whale, and the centrality of the hunt to the cultural and nutritional needs of the Eskimos

Alaska Marine Conservation Council (AMCC)

This community-based marine conservation group deals with fishing issues, habitat protection, wildlife declines, public outreach, and research They work through the Board of Fish, Congress, NMFS, and the North Pacific Fisheries Management Council Their key issues include Steller sea lion declines, bycatch, sustainable fishing, groundfish SEIS, seafloor habitat, marine habitat protection, and implementation of Magnuson-Stevens Act They have ten staff and fifteen members of Board of Directors including fishermen, subsistence harvesters, marine scientists, conservationists, and small-business owners Their geographic scope includes Alaska's oceans, especially coastal/nearshore environments From GEM, they are interested in fishing impacts, essential fish habitat, habitat requirements of commercial and non-commercial species, and habitat distribution on the sea floor They may act as a conduit to distribute and advertise information provided by the GEM Program

Alaska Oceans Network

This is a voluntary association of conservation, fishing, and Alaska Native organizations, whose goal it is to restore and maintain healthy marine ecosystems in Alaska Participants of the *Alaska Oceans Network* share a mutual concern about the deterioration of the North Pacific marine environment and the adverse impacts of this deterioration on biodiversity, the subsistence and cultural needs of Alaska Natives, and sustainable community-based fisheries They believe in the fundamental importance of maintaining a healthy and diverse marine ecosystem, which is central to sustaining subsistence way of life and stable coastal communities

The Network is focusing on federal groundfish fisheries reform. We believe that critical reforms are necessary to reduce bycatch, protect habitat, and to maximize sustainable, ecosystembased fishery management practices. They are seen by many groups as a conduit between conservation organizations and scientific researchers. The organization has five issue-oriented staff and an annual budget of \$750,000. They may collaborate with the GEM Program through data distribution and community outreach.

Aleut Marine Mammal Commission (AMMC)

The Aleut Marine Mammal Commission (Commission) was formed primarily for the following purposes

- to encourage and implement self-protection and self-regulation of marine mammal use by coastal Alaska natives by involving Native users in the decision making process,
- to provide education and information to the public, appropriate management agencies, and other interested parties,

- to represent its member coastal Alaska native communities in reviewing and commenting on regulatory changes or resource development which may affect marine mammals,
- to promote conservation of marine mammals for use by Alaska Natives,
- to be involved in all phases of scientific, biological, and other research programs involving marine mammals,
- to actively participate in the formulation of, and/or implementation of harvest monitoring efforts and protection of the marine mammal population, and,
- to encourage the Aleut Marine Mammal Commission, government of the United States, and other nations and indigenous groups to cooperate in exchanging information that contributes toward improved management of marine mammal populations

Currently, the Commission includes representatives from the communities of Nikolski, Atka, Unalaska, Akutan, False Pass, Nelson Lagoon, King Cove, Sand Point, and Cold Bay The Commission gathers and disseminates local knowledge regarding the Steller sea lion and other marine mammals in the Aleutian Islands and along the Alaska Peninsula Information will include but is not limited to

- the current level of subsistence take in these communities,
- historical perspectives on subsistence harvests,
- changes in mammal populations and local marine environments, and,
- Information on the historical and current distribution of marine mammals

The goal of the Commission is to provide information on subsistence harvest, particularly Steller sea lions, which will assist state and federal agencies in the management and conservation of the species

Alaska Native Harbor Seal Commission (ANHSC)

The ANHSC is a tribal consortium organized by Native Communities within the range of the harbor seal and founded with support from the *Exxon Valdez* Oil Spill Trustee Council, the National Marine Fisheries Service, and other sources The ANHSC region extends along the Pacific coast from southeast Alaska to the western tip of the Aleutian Island Chain The region encompasses six coastal areas represented by six ANCSA regional corporations including Southeast Alaska, Cook Inlet, Chugach, Kodiak, Bristol Bay, and Aleut The overall purpose of the ANHSC is to strengthen and increase the role of Alaska Natives in resource policy decisions affecting harbor seals and to maintain their cultural uses The goals of the ANHSC include

- educating and informing the public and western scientists on the traditional and contemporary relationship between harbor seals and Alaska Natives,
- informing western scientists about the type and extent of knowledge held by the local people about the harbor seal,
- involving Alaska Natives directly in harbor seal research, and,

 involving Alaska Natives in the management of haibor seals through co-management as provided for in Section 119 of the Marine Mammal Protection Act

In April of 1999 ANHSC and NMFS finalized and signed a co-management agreement for Harbor seals in Alaska that delineates the shared roles and responsibilities of each of the parties in harbor seal management. The goal and primary objective for the ANHSC continues to be to develop a solid working relationship between the federal government and the tribal governments as represented by the ANHSC. The co-management committee, comprised of three Alaska Natives and three NMFS people, has been established. Staff will

- work with involved villages to implement the guidelines of the agreement through village codes and ordinances,
- be responsible for the complimentary programs, such as outreach and education, and,
- act as a liaison between villages, the planners, and the federal agencies through the comanagement process

Alaska Sea Life Center (ASLC)

ASLC, located in Seward, is a regional center for research on marine life, including mammals, sea birds, and fish University and government scientists who need to learn how to care for marine resources use the laboratories, salt-water tanks, and marine aviaries of the Center It is an important regional research center for studies of the Steller sea lion The ASLC is open to the public and offers its facilities and staff for community and state educational purposes

Anchorage Waterway Council (AWC)

AWC is a nonprofit organization whose membership resides in the Municipality of Anchorage and believes that Anchorage's waterways and related habitats are a valuable resource AWC focuses on waterways within the Municipality of Anchorage and intends to prohibit further degradation The Council seeks to enhance the waterways through public outreach and education, ensuring safe and productive aquatic and riparian habitat for fish, wildlife, and monitoring activities that affect the Municipality's waterways

Audubon Alaska

This is the Alaska office of the highly credible and respected National Audubon Society, which is focused on the protection of natural ecosystems, emphasizing birds, other wildlife, and their habitat They do this through science-based advocacy, education, and on-the-ground conservation projects The Alaska office has four full-time staff, composed of biologists and birders and a budget of \$400,000, about 15-20 percent of which is dedicated to marine issues Their key issue related to GEM is the Important Bird Areas project located in Cook Inlet and the Bering Sea Audubon could provide information on good places to monitor seabirds, while GEM could help identify and monitor the IBAs Major strengths of this organization are that it involves residents in gathering useful scientific data and hosts training workshops for bird identification

Census of Marine Life (CoML)

CoML is being developed as a decade-long program to promote and fund research assessing and explaining the diversity, distribution, and abundance of species in the world oceans Related activities integral to this research include the design and implementation of innovative biological sampling techniques for the marine environment. Consultations and workshops during 1997-1998, largely funded by the Alfred P. Sloan Foundation (New York City), explored the potential benefits, issues (technical, scientific, and social), and limits of a marine census. A broad set of precepts for the Census of Marine Life has been prepared. An international Steering Committee fosters development of coherent goals and a scientific plan for the CoML. Planning and development for the Census is expected to require one to two more years. Pilot field projects should take place in 2002-2004. The main field projects should occur in 2005-2008. Analysis and integration of information should culminate in 2008-2010. The Ocean Biogeographical Information System (OBIS) is envisioned to be a distributed network of marine biological and environmental data for use in examining the changes in diversity, distribution, and abundance of organisms over time and space. OBIS is expected to be the means by which CoML gathers and distributes its information.

Center for Alaskan Coastal Studies (CACS)

CACS is a nonprofit group whose mission includes the generation of knowledge of the marine and coastal ecosystems of Kachemak Bay through environmental education and research programs The Center supports an annual Coast Walk program in Kachemak Bay for citizen collection of data about intertidal areas, and incorporates water quality and intertidal monitoring into school education programs

Conservation GIS Support Center

This organization, administered through the Alaska Conservation Alliance, provides conservation-related GIS services for conservation groups at a subsidized rate They strive for unbiased data presentation of anything mappable that relates to conservation They might collaborate with the GEM Program in the following ways

- Data sharing, especially in ESRI formats compatible with GIS
- Could provide maps of processes described in GEM
- Could train GEM staff about GIS (showing fast, efficient ways to express data)
- All their maps can be used free of charge in GEM publications as long as they receive credit

Consortium for Oceanographic Research and Education (CORE)

CORE promotes, encourages, develops, and supports efforts to advance knowledge and learning in the science of oceanography and to disseminate such knowledge to the scientific community and to the public It serves as a coordinating body for more than fifty marine-related institutions in the United States, including universities, governmental laboratories, and nonprofit aquaria CORE is the base for the International Steering Committee for the Census of Maune Life and the Secretariat, which the Steering Committee guides CORE also acts as the Program Office for the National Oceanographic Partnership program, NOPP

Cook Inlet Keeper (CIK)

CIK is a nonprofit group dedicated to protecting Cook Inlet's watershed The Lower Kenai Peninsula Watershed Health Project monitors four high value salmon streams with increasing human use This group also trains volunteers to monitor water quality at many sites in the Cook Inlet watershed Currently, monitoring sites are established around Kenai, Homer, and Anchor Point Parameters measured are temperature, pH, dissolved oxygen, salinity, turbidity, conductance, bacteria, oxidation-reduction potential, macroinvertebrates, ortho-phosphate, apparent color, and nitiate-nitrogen

Eastern Kenai Peninsula Environmental Action Association (EKPEA)

This small, local organization in Seward aims to facilitate effective individual and group action on environmental issues affecting the Eastern Kenai Peninsula Their major concerns are the impact of tourism activities on Eastern Kenai marine environment and the protection of archaeological sites

Earthjustice Legal Defense, Inc - Alaska Office

Earthjustice is a non-profit public interest law firm dedicated to protecting the magnificent places, natural resources, and wildlife of this earth and to defending the right of all people to a healthy environment. They bring about far-reaching change by enforcing and strengthening environmental laws on behalf of hundreds of organizations and communities. They have nine offices nationwide, about five lawyers per office plus support staff and roughly one-third of the Alaska office's resources focus on the marine environment. Their key issues include fishing, ESA listings, and oil development.

