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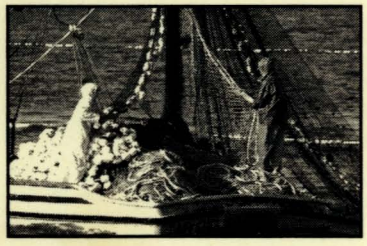
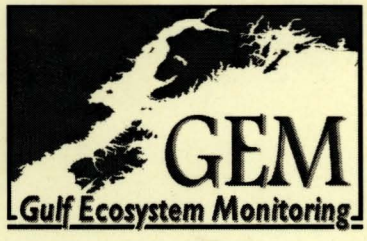
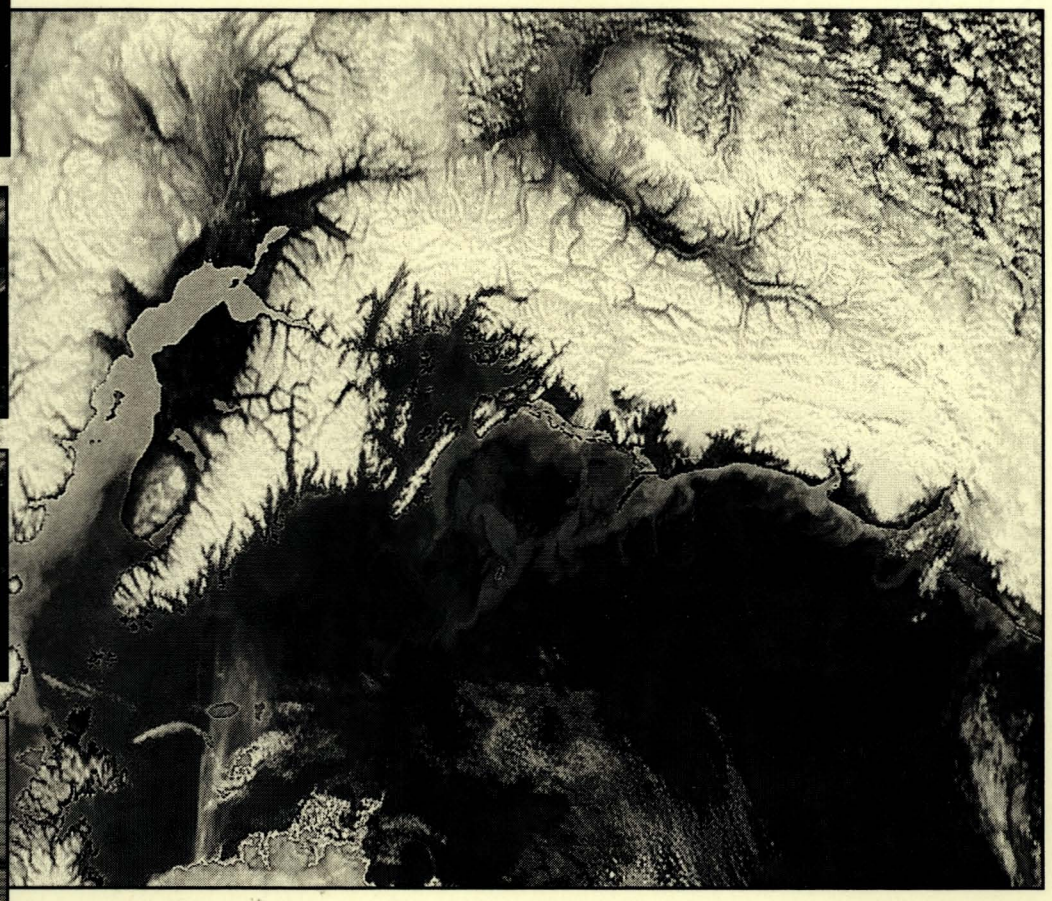




Gulf Ecosystem Monitoring

A sentinel monitoring program

for the conservation of the natural resources of the northern Gulf of Alaska



GEM Science Program NRC Review Draft

April 21, 2000

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Executive Summary

This document provides the foundation for the Gulf Ecosystem Monitoring (GEM) program, a long-term research and monitoring effort in the northern Gulf of Alaska The *Exxon Valdez* Oil Spill Trustee Council (Trustee Council) has endowed this program as a final legacy of its mission to restore the fish and wildlife resources injured by the 1989 *Exxon Valdez* oil spill

This document is composed of four main sections plus supporting materials

- Section I describes the Gulf of Alaska (GOA) region and the Trustee Council's program needs at this scale,
- Section II contains the Trustee Council's vision for meeting these regional needs,
- Section III is the framework of an institution and process for realizing that vision,
- Section IV presents and organizes the scientific information available to guide the Trustee Council as it develops and implements the GEM program Accordingly, Section IV attempts to be inclusive of all the biological and physical components of the GOA ecosystem

The GEM document is not itself a research and monitoring plan Rather, this document provides the overall framework for a program that includes a three-year process of developing, reviewing and adopting a research and monitoring plan Implementation of the future plan is expected to begin in October 2002

Within the northern GOA (including Prince William Sound, Cook Inlet, Kodiak Island and the Alaska Peninsula), 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

More than half of the state's 621,000 permanent residents live within the geographic area of the northern GOA and the nearby population center of the greater Anchorage area Most of the more than one-million tourists that travel to the state each year visit this region The private-sector economy of Alaska depends heavily on extraction of natural resources from this region, including petroleum, fish and shellfish, minerals, and timber Crude oil and fuel tanker traffic, increasing tourism and recreational use, expanded road building, and growing commercial and sport fishing pressure are all human activities that could affect the marine resources and ecosystem of the northern GOA 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

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 over-wintering 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

Understanding the sources of these changes, whether natural or influenced by human activities, requires a solid historical context This certainly has been the lesson of the 1989 *Exxon Valdez* oil spill, a large-scale ecological disaster, resulting in hundreds of millions of dollars invested in studies and restoration projects in the past decade Based on the knowledge and experience gained through this program, the Trustee Council has dedicated approximately $120 million to complete work on lingering oil-spill injury and to endow long-term monitoring and research in the world-renowned ecosystem of the northern GOA

For planning purposes, the program is referred to as the Gulf Ecosystem Monitoring (GEM) program The mission of the program is "to sustain a healthy and biologically diverse marine ecosystem in the northern 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 "

GEM has five major programmatic goals These are to

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,

PREDICT Develop the capacity to predict the status and trends of natural resources for use by resource managers and consumers,

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

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 annual earnings from a $120 million endowment will not be able to fund all that needs to be done to achieve the above goals Instead, the Trustee Council will focus a

large part of its efforts on providing leadership in identifying monitoring and research gaps and priorities, encouraging efficiency and integration through leveraging of funds, coordination, and partnerships, and involving stakeholders in local stewardship by having them help guide and carry out parts of the program

Recognizing that the gulf ecosystem under consideration is extremely complex, consisting 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 GEM instead will be focused, to a large extent, on key species and ecological processes in the system These will be selected on the basis of ecological importance, human relevance, and their ability to indicate ecosystem disturbance, as well as their importance for understanding the physical and biological bases for productivity In the end, GEM must be justified on what it can teach policy makers, resource managers and the public about options for directing human behavior toward achieving sustainable resource management goals

> "In the end, GEM must be justified on what it can teach policy makers, resource managers and the public about options for directing human behavior toward achieving sustainable resource management goals"

The GEM program will continue to work with resource managers, stakeholders, the scientific community and the public to refine a common set of priorities for research, monitoring and protection in the northern gulf In order to do that, we must share an understanding of which marine resources of the northern gulf are valued and what stressors or potential threats could affect their overall health The GEM program will build a matrix of who is monitoring what, where, and when and identify gaps in monitoring those things that are important to us GEM will work towards filling in the important gaps

The long-term monitoring element of GEM 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