Kenai River Sportfishing Association (KRSA)

KRSA is a nonprofit organization that provides financial support for riparian zone habitat conservation and rehabilitation KRSA works in cooperation with other organizations, such as state and federal land and fisheries management agencies, and volunteers to stabilize and revegetate banks eroded by human recreational use and housing development. KRSA has also been instrumental in widespread installation of riverfront walkways on public and private property The walkways are constructed of open metal bar screen that allows riparian plants to grow for bank stabilization, while preventing erosion from trampling by humans and providing access for recreation

Monterey Bay Aquarium Research Institute (MBARI)

MBARI is a private, non-profit research center funded by The David and Lucile Packard Foundation Founded in 1987, it is located at Moss Landing, California In the words of its founder, David Packard, "The mission of MBARI is to achieve and maintain a position as a world center for advanced research and education in ocean science and technology, "MBARI's efforts cover eight research themes, 1) benthic processes, 2) midwater research, 3) upper ocean biogeochemistry, 4) MBARI Ocean Observing System (MOOS), 5) remotely operated vehicle enhancements and upgrades, new in situ instruments, infrastructure support, and information dissemination and outreach It has two research ships, and is developing remotely operated vehicles nearby Monterey Bay MBARI maintains offshore moorings that are equipped with ocean-monitoring instruments Two MBARI moorings in the equatorial Pacific are part of the NOAA Tropical Atmosphere Ocean (TAO) array that plays an important role in studying the development of events in the El Nino southern oscillation

National Outdoor Leadership School (NOLS)

NOLS was founded in 1965 and is the leader in wilderness education NOLS is the largest backcountry permit holder in the United States and offers courses on four other continents NOLS is committed to the quality of courses and programs offered in the wilderness environment that serves as its classroom

National Wildlife Federation

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The Alaska office is one of ten regional offices throughout the U.S. Their goal is to protect fish, wildlife, and the wilderness character of wild lands nationwide. They have seven full-time staff plus volunteers/interns and a budget of \$250,000/yr. Their key issues of concern in the Alaska marine environment are establishing a terrestrial wilderness designation for the Copper River Delta and establishing Marine Protected Areas in Prince William Sound. They formed and chair the Prince William Sound Alliance. Possible collaboration with the GEM Program may include

- Jointly creating a "keeper" program to monitor Prince William Sound
- Public awareness of PWS biology
- Disseminating GEM monitoring results to public
- Work on the re-opener case with Exxon for unanticipated spill damages

North Pacific Universities Marine Mammal Research Consortium (NPUMMRC)

MMRC was formed with four participating institutions the University of Alaska, the University of British Columbia, the University of Washington, and Oregon State University The mission of the Consortium is to undertake a long-term program of research on the relationships between fisheries and marine mammals in the North Pacific Ocean and Eastern Bering Sea Studies will focus initially on the biology of the Steller sea lion and could include research on the effects of species interactions and oceanographic conditions on changes in sea lion abundance

Oceana

Oceana is a new non-profit, international advocacy organization created with the sole purpose of protecting the world's oceans to sustain the circle of life. We bring together dedicated people from around the world, building an international movement to save the oceans through public policy advocacy, science and economics, legal action, grassroots mobilization, and public education. They have a North Pacific office located in Juneau, Alaska

Ocean Conservancy

This nationwide marine conservation non-profit has been around for thirty years and focuses on marine mammals, dolphin-safe tuna, ocean wilderness, and sustainable fisheries Their key issue in Alaska is Marine Protected Areas, especially in Prince William Sound and Glacier Bay They may be able to find information gaps and synthesize information about Prince William Sound

Partners in Science Program

The M J Murdock Charitable Trust, Paitneis in Science Program sponsors high school science teachers' participation in research with scientists during two summers

Partnership for the Interdisciplinary Study of Coastal Oceans (PISCO)

PISCO is a long-term ecological consortium that consists of four universities (Oregon State University, UC Santa Cruz, Stanford University, and UC Santa Barbara) investigating the physical and biological processes of the nearshore region along the Oregon and California coasts The David and Lucille Packard Foundation originally funded PISCO to provide a new model for solving environmental problems faced by our seas

Prince William Sound Aquaculture Corporation (PWSAC)

PWSAC is a private non-profit corporation founded in 1974 under state law designed to promote development and operation of salmon hatcheries with the participation of local commercial harvesters Headquartered in Cordova, PWSAC operates four salmon hatcheries at sites throughout Prince William Sound, as well as one at the town of Paxson on the Copper River PWSAC produces pink salmon, sockeye salmon, Coho salmon and Chinook salmon The returning adults benefit commercial, sport fishing, personal use, and subsistence users, and also provide cost recovery to fund hatchery operations

Using technology developed and implemented with the support of the *Exxon Valdez* Oil Spill Trustee Council, PWSAC annually marks all of the more than 500 million juvenile pink salmon released from its hatcheries each year. The marks permit precise estimation of the proportion of hatchery salmon harvested, which permits protection of wild salmon during hatchery harvests The marks also permit highly precise estimates of marine survival, and detection of pink salmon of PWS origin in samples on the high seas

Prince William Sound Oil Spill Recovery Institute (OSRI)

OSRI was authorized by the United States Congress through Section 5001 of the Oil Pollution Act of 1990 (OPA 90) and through amendments included in the Coast Guard Authorization Act of 1996 The institutional goals of OSRI recognize long-range monitoring programs as essential to assessment and understanding of the long-range effects of arctic or subarctic oil spills on the natural resources of Prince William Sound and its adjacent waters

Prince William Sound Science Center (PWSSC)

PWSSC is an independent, non-profit organization devoted to implementing an ecosystem approach to research, monitoring, and management of natural resources The Science Center played an important role in implementation of the Trustee Council's ecosystem study, the Sound Ecosystem Assessment (SEA) (Section IV A 2)

Regional Citizens Advisory Council (RCAC)

RCAC bodies were established following the 1989 *Exion Valdez* oil spill under the federal Oil Pollution Act of 1990 (OPA 90) The act established, among other things, demonstration programs to involve local citizens in overseeing the environmental impact of oil terminals and tanker operations in two locations, Cook Inlet and PWS

Cook Inlet Regional Citizens Advisory Council (CIRCAC) monitors the environmental impacts of terminals and tankers in Cook Inlet The CIRCAC's environmental monitoring program includes studies of sediment chemistry, hydrocarbon accumulation, sediment toxicity, and ballast water issues

The PWS Regional Citizens Advisory Council (PWSRCAC) has conducted an environmental monitoring program for the past six years The Long-Term Environmental Monitoring Project monitors nine sites in PWS and the North Pacific region for hydrocarbons in the water, sediment, and mussels The data provide a benchmark for assessing the impacts of oil transportation and future oil spills The study discriminates among hydrocarbons resulting from biological processes, combustion sources (pyrogenic), and petroleum products or residues from natural coal deposits (petrogenic) The PWSRCAC has also studied the risk of invasion by non-indigenous species through the discharge of ballast water, control of tanker loading vapors, ballast water influent at the Valdez Marine Terminal, and the use of caged mussels to monitor effluent from the Alyeska Ballast Water Treatment Facility

Trustees for Alaska

This is a non-profit environmental public interest law firm formed in response to North Slope oil and pipeline construction It was originally an advocacy group, but now provides legal support to conservation groups regarding administrative and legal processes and has been around for twenty-five years The organization has eight lawyers plus support staff and is highly interested in anthropogenic effects on the marine environment, especially fishing

The Wilderness Society

Founded in 1935, The Wilderness Society is a 175,000-member nonprofit organization dedicated to the creation of a nationwide network of wild lands through public education, scientific analysis, and advocacy They work with federal agencies on planning, especially concerning the human component of management, such as Limits of Acceptable Change Their key issues relate to federal law and policy, oil/gas development, marine sanctuary issues They have a nationwide scope, but in Alaska, they are interested mostly in Prince William Sound and Glacier Bay They have four issue-oriented staff at Anchorage office They may collaborate with GEM by

- Acting as a watchdog group to ensure that federal agencies integrate GEM science into their policies
- Synthesizing GEM information so it is applicable to resource managers
- Making sure agencies monitor beaches and watersheds
- Using GEM data to help agencies establish Limits of Acceptable Change

World Wildlife Fund

This organization is a major international environmental group seeking to define and protect areas of high biodiversity throughout the globe The largest privately supported international conservation organization in the world, WWF has more than one million members in the U S alone Since its inception in 1961, WWF has invested in over 13,100 projects in 157 countries

WWF directs its conservation efforts toward three global goals protecting endangered spaces, saving endangered species and addressing global threats From working to save the giant panda, tiger, and rhino to helping establish and manage parks and reserves worldwide, WWF has been a conservation leader for forty years

Their key issues are biodiversity loss, fishing, education, outreach, habitat conservation, and oil development In the North Pacific, their focus is on the Bering Sea and the Chukotka Peninsula in Russia

Transboundary Organizations

Transboundary organizations coordinate informationgathering across national, provincial and state boundaries As a result of transboundary conventions addressing fishery management, pollution control, and other matters of concern in

the North Pacific, multinational and interstate management institutions have been in place for most of the twentieth century These institutions have amassed some of the longest time series of biological observations in the North Pacific

Arctic Monitoring and Assessment Programme (AMAP)

The Arctic Monitoring and Assessment Programme (AMAP) is an international circumpolar program which seeks to monitor anthropogenic pollutants in all parts of the arctic environment. Observations extend into the Bering Sea At a meeting in Rovaniemi, Finland, the nations of Canada, Denmark/Greenland, Iceland, Norway, Sweden, the Soviet Union, and the United States entered into the "Rovaniemi process" to promote arctic environmental protection The "Rovaniemi process" produced a series of "State of the Arctic Environment" reports on potential pollutants in different parts of the arctic environment and its ecosystems in 1991 The First Arctic Ministerial Conference in Rovaniemi, Finland established international cooperation for the protection of the arctic, and led to the adoption of the Arctic Environmental Protection Strategy (AEPS) The AMAP reports contain time series data on contaminants in the areas of interest. The policy body for AMAP is the Arctic Council

Conservation of Antarctic Marine Living Resources (CCAMLR)

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) was founded in 1982 as part of the Antarctic Treaty System, in response to concerns that an increase in krill catches in the Southern Ocean could have a serious effect on populations of krill and other marine life, particularly on birds, seals, and fish which mainly depend on krill for food

The CCAMLR Ecosystem Monitoring Program (CEMP) is a scientific program intended to identify changes in condition, abundance, and distribution of the animals within the convention area Since it is not realistic to monitor all the animals and their interactions that make up the antarctic marine ecosystem, CEMP identified species and parameters likely to be particularly sensitive to changes in food availability CEMP takes into account information obtained from monitoring these species in determining the regulation of human activity so as to ensure that the conservation principles of the convention are being applied

The parameters being studied fall into four categories reproduction, growth and condition, feeding ecology and behavior, and abundance and distribution Any changes found in the parameters will be because of changes either in food availability or environmental conditions. In order to identify the source of change, it is necessary to monitor krill abundance, krill distribution, and certain environmental parameters simultaneously with the monitoring of predators.

International North Pacific Fisheries Commission (INPFC-NPAFC)

The International North Pacific Fisheries Commission (INPFC) (1952-1993, U.S., Canada, Japan) and its successor, the North Pacific Anadromous Fish Commission (NPAFC) (1993 on), coordinate research and harvest of salmon and other anadromous species above latitude 330 N outside the 200-mile zones of the signatories Signatory nations are the United States, Canada, Japan, and Russia and the cooperating nations are Poland, South Korea, and Tarwan The INPFC published long time series of catches for principal groundfish species, crab, shrimp, and herring for the signatories and cooperating nations The INPFC statistical yearbooks (produced from 1952-1992) contain biological time series on groundfish, crabs, and marine mammals The NPAFC statistical yearbooks (produced from 1993-1995) are the definitive source for catch, weight, and hatchery releases for salmon in the North Pacific, as well as principal groundfish species, crab, shrimp, and herring

International Pacific Salmon Fishing Commission (IPSFC-PSC)

The International Pacific Salmon Fishing Commission (IPSFC) (1937-1985) was established by the United States and Canada in 1937 to restore the sockeye salmon of Canada's Fraser River and to allocate the catches between nations The IPSFC and its successor, the Pacific Salmon Commission (PSC), have compiled a very long time series of annual Fraser River salmon production, augmented by substantial time series of estimated sockeye salmon productivity by year of spawning The Pacific Salmon Commission was established by the Pacific Salmon Treaty (PST) between the United States and Canada in 1986 The PSC also has time series of annual harvest and exploitation rates for selected chinook salmon populations, as well as catch and other time series data for all salmon species

Northern Fund - Pacific Coastal Salmon Recovery Program (PSC)

The Northern Boundary and Transboundary Rivers Restoration and Enhancement Fund was established by Canada and the United States under the revised 1999 annexes to the Pacific Salmon Treaty The Northern Fund shall be used to support the following activities

- Development of improved information for resource management, including better stock assessment, data acquisition, and improved scientific understanding of factors affecting salmon production in the freshwater and marine environments,
- Rehabilitation and restoration of habitat, and improvement of natural habitat to enhance productivity and protection of Pacific salmon, and
- Enhancement of wild stock production through low technology techniques rather than through large facilities with high operating costs

The Northern Fund Committee ("the Committee") is responsible for approving expenditures from the fund The Committee consists of three US and three Canadian representatives

The Pacific Salmon Treaty's Fisheries Management and Stock Assessment are broken down into different annexes that are listed with their objectives in the sections below

PST Transboundary Rivers Annex:

- manage the district 106, 108, and 111 commercial net fisheries in such a manner as to abide by Treaty harvest sharing arrangements,
- provide estimates of the stock composition of the sockeye salmon harvested in Subdistricts 106-41, 106-30, District 108, and District 111 gillnet fisheries for each week of the fishing season,
- estimate the number of Transboundary Stikine River sockeye harvested in Subdistricts 106-41, 106-30, District 108, and Transboundary Taku River sockeye harvested in District 111,
- collect otoliths from sockeye salmon harvested in District 108 and 111 fisheries to allow estimation of the contribution of enhancement projects to the harvest,
- estimate the escapement of sockeye salmon in the Taku River on an in season basis using mark-recapture methods,
- document the stock timing of the sockeye salmon escapements to the Taku River drainage,
- collect scale samples and associated biological data from sockeye salmon returning to the Taku River through the period of escapement for stock identification and age composition purposes,
- collect scale samples and associated biological data from sockeye salmon returning to Crescent and Speel Lakes for stock identification and age composition purposes,
- statistically reconstruct the Taku River sockeye run, and,

 represent the department on the bilateral Transboundary Technical Committee and at the Pacific Salmon Commission (PSC) meetings and prepare reports and other documents needed for accomplishing our PSC assignments

PST Northern Boundary Annex.

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- manage the District 104 purse seine fishery, prior to Statistical Week 31, for an annual harvest of 2 45 percent of the AAH of Nass and Skeena sockeye salmon in a manner consistent with arrangements negotiated under the Pacific Salmon Treaty,
- manage the Tree Point (District 101) gillnet fishery for an annual harvest of 13 8 percent of the AAH and Nass sockeye salmon in a manner consistent with arrangements negotiated under the Pacific Salmon Treaty,
- manage the Southeast Alaska troll fishery for coho salmon in a manner consistent with specific conservation provisions detailed in the June 30, 1999 revision of the Pacific Salmon Treaty and as stipulated by the Alaska Board of Fisheries,
- estimate in season, chinook salmon harvest rates in the gillnet and purse seine fisheries so as to remain within the chinook salmon quota level for net fisheries,
- estimate the stock composition of sockeye salmon in major boundary net fisheries (District 101 purse seine and gillnet and District 104 purse seine) to nation and/or system of origin Commercial catches and escapements on the Boundary Area need to be representatively sampled for sex, length, and scale data,
- estimate the sockeye spawning escapements to Hugh Smith and McDonald Lakes in the southern Southeast Alaska Collect run timing information and scale and biological samples from these escapements,
- Index the escapement of pink and chum salmon to selected streams in southern Southeast Alaska Estimate observer specific counting rates and conversions between survey counts and actual escapements in these study streams,
- obtain peak survey counts of coho salmon escapements to fifteen streams in southern Southeast Alaska that represent a constant proportion to the total escapement to those systems when compared across years,
- estimate the escapement, harvests, and age composition of coho salmon returning to Hugh Smith Lake, and
- represent the department on the bilateral PSC Northern Boundary Technical Committee and at PSC meetings and prepare reports and other documents needed for accomplishing our PSC assignments

PST Chinook Annex

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 manage the Southeast Alaska troll fishery for chinook salmon in a manner consistent with the new aggregate abundance-based management regime detailed in the June 30, 1999 revision of the Pacific Salmon Treaty, and as stipulated by the Alaska Board of Fisheries,

- estimate migratory patterns, harvests, catch rates, and exploitation rates of various chunook stocks, and determine contributions of wild and hatchery stocks to commercial and recreational fisheries in Southeast Alaska,
- evaluate chinook salmon escapement goals in Alaskan and transboundary rivers and determine what information is needed to improve these estimates, and
- represent the department at PSC meetings and prepare reports and other documents needed for accomplishing our PSC assignments Participate in PSC technical committee activities relating to design and use of CWT statistics, abundance-based management of coastwide chinook salmon, and development and testing of the PSC chinook model

North Pacific Marine Science Organization (PICES)

The umbrella transboundary organization for the North Pacific, the North Pacific Marine Science Organization (PICES), was established in 1992 among Canada, the People's Republic of China, Japan, the Republic of Korea, the Russian Federation, and the United States PICES coordinates North Pacific (above 308 N) marine information and research on topics such as the ocean environment, global weather and climate change, living resources and their ecosystems, and the impacts of human activities. In order to facilitate the exchange of information, the PICES Technical Committee on Data Exchange has links to long time series on biological, physical, and chemical oceanography, fisheries, and meteorology and marine science organizations. The long time series data set is a compilation of voluntary submissions from data sources and is therefore not exhaustive

The International Pacific Halibut Commission (IPHC) was the first multinational fishery management organization in the North Pacific, established by the United States and Canada in 1923 The IPHC annual survey provides a long time series of standardized catch of Pacific halibut and associated species The IPHC time series of research vessel surveys starts in 1925 It is a particularly valuable record of organisms associated with the benthos because of the scrutiny it has received as the basis for many peer reviewed publications over the years

Pacific States Marine Fisheries Commission (PSMFC)

The Pacific States Marine Fisheries Commission (PSMFC) is an interstate organization created by the U.S. Congress in 1947 to coordinate fisheries issues among California, Oregon, Washington, Idaho, and Alaska The PSMFC Regional Mark Processing Center keeps the salmon coded wire tag data base, an authoritative source for time series observations on distribution of ocean catches from California to Alaska, including Canada, since 1972

Global Climate Change Research

The United States is part of a world-wide network dedicated to measuring and understanding global climate change Global change research programs are valued in the billions of dollars, with state, national, and international partners and cooperators Four international oceanographic investigations on global climate change have elements relevant to the North Pacific Global Ocean Ecosystem Dynamics (GLOBEC), the World Ocean Circulation Experiment (WOCE), the Joint Global Ocean Flux Study (JGOFS), and the Global Ocean Observing System (GOOS) each rely on the personnel, facilities, and finances of the nations and organizations that participate in the transboundary organizations described above

GLOBEC

GLOBEC is the global change program of the International Geosphere-Biosphere Programme (IGBP) of the International Council for Science The IGBP provides an international, interdisciplinary framework for the conduct of global change science GLOBEC is an oceanography program that is examining a number of hypotheses that include a commercially harvested fish species, pink salmon A key GLOBEC hypothesis is that rapid growth and high survival of pink salmon depend on cross-shelf import of large zooplankton from offshore to nearshoie waters GLOBEC is also collecting data on zooplankton species, including a copepod and several krill species Physical processes to be examined include stratification, cross-shelf-transport, downwelling, and mesoscale circulation in the North Pacific region Another part of IGBP is the Joint Global Ocean Flux Study (JGOFS), which is studying the role of the ocean in controlling climate change through the storage and transport of heat

GOOS

The GOOS, organized by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Social and Cultural Organization (UNESCO), is to be a permanent global system for collecting data, modeling, and analyzing marine and ocean processes worldwide Another IOC-sponsored program is the World Ocean Circulation Experiment (WOCE) under the auspices of the World Meteorological Association WOCE sponsors a large number of investigations directed at understanding the movement of water masses in the world's oceans, including the Pacific and North Pacific
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APPENDIX F. NORTH PACIFIC MODELS OF THE ALASKA FISHERIES SCIENCE CENTER AND SELECTED OTHER ORGANIZATIONS

F 1 Introduction

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The following summary of physical and biological modeling in the North Pacific was prepared by Kerim Aydin, National Marine Fisheries Service, Seattle (Kerim Aydin@noaa gov)

Narrative descriptions of the hypotheses embodied by each model are followed by details of model features and development in tabular formats for ease of reference and comparison of models Documentation on geographic areas covered, time periods addressed, status of development, and person to contact for more information (Table 1) is followed by information on spatial domains, currencies (unit measures), inputs and outputs (Table 2) References for the models conclude the Appendix

F.2 Descriptions of Model Hypotheses

F 2 1 Single-Species Stock Assessment Models That Include Predation

So far we have developed two of these models one for Eastern Bering Sea pollock (Livingston and Methot 1998) and one for Gulf of Alaska pollock (Hollowed et al 2000) We might develop one for Aleutian Islands Atka mackerel in the future. The purpose of these models is to better understand the sources and time trends of natural mortality for pollock by explicitly incorporating predation mortality induced by their major predators into an agestructured fish stock assessment model. We have learned that not only is natural mortality for younger fish much higher than that for adults, but also that it varies across time, depending on time trends in predator stocks. This finding about mortality has given us better ideas of what influences predation has on fish recruitment through time and helps us to separate predation and climate-related effects on recruitment. We can better show the demands of other predators such as marine mammals for a commercially fished stock and how it might influence the dynamics of that stock (although we still need to make progress in understanding the effects on the marine mammals)

F.2. 2 Bering Sea Multispecies Virtual Population Analysis (MSVPA)

We now have a multispecies virtual population analysis (MSVPA) model for the Bering Sea (Livingston and Jurado-Molina, 2000) This model includes predation interactions among several commercially important groundfish stocks and also predation by arrowtooth flounder and northern fur seal on these stocks This model can give us a better idea of the predation interactions among several stocks We can use outputs from this type of model to help us understand what the possible multispecies implications are of our single-species-oriented fishing strategies Results from these forecasting exercises show that a particular fishing strategy may have the opposite of the intended effect if multispecies interactions are taken into consideration. We have also done multispecies forecasting with this model by using different hypotheses about regime shifts and associated fish recruitment patterns.