The Trustee Council believes that encouraging local awareness and participation in research and monitoring enhances long-term stewardship of living marine resources Traditional and local knowledge can provide important observations and insights about changes in the status and health of marine resources and should be incorporated into GEM Citizen monitoring efforts are already underway in several communities in the GEM region and should be looked to for future collaboration

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 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 Some possible approaches include the use of models, periodic "State of the Gulf" and "State of the North Pacific" workshops and reports, and a GEM website The Trustee Council is committed to public input and outreach as vital components of the long-term GEM program

Notes

I Introduction

A program rooted in the science of a large-scale ecological disaster is uniquely suited to form the foundation for ecosystem-based management The knowledge and experience gained during ten years of biological and physical studies in the aftermath of the *Exxon Valdez* oil spill (EVOS) have 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 *Exxon Valdez* Oil Spill Trustee Council (Trustee Council) dedicated approximately $120 million for long-term monitoring and research in the northern Gulf of Alaska (GOA) The new fund is expected to be in place and functioning by October 2002 It will function as an endowment, with an annual program funded through investment earnings The goal is for the fund to be invested in a manner that allows for inflation-proofing and possible growth of the corpus (See Appendix A for the full text of the Trustee Council resolution)

In making the decision to allocate these funds for a long-term program of monitoring and research, referred to herein as the Gulf Ecosystem Monitoring (GEM) program, the Trustee Council explicitly recognized that complete recovery from the oil spill may not occur for decades and that through long-term observation and, as needed, restoration actions, injured resources and services are most likely to be fully restored The Trustee Council further recognized that conservation and improved management of these resources and services would require a 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 recovery requires increased knowledge of critical ecological information about the northern GOA This knowledge can only be provided through a long-term research and monitoring program that will span decades, if not centuries There are both immediate needs to complete our understanding of the lingering effects of the oil spill and long-term needs to understand the sources of changes in valued natural resources

I A Lingering Effects of the EVOS and Future Needs

The lack of information about the status of marine resources prior to the spill was and, in some cases, remains, a serious impediment to understanding the impact of human activities, both planned and unplanned In spite of the current shortage of information on some species, a large body of new information has been assembled during the course of research following the oil spill Much was learned about the plants and animals of the northern GOA (Figure 1) and their relationships to one another and the physical environment Even more important than the scientific insight gained so far may be the improved understanding of the magnitude of our ignorance of physical and biological systems Although it is reasonably clear that some of the injured natural resources and the services that depend on them have not fully recovered more than 11 years after the *Exxon Valdez* oil spill, the fate of others is still not known today (Table 1) Of the 28 resources and four services reviewed by the Trustee Council in March 1999, only two were categorized as clearly "recovered," while eight were placed in the category of "not recovering " The fact that most resources and all services were placed in the "recovering"

category may reflect a lack of knowledge concerning the status of the resources and services at the time of the oil spill That five resources were in the category of "recovery unknown" underscores the point that a solid historical context is essential to understand the sources of changes in natural resources Studies are underway to learn more about cutthroat trout, Dolly Varden, Kittlitz's murrelets, rockfish and residual oil in designated wilderness areas (EVOSTC 1999)

NOT RECOVERING	RECOVERING	RECOVERED	RECOVERY UNKNOWN
Common Loon	Archaeological resources	Bald Eagle	Cutthroat Trout
Cormorants (3 spp)	Black Oystercatcher	River Otter	Designated Wilderness Areas
Harbor Seal	Clams		Dolly Varden
Harlequin Duck	Common Murre		Kittlitz's Murrelet
Killer Whale (AB pod) _	Intertidal Communities		Rockfish
Pigeon Guillemot	Marbled Murrelet		
	Mussels	**Human Services**	
	Pacific Herring	*Injured human services are considered to be recovering*	
	Pink Salmon	Commercial Fishing	
	Sea Otter	Passive Use	
	Sediments	Recreation and Tourism	
	Sockeye Salmon	Subsistence	
	Subtidal Communities		

Table 1 Status of injured resources, *Exxon Valdez* oil spill as of March, 1999

The main concerns about the lingering effects of oiling relate to the potential effects of pockets of residual oil in the environment Studies in the laboratory have shown that contact with petroleum hydrocarbons from weathered oil can kill or harm early life stages of pink salmon and Pacific herring It is not yet known, however, whether such effects are actually occurring to any significant degree in Prince William Sound (PWS) or at other localities with residual oil Tissue samples from higher vertebrates, such as sea otters and harlequin ducks, also indicate possible ongoing exposure to petroleum hydrocarbons in PWS The effects of this exposure are not well established at the level of individual animals or at the population level

Additional concerns about lingering effects of the spill include the ability of populations to overcome the demographic effects of the initial oil-related mortalities and the interaction of the effects of the oil spill with the effects of other kinds of changes and perturbations in the marine ecosystem Sea otters around northern Knight Island are an example of a species with prolonged demographic effects in the heavily oiled western portion of PWS Examples of possible interactive, or cumulative, impacts are the combined effects of the oil spill and the 1998 *El Niño* event on common murres in the Barren Islands and the implications of changes in the availability of forage fishes on recovery of seabirds, such as the pigeon guillemot, from the effects of the oil spill

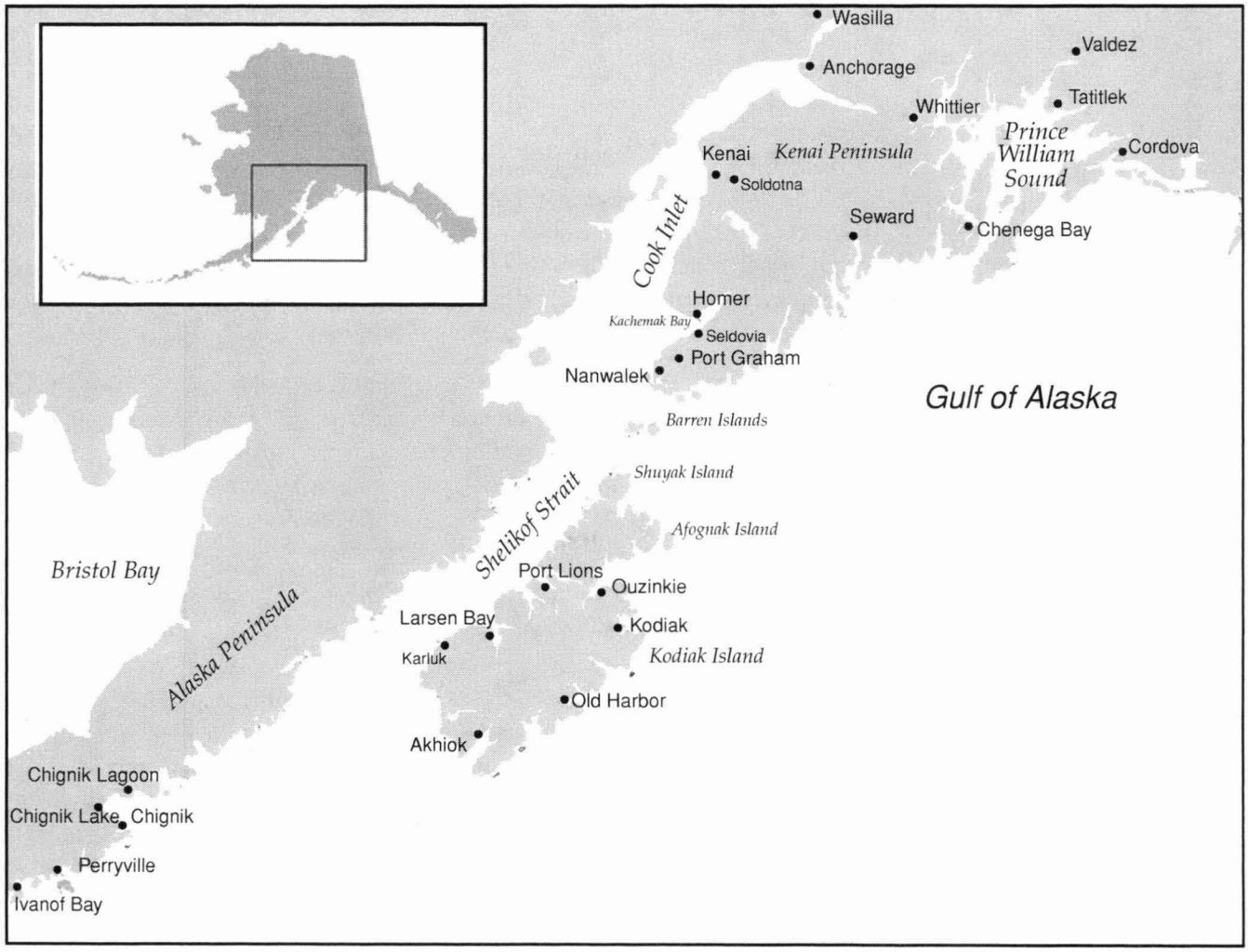

Figure 1. Map of the oil spill area showing the location of communities.