F 2 3 Boreal Migration and Consumption Model (BORMICON) for the Eastern Bering Sea

We have an initial version of a spatially explicit model of pollock movement and cannibalism in the Eastern Bering Sea. We hope to better understand the differences in spatial overlap of predators and prey and how that affects the population dynamics of each. The model we have modified for the Bering Sea, BORMICON (Boreal Migration and Consumption Model), is one being used in other boreal ecosystems. Migrations are prescribed currently with the hope that we can prescribe movement based on physical factors in the future. The influence of spatial overlap of cannibalistic adult pollock with juveniles on the population dynamics of pollock is being investigated. Hypotheses about larval drift positions and the resulting overlap and cannibalism are also being explored. This model could be linked in the future to an individual-based larval pollock model and to a nutrient-phytoplankton-zooplankton model that could prescribe zooplankton abundance by area as alternate food for adults and as the primary food for juveniles

F.2 4 Analytical Approach to Evaluating Alternative Fishing Strategies with Multiple Gear Types

The analytical approach for simulating current groundfish management in the North Pacific US Exclusive Economic Zone involves considering interactions among a large number of species (including target, nontarget, and prohibited) areas and gear types To evaluate the consequences of alternative management regimes, modeling was used to predict the likely outcome of management decisions by using statistics on historical catch of different species by gear types and areas Management of the Alaska groundfish fisheries is complex, given the large numbers of species, areas, and gear types The managers schedule fisheries openings and closures to maximize catch subject to catch limits and other constraints These management actions are based on expectations about the array of species likely to be captured by different gear types and the cumulative effect that each fishery has on the allowable catch of each individual target species and other species groups Management decisions were simulated by an in-season management model that predicts capture of target and nontarget species by different fisheries based on historical catch data by area and gear type The groundfish population abundance for each alternative regime was forecast for a 5-year period beginning from the present This approach provides a reasonable representation of the current fisheries management practice for dealing with the multi-species nature of catch in target fisheries

In addition to the model and its projected results, agency analysts also used the scientific literature, ongoing research, and professional opinion of fishery experts in their respective fields to perform qualitative assessments

F.2.5 Influence of Advection on Larval Pollock Recruitment

This model investigates the environmental relationship between surface advection during the post-spawning period (pollock egg and larval stages) and pollock survival Wespestad et al

(1997) found that during years when the surface currents tended north-north westward along the shelf, class strength was improved compared to years when currents were more easterly. They used the OSCURS surface advection model to simulate drift. Subsequently (Ianelli et al. 1998), their analysis was extended to apply within a stock assessment model. The model uses surface advection during a 90-day period to determine the "goodness" of the advective field for juvenile pollock.

F 2 6 Shelikof Pollock Individual-Based Model (IBM)

This IBM Model was designed to run in conjunction with the 3-D physical model (SPEM) and the Shelikof nutrient-phytoplankton-zooplankton model Its purpose is to examine, at a mechanistic level, hypotheses about recruitment of pollock in Shelikof Strait, especially as they refer to transport, growth, and (somewhat) mortality of pollock from spawning through the fall of the 0-age year

F.2 7 Global Ocean Ecosystem Dynamics (GLOBEC) Nutrient-Phytoplankton-Zooplankton (NPZ) 1-D and 3-D Models

This modeling effort (the 3-D NPZ model coupled with a physical model of the circulation of the region) is designed to test hypotheses about the effect of climate change/regime shifts on production in the coastal region of the Gulf of Alaska, including effects on cross-shelf transport, upstream effects, local production, and effect on suitability of the region as habitat for juvenile salmon

F.2.8 Steller Sea Lion Individual-Based Model (IBM)

This IBM model will be designed to examine how sea lion energy reserves change, through foraging and bioenergetics, depending on the distribution, density, patchiness, and species composition of a dynamic prey field (as influenced by factors such as potential local depletion by fishing) It should be applicable to any domain surrounding a specific sea lion rookery or haulout in the Bering Sea, Aleutian Islands, or Gulf of Alaska Lion characteristics such as age, location, life stage, and birth date are recorded Caloric balance is the main variable followed for each individual

F.2.9 Shelikof Nutrient-Phytoplankton-Zooplankton (NPZ) Model, 1-D and 3-D Versions

This NPZ model was designed to produce a temporally and spatially explicit food source (*Pseudocalanus* stages) for larval pollock, designed to be input to the pollock IBM model This set of coupled (biological and physical) models was designed to be used to examine hypotheses about pollock recruitment in the Shelikof Strait region

F.2.10 Gulf of Alaska Walleye Pollock Stochastic Switch Model

This model was designed as a mathematical representation of a conceptual model presented in Megrey et al 1996 It is a numerical simulation model of the recruitment process. A generalize description of stochastic mortality is formulated as a function of three specific mortality components considered important in controlling survival (random, caused by wind mixing events, and caused by prevalence of oceanic eddies) The sum total of these components, under some conditional dependencies, determines the overall survival experienced by the recruits

F.2.11 North Pacific Ecosystem Model for Understanding Regional Oceanography (NEMURO)

This model was designed to represent the minimum state variables needed to represent a generic nutrient-phytoplankton-zooplankton (NPZ) marine ecosystem model for the North Pacific Ecosystem fluxes are tracked in both units of nitrogen and silicon Carbon flux process equations have been recently added. The purpose of the model is to examine the effects of climate variability on the marine ecosystem through regional comparisons using the same ecosystem model structure and process equations.

F 2.12 Mass-Balance Ecosystem Models (Ecopath) for North Pacific Regions of Interest (Multiple Models)

Mass-balance food web models provide a way for evaluating the importance of predatorprey relationships, the roles of top-down and bottom-up forcing in modeled ecosystems, and the changes in ecosystem structure resulting from environmental perturbations (natural or anthropogenic) Additionally, the models may provide a way to compare natural predation mortality with respect to predator biomass and fishing levels, and determine the quality of data available for a given system

Eastern Bering Sea Shelf Ecopath Model 1 Although many of these models were done in the past for the Alaska region, the most up-to-date published model is the effort by Trites et al (1999) for the Eastern Bering Sea These models are highly aggregated across age groups and species groups and best highlight our gaps in understanding of how ecosystems function and our lack of data on certain ecosystem components Walleye pollock is broken into two biomass groups pollock ages 0 to 1 and pollock age 2 and older This model is useful for testing ecosystem hypotheses about bottom-up and top-down forcing and to examine system level properties and energy flow among trophic levels The Eastern Bering Sea model extent includes the main shelf and slope areas north to about 61° N and excludes near-shore processes and ecosystem groups

Eastern Bering Sea Shelf Model 2 and Western Bering Sea Shelf Ecopath Model. The second Eastern Bering Sea Shelf model breaks down the earlier model into more detailed species groupings to tease apart the dynamics of individual species, especially in the commercially important groundfish Spatial extensions to the model include subdividing into inner, middle, and outer biophysical domains The model will be calibrated with respect to topdown and bottom-up forcing with the use of "checkpoint" food webs for several years in the 1990s, the 1979 to 1998 time series of trawl data, and Multispecies Virtual Population Analysis (MSVPA)/other assessment analyses The primary purpose of this model is to investigate the relative role of natural and anthropogenic disturbances on the food web as a whole A Western Bering Sea Shelf model, built as a joint U S -Russian project, is currently being completed

Gulf of Alaska, Continental Shelf, and Slope (Excluding Fjord, Estuarine, and Intertidal Areas) Ecopath Model. Throughout the 1990s there have been extensive

commercial fisheries in the Gulf of Alaska (GOA) for groundfish, as well as crab, herring, halibut, and salmon Removals of both target species and bycatch by these (and historical) fisheries have been suggested as a possible cause for the decline of the western stock of Stellar sea lions, which are now listed as endangered species An Ecopath/Ecosim model for the GOA could test the hypothesis that fishery removals of groundfish and bycatch during the 1990s has contributed to the continued decline of Stellar sea lions

In addition, a community restructuring, in which shrimp populations declined dramatically and commercial fish populations increased between the 1960s and the 1990s, may have taken place, according to small mesh trawl surveys conducted by the National Marine Fisheries Service and Alaska Department of Fish and Game An additional hypothesis, which could be tested with this model, is that this trophic reorganization has had a negative impact on marine mammal and bird populations in the GOA Finally, the effects of an apparent increase in shark populations on their prey and the relative importance of these effects in the whole system could be evaluated with an Ecopath model

The Aleutian Island and Pribilof Islands Ecopath Models. While the Eastern Bering Sea and Gulf of Alaska model may capture broad-scale dynamics of widespread fish stocks, their scale is too large to address local depletion. This issue may be important for island-based fish such as Atka mackerel, and may be critical for determining the effect that changes in the food web may have on the endangered Steller sea lion. This smaller-scale Ecopath model will be used in conjunction with larger-scale models to examine the possibility of linking the models across scales

Prince William Sound Ecopath Models. An Ecopath model of Prince William Sound (PWS) was constructed by a collaboration of experts from the region during 1998-1999 (Okey and Pauly 1999) The *Exxon Valdez* Oil Spill Trustee Council funded this effort for the purpose of "ecosystem synthesis" The project was coordinated by the University of British Columbia Fisheries Centre and overseen by the National Marine Fisheries Service Office of Oil Spill Damage Assessment and Restoration Prince William Sound is well defined geographically, spatial definition of the system consisted of drawing lines across Hinchenbrook Entrance, Montague Strait, and smaller entrances The time period represented by the model, 1994 to 1996, is the post-spill period with the broadest and most complete set of ecosystem information Thus food web model consists of 48 functional groups ranging from single ontogenetic stages of special-interest species to highly aggregated groupings A variety of hypotheses are being addressed with the PWS model—most relate to the 1989 *Exxon Valdez* Oil Spill and the fisheries in the area

Model Name/			
Model Region	Time Period	Contact	Status
Single-species stock assessment	EBS 1964-95	Patricia Livingston	Working
models that include predation	GOA 1964-97		
	(Annual)		
Bering Sea MSVPA	1979-98	Patricia Livingston	Working
	3 Months (quarterly)	Jesus Jurado-Molina	
BORMICON for the eastern	1979-97	Patricia Livingston	Planning/
Bering Sea	1 Month		construction
Evaluating Alternative Fishing Strategies	Current	Jım lanellı	Working
Advection on larval pollock recruitment	90 Days of Larval Drift 1970s-present	Jım lanellı	Working
Shelikof Poliock IBM	YD 60-270	Sarah Hinckley	Working
	Daily		
GLOBEC NPZ 1-D and 3-D	YD 60-270 (eventually year-round)	Sarah Hinckley	In progress
Models	Daily		
Steller Sea Lion IBM	Summer or Winter,	Sarah Hinckley	Planning/
	Minutes to Days		Constructio
Shelikof NPZ Model 1-D and 3-D Versions	YD 60-270 (eventually year-round) Daily	Sarah Hınckley	In progress
GOA Pollock Stochastic Switch	32 years (replicates)	Bern Megrey	Working
	Daily		
NEMURO	1 Full Year, Daily	Bern Megrey	In progress
Eastern Bering Sea Shelf Model 1	1950s and early 1980s	Patricia Livingston	Completed
	Annual	· · · · · · · · · · · · · · · · · · ·	
Eastern Bering Sea Shelf Model 2	1979-1998	Kerim Aydın	In progress
	Annual		<u></u>
Western Bering Sea Shelf	Early 1980s	Kerim Aydın	In progress
	Annual	Victor Lapko	
Gulf of Alaska Shelf Ecopath	1990-99	Sarah Gaiches	In progress
	Annual		<u> </u>
Aleutian Islands Pribilof Islands	1990s-2000s	Patricia Livingston	Proposed
	Annual	Lorenzo Ciannelli	
Prince William Sound, Ecopath	Pre- and Post 1989 oil spill	Tom Okey	Completed
	Annual		