As the Trustee Council moves from the restoration program in the first decade following the spill to the GEM program, studies of lingering oil spill injury and recovery will be drawn to a conclusion in the near-term and, increasingly, replaced by long-term environmental monitoring and ecosystem studies. Studies that integrate our understanding of the biological processes of the entire marine ecosystem of the spill area in the context of climatic and anthropogenic forces are made possible by the long-term monitoring data provided by many programs, including GEM.

I. B. Background

On March 24, 1989, the T/V *Exxon Valdez* ran aground on Bligh Reef in PWS, spilling almost 11 million gallons of North Slope crude oil. It was the largest tanker spill in United States history, contaminating about 1,500 miles of Alaska's coastline, killing birds, mammals and fish, and disrupting the ecosystem in the path of the spreading oil. Damage assessment studies were concluded in 1992, although some of the lines of investigation were continued under the subsequent restoration program. More than $100 million was devoted to 164 damage assessment studies.

In 1991 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 (Memorandum of Agreement and Consent Decree 1991) Under the court-approved terms of the settlement, the Trustee Council was formed to administer the restoration funds Restoration activities undertaken by the Trustee Council have been guided primarily by the *Exxon Valdez* Oil Spill Restoration Plan (EVOSTC 1994), which was adopted by the council in 1994 In this plan, the Trustee Council laid out a program with five categories of restoration activities monitoring and research, general restoration, habitat protection, restoration reserve, and public information/administration

From 1991 to date (through federal Fiscal Year 2000), the Trustee Council has approved the expenditure of approximately $155 million for research, monitoring, and general restoration projects Up to an additional $12 million is designated for these purposes in FY 2001-2002 In its restoration program, the Trustee Council has focused primarily on knowledge and stewardship as the best tools for fostering the long-term health of the marine ecosystem, rather than on direct intervention

Most prominent among the projects funded by the Trustee Council are three ecosystem-scale projects, known by their acronyms SEA, NVP, and APEX The Sound Ecosystem Assessment (SEA) is the largest project undertaken by the Trustee Council, funded at $22 million over a seven-year period This project is formulating interacting numerical models designed to simulate the dynamic processes influencing the survival and productivity of juvenile pink salmon and herring in PWS SEA has provided new insights into ocean currents, nutrients, mixing of water masses, salinity, and temperatures and how these physical factors influence plant and animal plankton, prey, and predators in the food web

The Nearshore Vertebrate Predator project (NVP) is a six-year, $6 5 million study of factors limiting recovery of four indicator species that inhabit nearshore areas The project is looking at oil exposure, as well as natural factors such as food availability, as potential factors in the recovery of two fish-eating species, river otters and pigeon guillemots, and two invertebrate-eating species, harlequin ducks and sea otters

The Alaska Predator Ecosystem Experiment (APEX) concentrates on the productivity and recovery of seabirds based on the availability of forage fish as a food source This eight-year, $10 8 million project is looking at wide-ranging ecological changes in an effort to explain why some species of seabirds are not recovering

The three ecosystem projects, SEA, NVP, and APEX, are in the final stages of data analysis and report writing in FY 2000 The Trustee Council's emphases in FY 2001-2002 will be to monitor the recovery status of species injured by the oil spill, study factors that may persist in limiting recovery, conduct research that should lead to long-term improvements in resource management, disseminate restoration results, complete some general restoration efforts, and prepare for GEM

Restoration projects also have been conducted on key individual species injured by the oil spill The Restoration Plan identifies recovery objectives (measurable outcomes of restoration) and restoration strategies (plans of action) for each of the species known to have been injured by the oil spill These objectives and strategies are regularly reviewed and were updated in 1996 and 1999

For example, in addition to the pink salmon component of SEA, nearly $14 million has been spent on the restoration of pink salmon The recovery objective for pink salmon states that recovery will have occurred when population indicators, such as growth and survival, are within normal bounds and there are no statistically significant differences in egg mortalities in oiled and unoiled streams for two years each of odd- and even-year runs in PWS When last measured (1997), higher egg mortality persisted in oiled compared to unoiled streams Strategies currently being employed to achieve recovery of pink salmon are research and monitor the toxic effect of oil (including examining the natal habitat of pink salmon in PWS for evidence of oil contamination), provide management information (for example, conducting genetic studies related to survival), and supplement populations (on select streams)

Roughly $6 million has been spent on the restoration of Pacific herring in addition to that spent in the herring component of SEA The recovery objective for herring states that recovery will have occurred when the next highly successful year-class is recruited into the fishery and when other indicators of population health are sustained within normal bounds in PWS Increased biomasses of herring were identified in 1997 and 1998 However, the population has yet to recruit a highly successful post-spill year-class Current strategies for achieving recovery are investigate causes of the crash (in particular, disease) and investigate ecological factors that may be affecting recovery (such as effects of oceanographic processes on year-class strength and adult distribution)

More than $5 million has been spent on the restoration of marine mammals, primarily harbor seals The recovery objective for harbor seals states that recovery will have occurred when their population is stable or increasing The latest data, which are for the period 1990-1998, indicate that harbor seal populations have declined on average 2 5 percent annually The current restoration strategy for harbor seals is to continue to research and monitor populations, with research efforts focused primarily on food availability

During the course of its investigations, the Trustee Council collected information on hundreds of species of animals and plants, including sockeye salmon, cutthroat trout, black oystercatchers, river otters, mussels and kelp Occurrence and distribution of constituents of spilled oil and naturally occurring hydrocarbons were documented Oceanographic data, such as temperature and salinity, were also collected As of March 2000, Trustee Council research has resulted in more than 300 articles in scientific journals, numerous theses and dissertations, and hundreds of project reports

In addition to monitoring, research, and general restoration projects, protecting habitat has been a major restoration tool The Trustee Council has committed roughly $376 million to protect over 650,000 acres of mostly upland habitats important for restoration of injured resources, including more than 1,400 miles of shoreline and more than 300 salmon streams Many species injured by the oil spill nest, feed, molt, winter, and seek shelter in the areas protected through the Trustee Council's habitat protection and acquisition program Several other species live primarily in the nearshore environment and benefit from the protection of nearby uplands

In addition to the activities described above, each year since FY 1994 the Trustee Council has placed $12 million into the Restoration Reserve The general purpose of the reserve is to ensure that there are funds available for restoration activities after the final payment is received from Exxon in 2001 The reserve is the primary funding source for the GEM program

I C Socioeconomic Profile

Within the area directly affected by the oil spill (Figure 1) there are about 70,000 full-time residents, while two to three times that number use the area seasonally for work or recreation Numbers of permanent and seasonal residents are small compared to the millions of people outside the GOA region who are involved in commerce and consumption of its natural resources, especially oil, fish and tourism While this section describes the people of the northern GOA and their use of resources, it should be remembered that population growth outside the region fuels increasing demands for human uses and activities within the region

I C 1 PWS

PWS lies to the north of the GOA and to the west of Cordova About 7,000 people live in this area The largest communities–Cordova, Valdez and Whittier–are all coastal and predominantly non-Native, although Valdez and Cordova are home to Alaska Native village corporations and tribes Chenega Bay and Tatitlek are Alaska Native villages All five communities are accessible by air or water and all have dock or harbor facilities Only the ports of Valdez, in the north, and Seward, just outside the western entrance to PWS (see Kenai Peninsula, below), now link the area to the state's main road system, but this will change in 2000 The Alaska Railroad presently carries automobiles, boats and passengers to and from Whittier, a coastal community in PWS, north of Seward A road scheduled for completion in 2000 will allow cars to drive directly to Whittier

The economic base of the five communities in the sound is typical of rural south-central Alaska Cordova's economy is based on commercial fishing, primarily for pink and red salmon The PWS Science Center and its Oil Spill Recovery Institute provide a base for scientific research in Cordova As the terminus of the Trans-Alaska Pipeline, Valdez is dependent on the oil industry, but commercial fishing and fish processing, government and tourism also are important to the local economy Large oil tankers routinely traverse PWS and the northern GOA to and from Port Valdez In addition to working as oil industry employees, Whittier residents also work as government employees, longshoremen, commercial fishermen and service providers to tourists The people of Chenega Bay and Tatitlek augment commercial fishing, aquaculture and other cash-based activities with subsistence fishing, hunting and gathering

I C 2 Kenai Peninsula

The Kenai Peninsula, on the northwest margin of the GOA, separates Cook Inlet and PWS The central peninsula is on the main road system, only a few hours by car from the major population center of Anchorage About 49,000 people live on the Kenai Peninsula, two-thirds near the cities of Kenai and Soldotna The economy of this area depends on the oil and gas industry, commercial fishing, tourism, and forest products This area was the site of the first major Alaska oil strike in 1957, and it has been a center for oil and gas exploration and production since that time The Kenai River and its tributary, the Russian River, are major sport fishing rivers, attracting tourists from Anchorage and all over the world The ports of Kenai and Homer are home to major commercial fishing fleets for salmon, and Homer supports vessels that fish for herring, shrimp, crab, and such groundfish species as halibut Marine sports fishing is a major attraction for the tourist industry in Kenai, Seward, and especially Homer

The southern Kenai Peninsula contains the cities of Homer and Seldovia and the Alaska Native villages of Nanwalek and Port Graham Homer, on the north side of Kachemak Bay, is the southern terminus of the state's main road system on the peninsula Seldovia, Nanwalek and Port Graham, all located south of Kachemak Bay, are accessible only by air and sea Homer is the economic and population hub of the southern part of the peninsula and depends on commercial fishing, tourism, and forest products Nanwalek and Port Graham are largely dependent on subsistence hunting and fishing and village corporation enterprises, such as the salmon hatchery and cannery and logging enterprise at Port Graham

Kachemak Bay contains extensive biological resources, such as resident and migratory birds and many species of fish and shellfish The biological importance of Kachemak Bay has been recognized by its designation as the Kachemak Bay National Estuarine Research Reserve (NERR) Kachemak Bay NERR is part of a national system of estuaries specially recognized for their importance to the nation

Seward is a seaport on the eastern Kenai Peninsula near the western entrance of PWS It is the southern terminus of the Alaska Railroad, which transports marine cargo and passengers to and from Anchorage Seward can be reached by car from Anchorage Tourism is an important and growing part of Seward's economy Cruise ships dock at Seward's harbor and commercial vessels take passengers on tours of the nearby Kenai Fjords National Park

A number of marine scientific facilities are located in Seward Seward is the home port of the University of Alaska's general oceanographic research vessel, R/V *Alpha Helix*, which is owned by the National Science Foundation and operated by the University of Alaska, Fairbanks (UAF) The University of Alaska's Seward Marine Center provides shoreside support for the vessel, which includes maintenance shops for a variety of oceanographic equipment The university also maintains modern marine research laboratory facilities at the Seward Marine Center The Alaska SeaLife Center on the waterfront is not only a tourist destination, but also a marine research facility with emphases on marine mammals, seabirds, and fisheries research The Qutekcak Native Tribe operates a state-owned hatchery that produces clams and scallops for a growing aquaculture industry in PWS and southeastern Alaska

I C 3 Kodiak Island Archipelago

The Kodiak Island archipelago lies to the west of the northern GOA This region includes the city of Kodiak and the six Alaska Native villages of Port Lions, Ouzinkie, Larsen Bay, Karluk, Old Harbor and Akhiok About 14,000 people live in this region, although the population swells in the fishing season Communities on Kodiak Island are accessible by air and sea Approximately 140 miles of state roads connect communities on the east side of the island

The economy is heavily dependent on commercial fishing and seafood processing 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 or value of landings Residents of the Alaska Native villages largely depend on subsistence hunting and fishing Kodiak Island is also home to a commercial rocket-launch facility that held its first successful launch in 1999 The 27-acre Kodiak Launch Facility is 25 miles southwest of the city of Kodiak at

Cape Narrow The U S Coast Guard Station near Kodiak is a major landowner and employer Commercial timber harvest occurs on Afognak Island, which is north of Kodiak Island

Kodiak also has marine research and fisheries-related facilities The National Marine Fisheries Service (NMFS) maintains a research facility there, and plans in the future call for Kodiak to be home port to a federally funded marine research vessel The University of Alaska operates the Fisheries Industrial Technical Center, a center for research and teaching in marine science The Alaska Department of Fish and Game (ADF&G) maintains support facilities in Kodiak for its many monitoring and management programs on fish and shellfish in the Kodiak and Alaska Peninsula regions

I C 4 Alaska Peninsula

The Alaska Peninsula is on the western edge of the northern GOA Five communities on the south side of the Alaska Peninsula were affected by the *Exxon Valdez* oil spill Chignik, Chignik Lagoon, Chignik Lake, Ivanof Bay and Perryville The population of the area is about 400 year-round, but doubles during the fishing season All five communities are accessible by air and sea Numerous airstrips are maintained in these villages and scheduled and chartered flights are available There are no roads connecting these villages ATVs and skiffs are the primary means of local transportation

The cash economy of the area depends on the success of the fishing fleets Chignik and Chignik Lagoon serve as regional salmon-fishing centers, while Dutch Harbor, southwest of Perryville and outside the spill area, is a major center for crab and marine fisheries 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 Subsistence on fish and caribou is important to the people who live in Chignik and Chignik Lagoon

> "When the resident population is combined with over one million tourists each year, it becomes clear that the natural resources of the spill area cannot be immune to the pressures associated with human uses and activities"

Chignik Lake, Ivanof Bay and Perryville are predominantly Alaska Native villages and maintain a subsistence lifestyle Commercial fishing provides cash income Many residents leave during summer months to fish from Chignik Lagoon or work at the fish processors in Chignik Some trap during the winter, and all rely heavily on a diverse array of subsistence food sources, including salmon, trout, marine fish and shellfish, crab, clams, moose, caribou, and bear

I D Human Uses and Activities

The influence of human use and activities provides an important context for development of the GEM program Within the oil spill area and the nearby population centers of Anchorage and Wasilla live 54 percent of the state's 621,000 permanent residents When the resident population is combined with over one million tourists who visit the state each year, it becomes clear that the natural resources of the spill area cannot be immune to the pressures associated with human uses and activities The private sector economy of Alaska is heavily dependent on extraction of natural resources, primarily oil and fish and shellfish, followed by timber, minerals, and agricultural products An important part of the non-cash economy outside of cities is the subsistence use of resources, such as fish and shellfish, marine mammals, terrestrial mammals, birds and plants

I D 1 Oil and Gas Development

The oil and gas industry is a major economic force in two areas within the oil spill region–PWS and Cook Inlet Crude oil pumped from fields on the North Slope is transported by pipeline to Port Valdez, where it is loaded onto tankers and shipped to refineries on the west coast of the lower 48 states Tankers traverse PWS on their way south The number of tanker voyages from Port Valdez has declined from 640 in 1995 to 411 in 1999 The decline in tanker traffic reflects a sharp reduction in North Slope crude oil production over that time