Table 1 Model Areas, Time Period, Contact Person, and Model Status

Notes

BORMICON = Boreal Migration and Consumption Model EBS = Eastern Benng Sea GLOBEC = Global Ocean Ecosystem Dynamics GOA = Gulf of Alaska MSVPA = Multispecies Virtual Population Analysis NEMURO = North Pacific Ecosystem Model for Understanding Regional Oceanography NPZ = nutrient-phytoplankton-zooplankton YD = days of the year

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Model Name/	·····	· · · · · · · · · · ·	
Model Region	Model Spatial Domain	Inputs	Outputs/Currency
Single-species stock assessment models that include predation	Across EBS and GOA Pollock distributions	Fisheries data and predator biomass	Pollock population and mortality trends—number at age (and biomass at age)
Bering Sea MSVPA	The modeled region is the EBS shelf and slope north to about 61°N	Fisheries predator biomass, and food habits data This model requires estimates of other food abundance supplied by species outside the model	Age-structured population dynamics for key species—numbers at age
BORMICON for the Eastern Bering Sea	The model is spatially explicit with 7 defined geographic regions that have pollock abundance and size distribution information	Temperature is included and influences growth and consumption	Spatial size distribution of pollock
Evaluating Alternative Fishing Strategies	U S Exclusive Economic Zone	Gear-specific fishing effort including bycatch	Biomass of managed fish species
Advection on larval pollock recruitment	Southeast Bering Sea Shelf	OSCURS surface currents (wind-driven)	Index of pollock recruitment
Shelikof Pollock IBM	Western GOA from just southwest of Kodiak Island to the Shumagin Islands shelf water column to 100 m	From physical model Water velocities wind field, mixed-layer depth, water temperature, and salinity, Pseudocalanus field (from	Individual larval characteristics such as age, size, weight, location, life stage, hatch date, consumption, respiration
		NPZ model)	· · · · · · · · · · · · · · · · · · ·
GLOBEC NPZ 1-D and 3-D Models	Water column (0-100 m) Coastal GOA from Dixon Entrance to Unimak Pass, 100 m of water column over depths < 2000 m 5-m depth bins x 20 km	Irradiance, MLD Temperature, diffusivity bottom depths, water velocities (u, v, w)	Diffusivity ammonium, nitrate, detritus, small and large phytoplankton, dinofiagellates, tintinnids, small coastal copepods, neocalanus and euphausiids
	horizontal grid		nitrate and ammonium mmol/m ³
			all else mg carbon/m ³
Steller Sea Lion IBM	Should be applicable to any domain surrounding a specific sea lion rookery or haul-out in the Bering Sea, Aleutian Islands, or GOA	The main input will be a 3- D field of prey (fish) distribution, denved either from hypothetical scenarios or (later) modeled based on acoustic data	Individual sea lion charactenstics such as age, location life stage, and birth date are recorded Caloric balance is the main variable followed for each individual

	Table 2	Model S	patial Domains	s, Currencies,	Inputs.	, and Output	S
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Model Name/			
Model Region	Model Spatial Domain	Inputs	Outputs/Currency
Shelikof NPZ Model 1-D and 3-D Versions	Water column (0-100 m), GOA from southwest of Kodiak Island to Shumagin Islands 1-m depth bins for 1-D version 1 m depth x 20 km for 3-D version	Irradiance, MLD, temperature, bottom depths water velocities (u v w)	Nitrogen phytoplankton Neocalanus densities Pseudocalanus numbers/m-3 for each of the 13 stages (egg 6 naupliar 6 copepodite)s
GOA Pollock Stochastic Switch Model	Shelikof Strait Gulf of Alaska	Number of eggs to seed the model Base mortality additive and multiplicative mort Adjustment parameters for each mort Factor	Number of 90-day-old pollock larvae through time
NEMURO	Ocean Station P (50°N 145°W) Bering Sea (57 5°N 175°W) and Station A7 off the east of Hokkaido island Japan (41 3°N 145 3°W)	15 state variables and parameters, including 2 phytoplankton 3 zooplankton, and multiple nutrient groups	Ecosystem fluxes are tracked in units of nitrogen and silicon
Eastem Bering Sea Shelf Model 1 Ecopath	500,000 km ² in EBS south of 61°N	Biomass production, consumption, and diet composition for all major species in each ecosystem	Balance between produced and consumed per area biomass (t/km ²) Future work will explore energy (kcal/km ²) and nutrient dynamics
Eastern Bering Sea Shelf Model 2 Ecopath	500 000 km ² in eastern Bering Sea south of 61°N		
Western Bering Sea Shelf Ecopath	300 000 km ² on western Bering Sea shelf		
Gulf of Alaska Shelf Ecopath	NPFMC management areas 610, 620, 630, and part of 640		
Aleutian Islands, Pribilof Islands Ecopath	Not determined		
Рппсе William Sound Ecopath	Whole Prince William Sound		

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Table 2	Model	Spatial	Domains,	Currencies,	Inputs, an	d Outputs
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Model Name/			0.4
Model Region	Model Spatial Domain	Inputs	Outputs/Currency
Source Kenm Aydın			
Notes BORMICON = Boreal I EBS = Eastern Bering GLOBEC = Global Oce GOA = Gulf of Alaska km = kilometer kcal = kilo calone m = meter MLD = mixed layer dep mmol = millimolar MSVPA = Multispecies NEMURO = North Pacifi NPZ = nutrient-phytopl OSCURS = Ocean Sut t = metric ton YD = days of year	Migration and Consumption M Sea ean Ecosystem Dynamics oth s Virtual Population Analysis iffic Ecosystem Model for Und c Fishenes Management Cot lankton-zooplankton rface Current Simulations	ለodel derstanding Regional (uncil	Oceanography

Table 2 Model Spatial Domains, Currencies, Inputs, and Outputs

F.3 References

- Hollowed, A, J N Ianelli, and P Livingston 2000 Including predation mortality in stock assessments A case study for Gulf of Alaska pollock ICES J Mar Sci 57 279-293
- Ianelli, J N, L Fritz, T Honkalehto, N Williamson and G Walters 1998 Bering Sea-Aleutian Islands Walleye Pollock Assessment for 1999 In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions North Pac Fish Mgmt Council, Anchorage, AK, section 1 1-79
- Livingston, P A and R D Methot 1998 Incorporation of predation into a population assessment model of eastern Bering Sea walleye pollock P 663-678 In Fishery Stock Assessment Models Alaska Sea Grant College Program Publication AK-SG-98-01 1037p
- Livingston, P A and J-J Jurado-Molina 2000 A multispecies virtual population analysis of the eastern Bering Sea ICES J Mar Sci 57 294-299
- Megrey, B A, A B Hollowed, S R Hare S A Macklin and P A Stabeno 1996 Contributions of FOCI research to forecasts of year-class strength of walleye pollock in Shelikof Strait, Alaska Fish Ocean 5 189-203
- Okey, T A and D Pauly 1999 A mass-balanced model of trophic flows in Prince William Sound de-compartmentalizing ecosystem knowledge Pp 621-635 In S Keller (ed) Ecosystem approaches for fisheries management. University of Alaska Sea Grant, Fairbanks

- Trites, AW, P Livingston, S Mackinson, MC Vasconcellos, AM Springer, and D Pauly 1999 Ecosystem change and the decline of marine mammals in the eastern Bering Sea Testing the ecosystem shift and commercial whaling hypotheses Univ British Columbia, Fisheries Centre Research Reports 1999, Vol 7
- Wespestad, VG, LW Fritz, WJ Ingraham, and BA Megrey 1997 On Relationships between Cannibalism, climate variability, physical transport and recruitment success of Bering Sea Walleye Pollock, *Theiagia chalcogiamma* ICES International Symposium, Recruitment Dynamics of exploited marine populations physical-biological interactions Baltimore, MD, Sept 22-24

APPENDIX G. FISH AND INVERTEBRATE SPECIES FROM 1996 NMFS TRAWL SURVEY OF THE GULF OF ALASKA

The tables below provide the common and scientific names of fish and invertebrate species encountered during the 1996 Gulf of Alaska bottom trawl survey The maximum depth of sampling was 500 meters

Fish	Species
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Family	Species Name	Common Name
Lamnidae	Lamna ditropis	salmon shark
Squalidae	Squalus acanthias	spiny dogfish
	Somniosus pacificus	Pacific sleeper shark
Rajidae	Raja binoculata	bıg skate
	Bathyraja interrupta	Bering skate
	Raja rhina	longnose skate
	Bathyraja trachura	black skate
	Bathyraja parmifera	Alaska skate
	Bathyraja aleutica	Aleutian skate
Chimaeridae	Hydrolagus colliei	spotted ratfish
Bothidae	Citharichthys sordidus	Pacific sanddab
Pleuronectidae	Atheresthes stomias	arrowtooth flounder
	Atheresthes evermanni	Kamchatka flounder
	Hippoglossus stenolepis	Pacific halibut
	Hippoglossoides elassodon	flathead sole
	Lyopsetta exilis	slender sole
	Eopsetta jordani	petrale sole
	Parophrys vetulus	English sole
	Microstomus pacificus	Dover sole
	Glyptocephalus zachırus	rex sole
	Lımanda asper	yellowfin sole
	Platichthys stellatus	starry flounder
	Psettichthys melanostictus	sand sole
	Lepidopsetta cf sp bilineata	northern rock sole
	Lepidopsetta bilineata	southern rock sole
	lsopsetta isolepis	butter sole

Family	Species Name	Common Name
Pleuronectidae (continued)	Pleuronectes quadrituberculatus	Alaska plaice
Agonidae	Sarritor frenatus	sawback poacher
	Xeneretmus leiops	smootheye poacher
	Bathyagonus pentacanthus	bigeye poacher
	Bathyagonus nigripinnis	blackfin poacher
	Podothecus acıpenserınus	sturgeon poacher
	Aspidophoroides bartoni	Aleutian alligatorfish
	Hypsagonus quadricornis	fourhorn poacher
Ammodytidae	Ammodytes hexapterus	Pacific sand lance
Anarhichadidae	Anarrhichthys ocellatus	wolf-eel
Anoplopomatidae	Anoplopoma fimbria	sablefish
Argentinidae	Nansenia candida	bluethroat argentine
Bathylagıdae	Leuroglossus schmidti	northern smoothtongue
Bathymasteridae	Bathymaster caeruleofasciatus	Alaskan ronquil
	Bathymaster signatus	searcher
Chauliodontidae	Chauliodus macouni	Pacific viperfish
Clupeidae	Clupea pallası	Pacific herring
Macrouridae	Albatrossia pectoralis	giant grenadier
	Coryphaenoides cinereus	popeye grenadier
Cottidae	Thyriscus anoplus	
	Icelinus borealis	northern sculpın
	Icelinus tenuis	spotfin sculpın
	Gymnocanthus pistilliger	threaded sculpin
	Gymnocanthus galeatus	armorhead sculpin
	Artediellus sp	
	Malacocottus zonurus	darkfin sculpın
	Hemilepidotus hemilepidotus	red Irish lord
	Hemilepidotus jordani	yellow Irish lord
	Hemilepidotus papilio	butterfly sculpin
	Triglops forficata	scissortail sculpin
	Triglops scepticus	spectacled sculpin
	Triglops pingeli	ribbed sculpin
	Triglops macellus	roughspine sculpin