Discovered in 1957, the Swanson River oilfield in the Kenai National Wildlife Refuge is the site of the first commercial oil development in Alaska Much of the oil and gas development in the Cook Inlet area occurs on offshore platforms Underwater pipelines transport product to terminals on both sides of Cook Inlet Crude oil and refined product are shipped by tanker to the lower 48 states

In April 1999, the State of Alaska offered for lease all available state-owned acreage (approximately 2 8 million acres) in its first Cook Inlet Areawide Oil and Gas Lease Sale The acreage lies within an area that encompasses approximately 4 2 million acres of uplands, tidelands, and submerged lands extending from just north of Wasilla to Anchor Point in the south, and between the Chugach and Kenai mountains on the east and the Aleutian Range on the west As a result of the first sale, oil and gas leases have been issued on about 115,000 acres of land Successive Cook Inlet Areawide Oil and Gas Lease Sales are scheduled to be held annually each August

I D 2 Commercial Fishing

I D 2 a Overview

Commercial fishing continues to be a significant human use of natural resources in the spill area despite changes that have occurred in the industry since the spill The period before the oil spill was a time of relative prosperity for many commercial fishermen Since the spill, low prices have reduced the value of the pink salmon fishery and sharp declines in herring populations have resulted in closures that devastated the fishery

Within the oil-spill area, there are major commercial fisheries on sockeye salmon, pink salmon and Pacific herring The spill area includes portions of the commercial fishing districts of PWS, Cook Inlet, Kodiak and Chignik The species fished and the gear types used vary by district The gear types for commercial salmon fishing include purse seines, drift gill net, set gill net and beach seine Purse seiners harvest primarily pink salmon, whereas gillnetters harvest primarily sockeye salmon

In PWS, the average harvest and ex-vessel value of pink salmon far exceeds that of any other species of salmon The availability of pink salmon harvested in PWS is significantly increased by hatchery sales fish from private nonprofit hatcheries However, since the spill the earnings of salmon seine fishermen in PWS have been below the 1989 level Prices paid for pink salmon have dropped from 92 cents a pound in 1987-1988 to a low of 14 cents a pound in 1997 Low prices for pink salmon reflect, in part, an increased world supply of salmon Reduced earnings appear to have reduced the number of people involved in the fishery The number of salmon seine permits fished in PWS

declined from 255 in 1988 to 149 in 1998 The number of salmon gillnetters in PWS has remained at about 500 over the same period

Significant commercial sockeye salmon fisheries occur in upper Cook Inlet and in the Chignik area The Copper River also supports a major commercial salmon fishery Although the Copper River is outside the spill area, it flows into the northern GOA and its commercial fishery contributes to Cordova's economy Between 1992 and 1998, the average annual harvest in the Copper River commercial fishery was 836,000 sockeye salmon and 52,000 chinook salmon The average size of sockeye salmon is nearly twice that of pink salmon and they are worth at least ten times more per pound than pink salmon Consequently, their value to commercial fishers is much greater

There are four types of commercial herring fisheries the food/bait fishery, the spawn-on-kelp in pound fishery, the wild spawn-on-kelp harvest and the purse-seine and gill-net sac-roe fishery By far the largest of the commercial herring fisheries is the purse-seine and gill-net sac-roe fishery in which herring are netted to collect the egg-filled sacs, or ovaries, from the mature females Pacific herring fisheries are short but intense, and extremely valuable to commercial fishers In 1992, the estimated harvest of nearly 30,000 tons of Pacific herring in PWS and Cook Inlet was worth about $14 million However, the Pacific herring fishery in PWS was closed in 1993 after disease decimated the population Commercial fishing was canceled for four successive years Limited commercial herring fisheries were held in 1997, 1998 and 1999 All spring 2000 commercial herring fisheries have been canceled

Seafood processing in the spill area also has changed Major processors in Cordova and Kenai have closed and some smaller and more specialized processors have been introduced

I D 2 b Salmon Hatchery Issues

Salmon hatcheries in the GOA are notable because they produce the majority of some salmon species in some areas, and because hatchery salmon populations present research opportunities for understanding aspects of coastal and ocean productivity not available with other species or wild populations The degree to which the salmon harvests of the GOA result from hatchery production is also remarkable

Billions of juvenile salmon are released from hatcheries in three areas within the northern GOA Cook Inlet, Kodiak and PWS In addition, salmon hatchery production has important implications for the terrestrial and marine ecosystems of the northeast Pacific Ecological matters of concern include reduced production of wild fish due to 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

The contributions of hatchery salmon to the salmon fisheries are given below as the percentage of hatchery salmon in the total harvests by individual regions and for the GOA as a whole Please note that "percent hatchery" figures may be quoted for two different categories, total or overall harvest, and total traditional commercial harvest The categories are different because there are two types of commercial harvest, common property and cost recovery The total or overall commercial harvest is the sum of common property and cost recovery harvests Common property harvests are traditional commercial fisheries conducted to benefit all those entitled to participate Cost recovery fisheries are

relatively new commercial fisheries conducted to raise funds to support hatchery operations The distinction between categories is critical because hatchery salmon harvested as a percent of total traditional salmon harvest may understate the reliance of a region's salmon fishery on hatchery production

Within Cook Inlet, Kodiak and PWS, 56% of the salmon in the traditional commercial harvest were of hatchery origin in 1999 Traditional commercial fisheries are common-property fisheries that do not include cost recovery fisheries One percent of chinook, 17% of sockeye, 29% of coho, 66% of pink, and 60% of chum salmon harvested in these fisheries were of hatchery origin in 1999 Of the total number of salmon in the State of Alaska common-property harvest throughout the entire GOA in 1999, 25% were estimated to have been of hatchery origin

Hatchery production of salmon in PWS provides a majority of the pink and chum salmon harvested, and a substantial fraction of the sockeye and coho salmon harvested In 1999 hatchery pink salmon contributed 78% of the number of pink salmon harvested by traditional commercial fisheries Overall the commercial harvest of pink salmon in 1999 contained 84% hatchery-origin fish Twenty-one percent of the sockeye and 29% of the coho in the 1999 common property harvest in PWS originated in hatcheries

All releases of pink and chum salmon from hatcheries in PWS are marked by hatchery of origin As part of the restoration program in support of improved fishery management, the Trustee Council financed the research, development and application of thermal mass marking to hatchery embryos Thermal marking leaves each individual with distinct bands, similar to bar codes, on the inner ear bone (otolith) Since more than 600 million pink and chum salmon are released each year from PWS hatcheries, many marine research opportunities are created (SSRT 1999)

Hatcheries in the Cook Inlet region produce all five indigenous species of salmon (sockeye, chinook, coho, pink and chum) About 16% of the total common-property commercial harvest in Cook Inlet originated in hatcheries 1991 Seventy-five percent of the pink salmon, 5% of the coho and 12% of the sockeye harvested in the common-property fisheries of Cook Inlet were from enhancement programs

Salmon hatcheries in Kodiak largely produce pink salmon, but they also produce chinook, sockeye, coho and chum Twenty-nine percent of the salmon commercially harvested in Kodiak in 1999 were enhanced fish Enhanced pink salmon represented 34% of the total commercial pink harvest, while enhanced coho was 39%, sockeye 18% and chum 15 4% of those harvests

Negative interactions between hatchery and wild salmon stocks have long been a concern for fisheries management in the North Pacific (cf Cuenco et al 1993), and the northern GOA is no exception For example, it is considered possible that enhanced pink salmon stocks have been responsible for reducing, or even replacing, wild pink salmon in PWS (Eggers et al 1991) Other studies, however, have cast doubt on the extent and consequences of the interaction between hatchery and wild pink salmon in PWS (Kron 1995, Smoker and Linley 1997, Smoker et al in press) Information on the interactions between hatchery and wild fish in specific locations, and 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