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Family	Species Name	Common Name
Cottidae (continued)	Myoxocephalus polyacanthocephalus	great sculpin
	Myoxocephalus jaok	plaın sculpın
	Dasycottus setiger	spinyhead sculpin
	Psychrolutes paradoxus	tadpole sculpin
	Nautichthys pribilovius	eyeshade sculpın
	Nautichthys oculofasciatus	sailfin sculpin
	Rhamphocottus richardsoni	grunt sculpin
	Hemitripterus bolini	bigmouth sculpin
	Eurymen gyrinus	smoothcheek sculpin
	lcelus spiniger	thorny sculpin
Trichodontidae	Trichodon trichodon	Pacific sandfish
Gadıdae	Microgadus proximus	Pacific tomcod
	Gadus macrocephalus	Pacific cod
	Theragra chalcogramma	walleye pollock
Hexagrammıdae	Ophiodon elongatus	lingcod
	Pleurogrammus monopterygius	Atka mackerel
	Hexagrammos octogrammus	masked greenling
	Hexagrammos stellen	whitespotted greenling
	Hexagrammos decagrammus	kelp greenling
Cyclopteridae	Aptocyclus ventricosus	smooth lumpsucker
	Eumicrotremus birulai	round lumpsucker
	Eumicrotremus orbis	Pacific spiny lumpsucker
	Careproctus melanurus	blacktail snailfish
	Careproctus gilberti	smalldisk snailfish
	Paraliparis sp	
Melamphaeıdae	Poromitra crassiceps	crested bigscale
Melanostomiidae	Tactostoma macropus	longfin dragonfish
Merluccidae	Merluccius productus	Pacific hake
Myctophidae	Stenobrachius leucopsarus	northern lampfish
	Diaphus theta	California headlightfish
	Lampanyctus rtter 🖉	broadfin lanternfish
	Lampanyctus jordani	brokenline lampfish
Paralepidae	Paralepis atlantica	duckbill barracudina

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Family	Species Name	Common Name
Osmeridae	Thaleichthys pacificus	eulachon
	Hypomesus pretiosus	surf smelt
	Mallotus villosus	capelin
	Spirinchus thaleichthys	longfın smelt
Salmonidae	Oncorhynchus tshawytscha	chinook salmon
	Oncorhynchus kısutch	coho salmon
	Oncorhynchus gorbuscha	pınk salmon
	Oncorhynchus keta	chum salmon
	Oncorhynchus nerka	sockeye salmon
	Salvelınus malma	Dolly Varden
Cryptacanthodidae	Cryptacanthodes giganteus	giant wrymouth
Stichaeidae	Lumpenus maculatus	daubed shanny
	Lumpenus sagitta	snake prickleback
	Lumpenella longırostrıs	longsnout prickleback
	Chirolophis decoratus	decorated warbonnet
	Poroclinus rothrocki	whitebarred prickleback
Zaproridae	Zaprora silenus	prowfish
Zoarcidae	Bothrocara pusıllum	Alaska eelpout
	Lycodes paleans	wattied eelpout
	Lycodes diapterus	black eelpout
	Lycodes brevipes	shortfin eelpout
	Lycodes pacificus	blackbelly eelpout
	Lycodapus sp	
Scorpaenidae	Sebastolobus alascanus	shortspine thornyhead
	Sebastes aleutianus	rougheye rockfish
	Sebastes alutus	Pacific ocean perch
	Sebastes brevispinis	silvergray rockfish
	Sebastes ciliatus	dark dusky rockfish
	Sebastes cf sp ciliatus	light dusky rockfish
	Sebastes cramen	darkblotched rockfish
	Sebastes elongatus	greenstriped rockfish
	Sebastes entomelas	widow rockfish
	Sebastes flavidus	vellowtail rockfish

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Family	Species Name	Common Name
Scorpaenidae (continued)	Sebastes helvomaculatus	rosethorn rockfish
	Sebastes maliger	quillback rockfish
	Sebastes melanops	black rockfish
	Sebastes nigrocinctus	tiger rockfish
	Sebastes paucispinis	bocaccio
	Sebastes pinniger	canary rockfish
Scorpaenidae	Sebastes polyspinis	northern rockfish
	Sebastes pronger	redstripe rockfish
	Sebastes ruberrimus	yelloweye rockfish
	Sebastes babcockı	redbanded rockfish
	Sebastes variegatus	harlequın rockfish
	Sebastes wilsoni	pygmy rockfish
	Sebastes zacentrus	sharpchın rockfish
	Sebastes borealis	shortraker rockfish
	Sebastes reedi	yellowmouth rockfish

Source Martin, M H Data report. 1996 Gulf of Alaska bottom trawl survey 1997 U S Department of Commerce, National Oceanic and Atmospheric Administration

Invertebrate Species

Phylum	Species/Taxon Name	Common Name
Cnidaria	Cyanea capillata	
	Alcyonium sp	
	Gersemia_sp	sea raspberry
	Anthomastus sp	
	Anthomastus sp A	}
	Anthomastus sp B	
	Primnoa willeyi	
	Paragorgia arborea	
	Callogorgia sp	
	<i>Stylatula</i> sp	slender seawhip
	Pavonaria finmarchica	
	Ptilosarcus gumeyi	

Phylum	Species/Taxon Name	Common Name
Cnidaria (continued)	Metridium senile	
	Liponemis brevicornis	
	Stylaster brochi	
	Cyclohelia lancellata	
	<i>Errinopora</i> sp	
	<i>Plumarella</i> sp 1	
	Thouarella sp	
	Fanellia compressa	
	<i>Muriceides</i> sp	
	Amphilaphis sp	
	Arthrogorgia sp	
Annelida	Cheilonereis cyclurus	
	Eunoe nodosa	giant scale worm
	Eunoe depressa	depressed scale worm
	Serpula vermicularis	
	Carcınobdella cyclostomum	striped sea leech
Arthropoda	Balanus evermannı	giant barnacle
	Balanus rostratus	beaked barnacle
	Pandalus jordani	ocean shrimp
	Pandalus borealis	northern shrimp
	Pandalus tridens	yellowleg pandalıd
	Pandalus platyceros	spot shrimp
	Pandalus goniurus	humpy shrimp
	Pandalus hypsinotus	coonstripe shrimp
	Pandalopsis dispar	sidestripe shrimp
	Eualus macılenta	
	Lebbeus groenlandicus	
	Crangon communis	twospine crangon
	Crangon dallı	ridged crangon
	Crangon septemspinosa	sevenspine bay shrimp
	Argıs dentata	Arctic argid
	Sclerocrangon boreas	sculptured shrimp
	Argıs lar	kuro argıd

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Phylum	Species/Taxon Name	Common Name
Arthropoda (continued)	Pasiphaea pacifica	Pacific glass shrimp
	Pasıphaea tarda	crimson pasiphaeid
	Cancer magister	Dungeness crab
	Cancer oregonensis	Oregon rock crab
	Cancer gracilis	graceful rock crab
	Pinnixa occidentalis	pea crab
	Oregonia gracilis	graceful decorator crab
	Chorilia longipes	longhorned decorator crab
	Chionoecetes tanneri	groved tanner crab
	Chionoecetes bairdi	baırdı tanner crab
	Chionoecetes angulatus	triangle tanner crab
	Hyas lyratus	Pacific lyre crab
	Pagurus brandtı	sponge hermit
	Pagurus aleuticus	Aleutian hermit
	Labidochirus splendescens	splendid hermit
	Pagurus confragosus	knobbyhand hermit
	Pagurus dallı	whiteknee hermit
	Pagurus kennerlyı	bluespine hermit
	Pagurus ochotensis	Alaskan hermit
	Pagurus rathbuni	longfinger hermit
	Pagurus tannen	longhand hermit
	Elassochirus tenuimanus	widehand hermit crab
	Pagurus capillatus	hairy hermit crab
	Elassochirus cavimanus	purple hermit
	Elassochirus gilli	Pacific red hermit
	Lopholithodes foraminatus	box crab
	Acantholithodes hispidus	fuzzy crab
	Lithodes aequispina	golden kıng crab
	Hapalogaster grebnitzkii	
	Rhınolıthodes wosnessenskıı	rhinoceros crab
	Paralithodes camtschaticus	red king crab
	Paralithodes platypus	blue king crab
	Placetron wosnessenskıı	scaled crab

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Phylum	Species/Taxon Name	Common Name
Arthropoda (continued)	<i>Pugettia</i> sp	kelp crab
	Munida quadrispina	
Mollusca	Tochuına tetraquetra	giant orange tochui
	Tritonia diomedea	rosy tritonia
	Chlamylla sp	
	Cranopsis major	
	Natica clausa	arctic moonsnail
	Natica russa	rusty moonsnail
	Polinices pallidus	pale moonsnail
	Colus herendeenıı	thin-ribbed whelk
	Volutopsius harpa	left-hand whelk
	Volutopsius fragilis	fragile whelk
	Beringius kennicottii	
	Beringius undatus	
	Neptunea amianta	
	Neptunea pribiloffensis	Pribilof whelk
	Neptunea lyrata	lyre whelk
	Plicifusus kroyeri	
	Volutopsius callorhinus	
	Aforia circinata	keeled aforia
	Fusitnton oregonensis	Oregon triton
	Bathybembıx baırdıı	
	Cıdarına cıdarıs	
	Buccinum plectrum	sinuous whelk
	Buccinum scalariforme	ladder whelk
	Arctomelon stearnsıı	Alaska volute
	Modiolus modiolus	northern horsemussel
	Mytilus edulis	blue mussel
	Chlamys rubida	reddish scallop
	Patinopecten caurinus	weathervane scallop
	Yoldıa scıssurata	crisscrossed yoldia
	Yoldıa thracıaeformıs	broad yoldıa
	Nuculana sp	

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Phylum	Species/Taxon Name	Common Name
Mollusca (continued)	Limopsis akutanica	Akutan limops
	Musculus niger	black mussel
	Musculus discors	discordant mussel
	Astarte crenata	crenulate astarte
	Tridonta borealis	boreal tridonta
	Cyclocardia ventricosa	stout cyclocardia
	Cyclocardıa crebricostata	many-rıb cyclocardıa
	Clinocardium nuttallii	Nuttall cockle
	Clinocardium ciliatum	hairy cockle
	Clinocardium californiense	California cockle
	Mactromens polynyma	Arctic surfclam
	Siliqua sp	
	Serripes groenlandicus	Greenland cockle
	Serripes laperousii	broad cockle
	Pododesmus macroschisma	Alaska falsejingle
	Opisthoteuthis californiana	flapjack devilfish
	Octopus dofleını	giant octopus
	Rossia pacifica	eastern Pacific bobtail
	Berryteuthis magister	magistrate armhook squi
Echinodermata	Evasterias troschelii	
	Evasterias echinosoma	
	Orthasterias koehleri	
	Leptasterias hylodes	
	Rathbunaster californicus	
	Pycnopodia helianthoides	
	Stylasterias forreri	
	Lethasterias nanimensis	
	Pedicellaster magister	
	Poraniopsis inflata	
	Henricia sanguinolenta	
	Henricia leviuscula	
	Leptasterias polaris	
	Gephvreaster swifti	