I D 3 Recreation and Tourism

Between 1990 and 1998, the number of nonresident visitors to Alaska increased from 900,000 to 1 35 million per year The average annual rate of increase over this period was 5% Between 1990 and 1997, the average annual increase in cruise ship traffic was 11% In 1998, the rate of growth in cruise ship traffic slowed to 3% That year, the highway system and Alaska Marine Highway System posted the largest increases in visitor arrivals These figures reflect statewide visitation and include business travelers as well as vacationers Regional visitation data have not been updated since 1993-1994

Major attractions within the spill area include Portage Glacier, Kenai Fjords National Park, Columbia Glacier, Kachemak Bay and Katmai National Park World-class salmon fishing attracts residents and visitors alike to the Kenai River, the Russian River and other rivers on the Kenai Peninsula Camping, hiking, kayaking, and wildlife viewing attract visitors to the Kodiak Island National Wildlife Refuge, the Chugach National Forest, and numerous state park units within the spill area

New visitor attractions and transportation improvements are changing the patterns of recreation and tourism activities in these areas The Alaska SeaLife Center, which was partially funded by the Trustee Council, opened in Seward in May 1998 During its first year of operation, 193,000 people visited the center Visitation was 161,000 in 1999 and is projected to increase slightly to 163,000 in 2000

In June 2000, the Anton Anderson Memorial Tunnel linking the Seward Highway with Whittier will open for vehicle traffic The tunnel will improve access to PWS and increase the number of visitors to the sound Until this year, it has not been possible to drive a car or bus from the Seward Highway to Whittier At Portage, about midway between Anchorage and Seward, passengers and vehicles board the Alaska Railroad for a short train ride through a tunnel to Whittier Opening the Anton Anderson Memorial Tunnel will allow cars and trains to take turns traveling through the tunnel It is expected that the increased access will result in a significant increase in recreational boat traffic in PWS

Charter halibut fishing is an important and growing recreational activity in the oil spill region In 1998, about 84,000 people used saltwater charter services in Southcentral Alaska Most of these clients (64%) were non-residents About 500 vessels were active in the charter halibut fishing industry in Southcentral Alaska that year The average annual growth rate in charter halibut fishing for Southcentral Alaska for the period 1994-1998 was 5 1% based on numbers of fish harvested and 6 7% based on weight of fish Two-thirds of the harvest for the period 1994-1998 came from Cook Inlet Only 12% of the harvest over this period came from PWS, but charter halibut fishing is expected to increase in the sound once access to Whittier is improved Until recently, there was no limit on the annual harvest of halibut by anglers utilizing charter boats, lodges and outfitters Concerned that pressure from these operations may be contributing to localized depletion of halibut, the North Pacific Fisheries Management Council recently set guidelines for halibut charter harvests in Southcentral Alaska

I D 4 Subsistence

Fifteen predominantly Alaska Native communities in the oil-spill area, with a total population of about 2,200 people, 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 Subsistence harvests in 1998 varied among communities from 250 to 500 pounds per person, indicating strong dependence on subsistence resources While subsistence harvest levels are at or approaching prespill levels, subsistence users report the scarcity of a number of important subsistence resources, including harbor seals, herring, clams and crab There is an increased reliance on fish in subsistence diets and decreased consumption of marine mammals and shellfish The decline in shellfish consumption reflects food safety concerns, as well as reduced availability of shellfish In interviews of subsistence users in 1998, concerns about paralytic shellfish poisoning (PSP) in clams outweighed concerns about lingering hydrocarbon contamination from the oil spill

I D 5 Logging

There currently are no major timber operations in PWS, but logging continues on Afognak Island in the Kodiak archipelago and small-scale timber operations are planned for parts of the Kenai Peninsula Koncor Forest Products recently announced that it is downsizing in response to poor lumber markets, increased competition and a dwindling timber supply Nonetheless, Koncor still owns enough timber on Afognak Island to continue logging for 30 years Afognak Native Corporation also has logging operations on Afognak Island and will soon begin a major reforestation effort on its land Logging operations on Port Graham Corporation lands on the southern Kenai Peninsula have concluded, but some logging may take place on Native allotments near Port Graham

The State of Alaska has announced a Five-Year Schedule of Timber Sales for the Kenai-Kodiak area from 2000 through 2004 One of the main factors affecting forest planning in the Kenai-Kodiak area is a major epidemic of the spruce bark beetle The proposed timber sales are designed to utilize dead and dying timber, or to harvest timber with a high likelihood of infestation in the next few years Over this five-year period, the state plans to hold 31 timber sales on about 23,000 acres of state land on the Kenai Peninsula Harvest from these lands is estimated to be 125,000 MBF (MBF=1,000 board feet) of spruce and hemlock and 410 CCF (CCF=100 cubic feet) of birch, cottonwood and aspen

I D 6 Small-scale Spills of Toxic Substances

Large spills like the *Exxon Valdez* oil spill are extremely rare More common are smaller discharges of refined oil products, crude oil, and hazardous substances Under state law, the release of hazardous substances and oil must be reported to the Alaska Department of Environmental Conservation (ADEC) In 1998 and 1999, a total of 1,325 spills was reported in the *Exxon Valdez* oil spill region, resulting in a total discharge of 218,000 gallons of refined oil products, crude oil and hazardous substances Although small spills were reported throughout the spill area, by far the largest number of spills (1,037) and greatest volume of discharge (198,000 gallons) occurred in the Cook Inlet region Most of the spills (87%) involved refined oil products, these spills accounted for about 90% of the total volume discharged Only 6,000 gallons of crude oil were reported spilled in the region in 1998-1999

Figures reported to ADEC include spills onshore as well as discharges into the marine environment The effects of these small spills depend upon 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

Small spills have been caused by a variety of industries, such as the oil and gas, timber, fishing, and seafood processing industries, as well as small commercial establishments like gas stations and dry cleaners However, a court settlement in 1995 focused on the activities of the oil and gas industry in Cook Inlet That year, local conservation groups negotiated a settlement with Cook Inlet oil and gas producers for over 4,000 violations of the federal Clean Water Act in Cook Inlet As part of the settlement, the oil companies agreed to direct three years of start-up funding to Cook Inlet Keeper, a nonprofit organization located in Home and dedicated to protecting the Cook Inlet watershed

I D 7 Roadbuilding and Urbanization

Changes in land surfaces can change entire hydrologic systems Increased areas of impervious surfaces through new roads and subdivisions usually increase stormwater runoff This change tends to lower base flows in streams and increase peak flows Stream macroinvertebrates and fish populations are sensitive to these changes Roadbuilding and other construction activities also increase sedimentation

Within the oil-spill region, the greatest concentration of roads and subdivisions is on the west side of the Kenai Peninsula In 1999, the Kenai Peninsula Borough approved plats for 250 subdivisions Most of the subdivisions were small, but a few were 40 acres or more The borough recently initiated a road-permitting program that will address placement and design of new roads

Although not within the oil spill area, the Municipality of Anchorage is within the Cook Inlet watershed 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 U S Environmental Protection Agency (EPA) 319 grant from ADEC, the United 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

I E Global Climate Change

Global climate change is an essential part of the environmental context for development and implementation of the GEM program Uncertainty over how and the extent to which the forces of climate drive the abundances of plants and animals in marine ecosystems has long been with us The ability to measure large-scale climate change and to understand its possible roles in biological production in the North Pacific have increased dramatically in the past decade The climate of the North Pacific is known to change sharply over periods of decades, centuries and millennia, in concert with climatic processes in other parts of the world, such as in the North Atlantic Some of these changes have been correlated through time with sharp changes in production and relative abundance of species of seabirds, salmon and other fishes, marine mammals, shrimp and crabs (Section IV) The timing of changes in climate also appears to coincide with changes in the

production and species composition of the plankton on which all these species feed, directly or indirectly That mechanisms of biological production respond directly to the physical forces of climate change is known as the bottom-up control hypothesis, because climatic effects are thought to mainly start at the bottom of the food chain and work their way up

Global climate change is important for understanding how humans affect biological production Long-term population declines are apparent in animal populations that depend on the ecosystems of the GOA, such as cormorants, kittiwakes, fur seals, Steller sea lions, harbor seals, red king crab, and sablefish, among others (Section IV) Are these declines the result of bottom-up control forced by climate change? Are they due to top-down control through removals of breeding animals and prey species by fisheries, mortality and depression of reproduction by oil and other pollutants? Or are alterations to critical habitat and other human activities to blame? Is it some complex interaction of all of these? Some populations of fish and marine mammals that show long time 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

I F Fishery and Ecosystem-based Management

Growing human uses and the requirement for sustainable uses of natural resources are important concerns for designing GEM In these contexts, GEM must provide products that are relevant to the needs of resource managers, consumers, and conservationists The growing demand within the northern GOA for recreational, commercial, and subsistence harvests of fish and shellfish appears to be driven by growing human population, increasing tourism, and application of existing policy mandates

Policies requiring sustainable use of fisheries resources have long been clear, but the overall information required for implementation is rapidly increasing The Constitution of Alaska (1959) and the federal Magnuson-Stevens Fisheries Conservation and Management Act (1976) (MSFCMA) provide the basic state-federal mandates for sustainable use Experience over the last decade with an amended MSFCMA and application of the federal Endangered Species Act (1973) to marine birds, mammals and fish have made the need for ecosystem-based approaches to sustainable management obvious The old definition of conservation that focused on protecting single species in narrow geographic contexts has been replaced by the concept of protecting the ecosystem components and processes that produce the single species Information required to protect the habitats, predators and prey of target species is much greater under the new definition of conservation than was formerly thought to be required to prevent overharvest of the single species Ecosystem-based management may be in its infancy, but it is widely recognized among professionals as the heir to traditional fishery management (NPFMC 1999)

On a worldwide basis, many fisheries are fully exploited or depleted, and pressures on marine fisheries resources are increasing and are expected to increase further as human populations grow Virtually all living marine resources on the continental shelf off Alaska probably were negatively impacted by international fishing fleets until about 1975 Impacts were not limited to species represented by catch statistics, since other species were caught

but not kept for sale Additional species were probably impacted through habitat loss from destructive fishing methods, derelict fishing gear and pollution As a consequence, reductions in populations of many marine species during the first three-quarters of the 20th century were probably fairly severe, although evidence is limited to a few species For example, reductions in baleen whales in the first half of the twentieth century were particularly severe Starting at various times in the mid-1970s and 1980s, steep declines were noted in the Bering Sea and GOA in populations of fur seals, harbor seals, murres, kittiwakes, and the Aleutian Island pollock Declines in Steller sea lions were serious enough for the species to be listed under the federal Endangered Species Act in 1990

How might GEM contribute to implementing ecosystem-based fishery management? GEM may contribute through improving understanding of the functioning of the ecosystem as a whole, which is a basic requirement of ecosystem-based management Knowledge of how the system produces the valued resources and what must be conserved to sustain healthy populations and a robust ecosystem comes from understanding ecosystem dynamics At present, available information appears inadequate to answer even the most basic ecosystem-based management question of whether removing species from the top of the food chain serves to reduce the long-term productivity of the ecosystem Removal of large quantities of seals, toothed and baleen whales, and predatory fish species could seriously alter all aspects of the food web, but the specifics in the GOA are not understood Another issue important to implementing ecosystem-based fishery management is understanding the role of weather in driving production of marine species, which is known to be important, but is poorly understood

I G Marine Habitat Protection

The management and conservation of habitats in the marine environment of the GOA is not well advanced compared to such efforts in adjacent terrestrial environments For instance, in the oil-spill area the protection of about 650,000 acres of upland habitat by the Trustee Council was added to the protection afforded to large areas of land already in public ownership With the exception of a few cases where tidelands are privately owned, marine habitats cannot be purchased as uplands can be An additional problem is that relatively little is known about which areas are important to which species and at what seasons The life histories and habitat requirements of many marine species are not well understood, making it difficult to develop appropriate conservation and management strategies

Protection has already been afforded to marine habitats in some cases by excluding gear types that are thought to be injurious to habitat For example, the eastern GOA is now closed to trawling and dredging in part to protect coral habitats from possible trawling impacts This closure also serves to allocate the allowable catch of rockfish to the longline fishery

In addition there are numerous trawl-and-dredge closure areas in the vicinity of Kodiak Island, the Alaska Peninsula and the Aleutian Islands Marine areas where marine mammals feed and adjacent to their haul-out areas also have been closed to commercial fishing in parts of the Bering Sea, Aleutian Islands and GOA Given the amount of marine habitats already subject to closure, more information on how to define critical marine habitats is essential to balancing fishing opportunities and protection of habitat

While lack of information plagues the discussion of marine habitat protection, there seems little question that pressure on marine habitats will continue to increase For example, the impending road connection between Anchorage and the PWS port of Whittier will increase public visitation to northwestern PWS The Whittier road is expected to generate increases in requests for permits for facilities (e g , boat fuel and other supplies) on shorelines, tidelands, or nearshore waters, as well as result in other potential actions that may impact marine habitats and the fish and wildlife populations that rely on these habitats

Continued expansion of urban areas and resulting expansion of suburban zones inevitably degrade habitat Urban growth leads to increasing disposal of human wastes Even treated wastes may lead to changes in species composition and productivity in watersheds, estuaries and nearshore areas Introduction of petroleum compounds associated with motor oil and fuels through runoff from urban areas may have an insidious negative effect on productivities of freshwater and marine areas Recent findings at the Auke Bay Laboratory of the National Marine Fisheries Service (Stanley Rice, personal communication) have indicated that concentrations of oil in water that are much lower than previously documented can harm salmon 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

Information is not now available to fully identify sensitive areas and critical seasons Some sensitive locations and seasons are easily recognized, such as during the breeding season at well-documented seabird nesting colonies, but many other information needs are poorly satisfied For example, through the Trustee Council's large-scale ecosystem projects, we are starting to understand the full annual cycle of the Pacific herring, including identification of over-wintering habitats and requirements for juvenile herring This type of information is crucial to long-term protection of herring stocks There is much more to be learned about the habitat requirements of herring, to say nothing of other forage fishes, such as capelin and sand lance, which are key to healthy seabird and marine mammal populations

I H Contaminants, Water Quality and Food Safety

The presence of industrial and agricultural contaminants in aquatic environments has resulted in worldwide concerns about potential effects on marine organisms and on human consumers Polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and organochlorine pesticides, such as DDT and its derivatives, are widely distributed around the world in marine and coastal waters and in the rivers and watersheds that feed fresh water into these environments Such pollutants can be transported great distances by winds and ocean currents following their releases from industrial and agricultural sources In addition, mercury and other metals, such as inorganic arsenic,

cadmium, and selenium, are naturally present in the environment at low concentrations, but anthropogenic sources can contribute additional quantities to the environment

The remoteness of the northern GOA from centers of industry and human population might be expected to protect much of this region from deposition of environmental contaminants There is evidence, however, of wide geographic distribution of persistent organochlorines (DDT, DDE, PCB), organic pollutants and heavy metals in the arctic and subarctic regions (Crane and Galasso 1999) Measurable amounts of organochlorines have been found in even apparently pristine areas such as the Copper River Delta, which forms the eastern boundary of PWS 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 Some of these contaminants, such as PCBs and DDT, can bioaccumulate in living marine organisms For example, research on killer whales following the oil spill revealed that some marine mammal-eating transient killer whales sampled in PWS carry concentrations of PCBs and DDT derivatives that are many times higher than those in fish-eating resident whales The sources of these contaminants are not specifically known It has been established, however, that these contaminants are passed from nursing female killer whales to their calves