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Phylum	Species/Taxon Name	Common Name
Echinodermata (continued)	Hippasteria spinosa	
	Pseudarchaster parelıı	
	Mediaster aequalis	
	Ceramaster japonicus	red bat star
	Ceramaster patagonicus	orange bat star
	Luidia foliata	
	Solaster endeca	
	Solaster dawsoni	
	Solaster stimpsoni	
	Solaster paxıllatus	
	Crossaster borealis	
	Crossaster papposus	rose sea star
	Lophaster furcilliger	
	Pteraster tesselatus	
	Pteraster militaris	
	Pteraster obscurus	
	Diplopteraster multipes	
	Asterias amurensis	purple orange seastar
	Ctenodiscus crispatus	common mud star
	Leptychaster pacificus	
	Dipsacaster borealis	
	Luidiaster dawsoni	
	Strongylocentrotus droebachiensis	green sea urchin
	Strongylocentrotus franciscanus	red sea urchin
	Strongylocentrotus pallıdus	white sea urchin
	Allocentrotus fragilis	orange-pink sea urchin
	Brisaster latifrons	
	Echinarachnius parma	Parma sand dollar
	Gorgonocephalus caryı	
	Asteronyx loveni	
	Ophiura sarsi	
	Amphiophiura ponderosa	
	Ophiopholis aculeata	

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Phylum	Species/Taxon Name	Common Name
Echinodermata (continued)	Parastichopus californicus	
	Molpadia intermedia	
	Pentamera lissoplaca	
	Bathyplotes sp	
	Cucumaria fallax	
	Stichopus japonicus	
	Psolus fabricii	
Porifera	Suberites ficus	hermit sponge
	Aphrocallistes vastus	clay pipe sponge
	Mycale loveni	tree sponge
	Halıchondrıa panıcea	barrel sponge
	Myxilla incrustans	scallop sponge
	Hylonema sp	fiberoptic sponge
Bryozoa	Eucratea loncata	feathery bryozoan
	Flustra serrulata	leafy bryozoan
Brachiopoda	Terebratalia transversa	
	Terebratulina unguicula	
	Laqueus californianus	
Chordata	Styela rustica	sea potato
	Boltenia sp	
	Halocynthia aurantium	sea peach
	Aplıdıum sp	
	Synoicum sp	
	Molgula retortiformis	sea clod
	Molgula grifithsu	sea grape

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Source Martin, M H Data report 1996 Gulf of Alaska bottom trawl survey 1997 U S Department of Commerce, National Oceanic and Atmospheric Administration

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APPENDIX H. – COLLECTED RESEARCH QUESTIONS

H.1. Introduction

This appendix contains potential GEM research questions collected from a number of sources including workshops, public meetings, and

discussions among scientists and resource managers working in the GOA Some of these questions have been published in earlier versions of the GEM Program Document

H.2 Research Questions From Appendix C, Gem 2000

Appendix C of the GEM 2000 Draft Program Document (April 2002) contained a number of research questions that were presented as possible starting points for GEM research

H 2.1 Climate, Sea Surface Interactions and Physical Oceanography

- a What are the periodic and aperiodic changes in the atmosphere that influence the northern GOA? Are they predictable? How will the trend in global warming affect cycles in the future?
- b What is the annual, interannual, and interdecadal variability in the position and strength of the Alaska Coastal Current? What is the annual, interannual, and interdecadal variability in the Alaska Current and Alaska Stream?
- c How is downwelling of onshore-driven water and upwelling of deep water affected by changes in wind and coastal precipitation during different climatic regimes? Does freshwater-induced stratification and wind-induced mixing on the continental shelf change significantly under various climatic regimes?
- d How do fronts and eddies affect biological production and onshoreoffshore transport?
- e How do nearshore and shelf exchange processes change over time and what are the biological consequences of such changes?
- f What are the fluctuations in freshwater input to the coastal gulf and how do these changes affect circulation, stratification, and inshore-offshore exchange?

H 2 2 Ocean Fertility and Plankton

- a How are nutrient transport and recycling in the central GOA and on the shelf different in different climatic regimes?
- b What are the relative roles of local nutrient recycling versus deep-water supply and cross-shelf transport in PWS, Cook Inlet and Kodiak Island?
- c Does the intense upwelling in outer Cook Inlet vary significantly interannually or interdecadally ? Do long-term changes in some tidal nodes (e g , an 18 6-year nodal cycle) affect nutrient supply in this region?
- d Are PWS, Cook Inlet and the Kodiak shelf net importers or net exporters of nutrients, carbon and energy?
- e How do the timing, magnitude, duration, and species composition of the spring bloom respond to seasonal and interannual variability in nutrient supply and physical conditions?
- f What is the zooplankton community response to seasonal and interannual variability in phytoplankton? What is the fate of offshelf zooplankton production under different climatic regimes?
- g What combinations of physical conditions and primary and secondary production lead to favorable conditions for higher trophic level consumers (fish, birds, mammals), and what is the spatial and temporal variability and frequency of occurrence of these combinations?

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- h What are the relative contributions of the net plankton, microheterotrophs, and bacteria in the overall energy budget of the ecosystem?
- 1 What is the role of imported terrestrial plant carbon in nearshore marine communities? Do increases in temperature and freshwater inflow that occur during positive Pacific Decadal Oscillations bring significantly greater inputs of terrestrial produced carbon?

H 2 3 Fish and Fisheries

- a What are the mechanisms responsible for interannual and interdecadal variations in populations of major species of forage fish (herring, pollock, capelin and eulachon) in the GOA?
- b What is the balance between nearshore survival of juvenile salmon and survival through the remainder of the life cycle in the GOA in determining fluctuations in salmon returns in the region?
- c Are there particular combinations of periods of wind-free, onshore transport of deep water with high nutrient content and periods of wind-driven mixing that prevent prolonged stratification of surface

water that are optimal for inshore survival of young herring and salmon?

- d Does enhanced late-season plankton production favor survival of 0+ age class fish?
- e How important to overwintering survival of forage fish are warm winter water temperatures and holdover zooplankton production?
- f What is the long-term effect of salmon hatcheries on the allocation of pelagic food resources in the GOA?
- g What are the trophic dynamic processes that determine production of fish and shellfish in the North Pacific?
- h What are the linkages between plankton dynamics and early life histories of fish and shellfish and subsequently observed changes in fish, shellfish, bird, and marine mammal populations?
- 1 What are the biotic implications of climatic forcing and nutrient transport conditions, from effects on primary and secondary producers to effects on invertebrates, fish, birds, and marine mammals through the pelagic and benthic food webs?

H 2 4 Benthic and Intertidal Communities

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- a How do populations and productivity of benthic and intertidal communities fluctuate interannually and interdecadally?
- b What conditions cause fluctuations in the fraction of the spring bloom that falls ungrazed to support the benthic fish and invertebrate community?
- c How does nutrient supply to nearshore plants fluctuate?
- d What are the linkages between commercially important fish species (e g , cod, halibut, sable fish) and benthic productivity?

H 2 5 Bird and Mammal Populations

- a How do populations and productivity of seabirds fluctuate interannually and interdecadally? Is the availability of fatty forage fishes (e g, herring, capelin and eulachon) in the shelf environment the main determinant of population success?
- b How do populations and productivity of harbor seals fluctuate interannually and interdecadally?
- c Do populations of harbor seals fluctuate with the availability of fatty forage fishes (e g , herring, capelin and eulachon) in the shelf environment?

- d How do populations and productivity of sea otters fluctuate interannually and interdecadally? Does food supply play the main role, or do disease and predation?
- e To what extent does transport of marine nitrogen from the GOA determine or limit the production of terrestrial bird and mammal populations?

H 2 6 Anthropogenic and Natural Contaminants

- a What are the concentrations of bioaccumulated anthiopogenic chemicals in the coastal and shelf organisms?
- b What is the loss rate of residual *Exron Valdez* oil spill hydrocarbons from the spill area?
- c Are anthropogenic chemicals having adverse effects on the health of marine organisms, especially apex predators with high accumulations of persistent synthetic chemicals?
- d What are the concentrations of bioaccumulated natural toxins, such as domoic acid, in the coastal and shelf environment?
- e Are natural toxins having adverse effects on the health of marine organisms, such as killer whales and other apex predators with high accumulations of persistent synthetic chemicals?
- H.3. General Research Questions From Volume II, Chapter 3, Gem 2001

The following research questions were included in the Scientific Background Section of the GEM 2001 Program Document (Volume II, Chapter 3) Based on comments received from the National Research Council, these questions have been removed from that section and included here

H 3 1 Physical and Geological Oceanography Coastal Boundaries and Coastal and Ocean Circulation (Chapter 7 6)

- a What physical-chemical processes control primary and secondary production, and in particular, what processes control the timing, duration, and magnitude of the spring bloom on the inner continental shelf, including the inlets, sounds, and fjords?
- b Does stratification of the water column in the euphotic zone of the ACC depend primarily on the rate at which fresh water spreads offshore as a consequence of three-dimensional circulation and mixing processes associated with ocean dynamics?

- c Do physical oceanographic shelf processes in the ACC in the months leading up to the spring bloom precondition the magnitude and sequence of biological events during the spring bloom?
- d Does zooplankton recruitment in the ACC depend on shelf physical processes during a "preconditioning period" leading up to the onset of the spring bloom?
- e What are the sources of the nutrients in the euphotic zone on the inner shelf in the spring?
- f How are exchanges of carbon and nutrients, detritus and plankton, at the shelf break influenced by the interactions of physical processes with the Alaska Stream and the Alaska Current with the complex bathymetry of the northern and western GOA?
- g What is the effect of eddy structure on nutrient flux across the continental shelf slope?
- h How and where does the interaction of the tidal wave with varying bottom topography generate residual flows that transport nutrients and carbon across water mass boundaries on the inner shelf?
- 1 Do durnal-period shelf waves along the Kodiak shelf influence biological production and the dispersal of planktonic organisms?

H.3 2 Chemical Oceanography Marine Nutrients and Fertility (Chapter 7 7)

- a What is the role of the Pacific High pressure system in determining the timing and duration of the movement of dense slope water onto and across the shelf to renew nutrients in the coastal bottom waters?
- b Is freshwater runoff a source of iron and silicon that is important to marine productivity in the ACC and other marine waters?
- c Does iron limitation control the species and size distribution of the plankton communities in the offshore areas?
- d Does zooplankton, especially microzooplankton, control the amount of food produced by phytoplankton in the offshore?

H 3 3 Biological Oceanography Plankton and Productivity (Chapter 7.8)

a What are the relationships between the inshore (watersheds, intertidalsubtidal, and ACC) and offshore production cycles, how are the inshore and offshore phased through time, and how do they interact at their boundaries over the shelf?

- 1 How are the relationships between offshore and inshore production manifested in food webs supporting birds, fish and mammals?
- 2 How are the effects of future climate change manifested in inshore and offshore food webs supporting birds, fish and mammals?
- b What are the changes in abundance of the individual species of large copepods, amphipods and euphausids that make up the bulk of the secondary production in the inshore and offshore GOA?

H 3 4 Nearshore Benthic Communities (Chapter 7 9)

- a What are sources and rates of natural disturbance to these communities, and what are rates and patterns of recovery?
- b How variable is recruitment in space and time, and among planktonic species?
- c What is the relationship between recruitment rates and growth rates of filter feeders? Algae? Predators?
- d What are primary energy and nutrient sources of intertidal and benthic communities—in situ, upwelling, offshore, terrestrial runoff?
- e Under what conditions are populations limited by recruitment, food, space, natural disturbance, temperature, predators, competitors, and disease?
- f How do the substrates, bathymetry, physical factors, biological forces such as predation and competition, and human activities act together to define community structure?
- g What controls the rates of recruitment of key plant and animal species to the nearshore benthic communities?
 - 1 To what degree do recruitment processes control community structure and population abundances in intertidal-subtidal benthic systems?
 - 2 How does predation limit the abundance, diversity, and size composition of benthic marine invertebrates?
- h What is the relationship between biological production processes and physical transport phenomena in the coastal ocean and settlement patterns and intensities of various species in intertidal-subtidal benthic communities?
- How do biological interactions, both direct (such as predation and interference competition), and indirect (such as trophic cascades), influence the dynamics of community change and successional recovery from disturbance in intertidal-subtidal systems?

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- J How does intertidal and subtidal habitat change influence species of fish, seabirds, and marine mammals from this and the other systems?
 - 1 How do offshore, ACC and watershed processes influence the abundance, production, and dynamics of inter-tidal and subtidal species such as fishes, seabirds, and marine mammals?
 - 2 How do intertidal and subtidal habitats influence the abundance, production, and dynamics of species such as fishes, seabirds, and marine mammals in the offshore, ACC and watershed habitats?
 - 3 What are the relative contributions of carbon fixed by microalgae and macroalgae in the intertidal and subtidal?
- k What are the approaches to measuring community structure that allow the effects of human activities to be distinguished from the effects of natural forces in the intertidal and subtidal?
- 1 To what degree do human activities, such as watershed modifications, persistent organic pollutants (POPs) releases, organic loading, and direct and indirect effects of exploitation of marine resources, have important impacts on intertidal-subtidal benthic communities on rocky shores and in sedimentary habitats?
- m What is the degree to which toxins ingested by benthic invertebrates are transferred up the food chain in a form that can affect reproduction, growth, or survival of vertebrate consumers of those benthic prey?
- n What is the functional significance of biodiversity and apparent functional redundancy of the diverse suite of component species of intertidal/subtidal communities?

H 3 5 Forage Species (Chapter 7 10)

- a How can trends in abundance of forage species be explained?
- b What is the role of large-scale atmospheric forcing in controlling the structure of marine fish communities in the western central GOA ecosystem?
- c Are species that spawn in the winter favored by periods of early peak primary production, and species that spawn in the spring and summer favored by periods of delayed production?
- d Do ocean conditions that favor concentration of forage fish and their prey enhance production of forage species?
 - 1 Do eddies favor enhanced production and recruitment of forage species?

- e Is the amount of wind mixing inversely or directly (for example, Rothschild-Osborn) proportional to forage fish production?
- f Does predation limit the abundance of forage species populations?
- g Does the aggregation of forage species by gradients (fronts) or water mass characteristics allow top predators to control forage species abundance in the ACC and offshore?
- h What is the role of food quality as shown by prey preference selection in controlling forage species abundance?
- 1 What is the role of accumulations of toxic chemicals in forage species in influencing reproduction, growth, and death of forage species?

H 3 6 Fish and Shellfish (Chapter 7 12)

- a How can trends in abundance of fish and shellfish species be explained?
 - 1 Does large-scale atmospheric forcing control the quality of food available to larval fish and shellfish through its influence on the species composition and size distribution of primary producers?
 - 2 How do the rates of recruitment of benthic animals with planktonic larvae respond to mechanisms of transport that may control the distribution of larvae relative to suitable bottom habitat?

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- 3 How do the rates of recruitment of fish species with planktonic larvae respond to mechanisms of transport that may control the distribution of larvae relative to suitable juvenile rearing habitat?
- 4 Are fish species that spawn in the winter favored by periods of early peak production, and species that spawn in the spring and summer favored by periods of delayed production?
- 5 What life history strategies permit the arrowtooth flounder to be so widespread and abundant?
- 6 How well are the species composition, relative abundances and trophic structure of fish and shellfish communities understood, based on current sampling methods?
- 7 What are the underlying mechanisms whereby climate induces changes in productivity, and whereby fishing induces variations in the ocean production of salmon?
- 8 How can salmon stocks be identified?
- 9 What are the ecological processes in the ocean that control productivity of salmon?

10 What are the interannual variations in ocean growth, distribution, and migratory timing of salmon stocks?

H 3 7 Marine Mammals (Chapter 7 13)

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- a What are the factors responsible for the decline of marine mammal populations?
 - 1 What is the role of marine mammal predation (consumption) in structuring their prey populations (plankton, fish, and mammals)?
 - 2 What is the relation between abundance of maine mammal populations and the availability and quality of prey species?
 - 3 What is the relation between abundance of marine mammal populations and the removals of prey species by fishing?
 - 4 What is the relation between reproduction and abundance of marine mammal populations and contaminant burdens?
 - 5 How does variation in the amount of food produced affect the geographic distributions, fecundities and survivals of marine mammal populations?
- b What are the factors responsible for regulation of population size in sea otters?
 - 1 Can availability of food become limiting?
 - 2 Can predation, contamination, human take, or disease play important roles in structuring sea otter populations?

H.4. Interdisciplinary Research Questions II, Chapter 3 This section attempted to develop generalized interdisciplinary research questions

generalized, interdisciplinary research questions from the more specific, disciplinary questions presented above The questions have been organized under three major lessons from the scientific background Aspects important to understanding and detecting changes in all plant and animal species are covered here, although not all species are mentioned by name

H 4 1 The Importance of Weather

Patterns in current structure, upwellings and convergences, temperature, salinity, and density in the waters of the northern GOA are established in response to strong external meteorological conditions affecting the subarctic region of the North Pacific Ocean and through interactions with the coastal topography and the bathymetry of the shelf and coastal regions

a How variable-seasonally and annually-are the cross-shelf and along-shore flows over the shelf and inner coastal regions?

- b Under what oceanographic conditions are shelf eddies formed, what are their sizes and how long do they persist?
- c How are seasonal and interannual cycles in upper-layer stability influenced by the conditions of strong or weak Aleutian Low pressure systems?

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- d How frequently are deep bottom waters in coastal fjords renewed, and how is this process related to climate forcing on seasonal, annual and longer time scales?
- e Under what conditions, where, and during which seasons are oceanographic frontal regions formed in the northern GOA? How are these regions affected by swings in the strength of the Aleutian Low Pressure system?

H 4 2 The Importance of Nutrient Transport

Primary productivity in the euphotic zone is controlled by amounts and supply rates of inorganic nutrients. The deep waters of the GOA contain some of the highest nutrient concentrations found anywhere. However, the seasonally permanent pychocline between 110 and 150 m generally restricts deep mixing and access to this valuable pool.

- a How do shelf and coastal eddies, frontal regions and areas of upwelling and convergences affect the supply of inorganic nutrients to the upper layers under different conditions of ocean climate in the GOA?
- b What are the processes by which deep and shallow coastal waters become enriched with nutrients each year? How are nutrient renewal processes influenced by the broader climate-forced oceanography of the GOA?
- c What role does the input of fresh water along the northern coastline play in supplying nutrients and influencing recycling from deeper waters? How is this role affected by varying ocean climate on seasonal, annual, and longer time scales?
- d How important and under what oceanographic and meteorological conditions are marine-derived nutrients brought into coastal watersheds and incorporated in the coastal ecology?
- e What are the conditions that provide sufficient nutrient resupply to the surface waters in the fall to promote a fall plankton bloom?
- f How does winter/early spring physical "preconditioning" of the upper layers promote or constrain plankton production through control of nutrient supply rates and photosynthesis in oceanic, shelf, and coastal waters?
- g How is the energy of the diurnal tides used to promote nutrient resupply in the surface waters at selected locations in the northern GOA?

H 4 3 The Importance of Plankton Dynamics

In the northern GOA, open ocean and shelf/coastal plankton communities differ in their species composition and annual production By definition, deep and shallow currents distribute the plankton, and standing stocks occurring at specific times and places are the result of local productivity and the addition or dilution of stocks by advection

- a Under what physical conditions and to what extent does the oceanic plankton community invade the shelf environment, including the coastal and inside waters? What role does the intruding plankton play in the ecology of the coastal waters?
- b What is the biological nature of the boundary between the oceanic and shelf pelagic ecosystems, and how is the primary and secondary productivity in these regions phased through time and influenced by the state of the Aleutian Low?
- c How is the efficiency of food-web transfer from plankton to fishes, birds, and mammals influenced by varying levels of the dominant macrozooplankton, including large calanoids, euphausiids, and amphipods?
- d How is the time-varying spatial distribution of the dominant zooplankton reflected in seasonal, annual, and longer-period patterns in eddy formation, frontal regions, convergences/divergences, and cross-shelf and along-shore flows?
- e What are the interacting physical and biological processes that establish levels of recruitment in plankton and nearshore benthic communities? How do these processes vary under different conditions of the Aleutian Low pressure system?
- f How can the effects of human influences on the near-shore benthos be distinguished from natural perturbations?

H 4 4 The Importance of Trophic Dynamics

The transfer of energy in food webs (trophic dynamics) supporting fishes, birds, and mammals is influenced by the composition of the forage and its quality and availability The behaviors of forage species that result in seasonal swarming/schooling or layering provide enhanced opportunities for food web transfers External factors like fishing, hunting, and contaminant levels may significantly affect population structure and size, thereby altering food webs

a How does the species composition and quantity of small schooling fishes in shelf and coastal habitats reflect the state of the cycling ocean climate in the northern GOA?

- b In what way do the conditions that favor the concentration of forage species also favor their levels of productivity?
- c How do fluctuations in abundance and species composition of forage stocks and higher level consumers reflect their unique life history strategies under different conditions of ocean climate–winter, spring, and summer spawners?
- d How does the distribution and abundance of forage species reflect losses to predators?
- e How do climate-forced shifts in the species composition and abundance of forage species control seabird populations?
- f How can the influences of prey availability on seabird abundance be separated from the effects of regional scale properties unique to colony locations, like glaciers?
- g What is the relationship between commercial fishing and the abundance of seabird populations?
- h Do local trends in the abundance of murres and kittiwakes reflect mesoscale or regional scale climate and oceanographic processes affecting prey availability?
- 1 To what extent are fish, seabird, and mammal stocks affected by top down influences, including fishing and other harvest practices?
- J How is the recruitment to fish and shellfish stocks with pelagic eggs and larvae influenced by variable transport processes connecting with nursery areas?
- k How do climate-influenced transport mechanisms influence the distributions of the drifting larvae of benthic populations relative to suitable settlement substrates?
- 1 How can long-term trends in salmon production be explained by climateinduced changes in ocean productivity and variations in fishing?
- m How is salmon production controlled by ecological processes in the ocean? How can individual stocks be identified?
- n What are the annual levels of ocean production of salmon by region of origin?
- o How is the abundance and distribution of marine mammals related to the availability of forage stocks?
- p How is the abundance of marine mammal populations related to the body burden of marine contaminants?

q Which life history stages of fishes, seabirds and marine mammals are most at risk to climate change and which to human influences?

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APPENDIX H JULY 2002