There is also concern about the potential effects of contaminants on people, especially those who are heavily dependent on subsistence resources, such as 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 Following the oil spill, there was much concern about hydrocarbon contamination in subsistence foods, and sampling programs for food safety were sustained through 1994 There continues to be concern about food safety in relation to the oil spill and more generally among Alaska Natives in coastal communities

> "A systematic effort to gather data on environmental contaminants in the oil-spill area could provide valuable "early warning" information to local residents and other consumers, especially subsistence users, and alert scientists to contaminants that may affect fish and wildlife populations"

The information available on the distribution and concentrations of contaminants in the northern GOA is limited (Crane and Galasso 1999) The State of Alaska, for example, does not monitor environmental pollutants in the marine environment nor in marine organisms on a regular basis Similarly, 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 Subsistence food safety testing was conducted from 1989 through 1994 in conjunction with damage assessment and restoration activities following the oil spill In addition, restoration activities included a resource abnormality study, which provided an opportunity for subsistence users to send in samples of abnormal resources for examination by pathologists in federal fiscal years 1994-1996

Potential GEM projects that sample birds, fish or mammals may provide environmental agencies, such as ADEC and the EPA, a relatively low cost means to acquire samples for contaminants testing GEM also may contribute to coordination of

tissue collection from the multitude of small and large sampling efforts on marine animals throughout the GOA, which could enhance existing agency efforts A systematic effort to gather data on environmental contaminants in the oil-spill area could provide valuable "early warning" information to local residents and other consumers, especially subsistence users, and alert scientists to contaminants that may affect fish and wildlife populations

Notes

II Vision for Gem and Northern Gulf of Alaska

II A Mission

The original mission of the Trustee Council adopted in 1993 was to "efficiently restore the environment injured by the *Exxon Valdez* oil spill 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 adopted by the Trustee Council in the 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 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 involve stakeholders in local stewardship by guiding and carrying out parts of the program

II B Goals

GEM has five major programmatic goals in order to accomplish its 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,

PREDICT Develop the capacity to predict the status and trends of natural resources for use by resource managers and consumers,

INFORM Provide integrated and synthesized information to the public, resource managers, industry and policy makers in order for them to respond to changing conditions, and

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

Given the size and complexity of the ecosystem under consideration and the available funding, it will not be possible for GEM, by itself, to meet these goals Addressing them will require focusing on the institutional goals to

IDENTIFY research and monitoring gaps currently not addressed by existing programs,

LEVERAGE funds from other programs,

PRIORITIZE research and monitoring needs,

SYNTHESIZE research and monitoring to advise in setting priorities,

TRACK work relevant to understanding biological production in the GOA, and

INVOLVE other government agencies, non-governmental organizations, stakeholders, policy makers, and the general public in achieving the mission and goals of GEM

II C Geographic Scope

Consistent with the Restoration Plan, the primary focus of the GEM program is within the oil-spill area, which is generally the northern GOA, including PWS, Cook Inlet, Kodiak Island and the Alaska Peninsula (Figure 1) Recognizing that the marine ecosystem impacted by the oil spill does not have a discrete boundary, some monitoring and research activities will necessarily extend into adjacent areas of the northern GOA

It is important to note that the northern gulf ecosystem includes the watersheds, estuaries, coastlines, continental shelf and open ocean systems that affect the marine resources of the northern gulf It is also important to note that waters from the shelf and basin of the GOA eventually enter the Bering Sea and the Arctic Ocean (through the Bering Strait) While GEM has a regional (GOA) outlook, the program will be of vital importance in understanding the downstream Bering Sea and Arctic Ocean ecosystems 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, fishes and mammals that also move through these regions

"It is important to note that the northern gulf ecosystem includes the watersheds, estuaries, coastlines, continental shelf and open ocean systems that affect the marine resources of the northern gulf"

II D Funding Potential

The intent of the Trustee Council is to fund the GEM program beginning in October 2002 with the funds it allocated for long-term research and monitoring, estimated to be approximately $120 million The Trustee Council intends to manage these funds as an endowment, with the annual program funded by investment earnings after inflation-proofing The *Exxon Valdez* oil spill settlement funds have previously been required by federal law to be invested in the U S Treasury, and specifically by the terms of the court order, within the Court Registry Investment System (CRIS) in the U S Treasury Recent Congressional action (PL 106-113, 1999), however, now allows the funds to be invested in accounts outside the U S Treasury and CRIS That change should be fully implemented by July 2000

Similar endowments, such as the State of Alaska Permanent Fund, the State of Alaska retirement fund, the University of Alaska Foundation, and others are invested in a prudent manner and earn on average considerably more than 5% per annum Given the past record of the stock market, investment returns of 18-20% and higher are typical in recent years However, even prior to the recent high stock market returns, most foundations were averaging an 8-10% rate of return An 8% rate of return on a $120 million fund would realize $9 6 million in annual earnings Assuming a 3% inflation rate, $3 6 million would go towards inflation proofing, leaving $6 million available to spend This investment scenario would allow for a stable program over time The Trustee Council also would have the option of funding a smaller program in the early years in order to build the corpus of the fund

It is the long-term goal of the Trustee Council to establish the research fund in such a manner as to allow for additional deposits and donations to the fund from other sources

in order to increase the corpus This might require some form of state or federal legislation and possibly a change in the consent decree, and will be pursued at a later time

II E Governance

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 and to restore 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 They currently are the U S Interior Department's Special Assistant to the Secretary for Alaska, the Alaska Director of the National Marine Fisheries Service, and the Supervisor of the Chugach National Forest for the Department of Agriculture All decisions by the Trustee Council are required to be unanimous It is expected that the current Trustee Council will continue to 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 be established to administer or guide the research and monitoring 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 However, use of a new governance structure, if justified, would require changes in law and the applicable court decrees Such changes are not anticipated in the near future

III. Structure and Approach

Notes

The mission and goals of the GEM program can only be achieved if the program provides leadership in working with others to establish consensus priorities for research and monitoring in the northern Gulf of Alaska (GOA), coordinates GEM efforts with other programs and funding sources, and encourages leveraging funds and developing strategic partnerships GEM's scientific program will consist of two primary complementary components long-term ecological monitoring and shorter-term targeted research A core of long-term monitoring measurements are intended to track ecosystem changes on the scale of decades Shorter term research will be used to explain the reasons for changes over time and to clarify functional relationships within the ecosystem The GEM program will be designed, carried out, and evaluated with the benefit of independent scientific peer review and the participation of natural resource managers, stakeholders, and residents in coastal communities The selection, design, and execution of projects will be coordinated with and complementary to ongoing programs and projects of government agencies and other institutions The use and application of traditional and local knowledge will be encouraged, as will the participation and education of young people in coastal communities The synthesis, interpretation, and dissemination of what is learned about the status, trends, management, and conservation of marine resources will be a priority throughout the program Periodic "State of the Gulf" workshops, invitations to submit proposals, and reports to the public will be part of GEM's adaptive management process and means for public outreach

III A Leadership

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 GOA ecosystem With multiple programs gathering data on marine resources in the gulf, there currently exists a vacuum in integrating and synthesizing results Without this broad context, interpretation of individual data sets can be problematic or inaccurate Natural resource managers and stakeholders are not able to obtain a "big picture" perspective on what is happening in the GOA There will be different ways that the necessary syntheses can be achieved, and different ways to convey this information to users What is important is for the GEM program to provide the leadership in conveying the needed information in formats that are accessible to and useful for a variety of users, including scientists, resource managers, stakeholders, and the public

One approach to synthesizing an array of ecological data is modeling Useful models of three-dimensional water circulation, plankton production, juvenile pink salmon survival, Pacific herring overwintering, the energetics of colony-nesting seabirds, and carbon mass-balances in Prince William Sound (PWS) exist or are in advanced stages of development These models show great promise as a means of integrating large volumes of data in ways that yield insights about how marine ecosystems work These models also offer a means of identifying knowledge gaps or making predictions about climate forcing, oceanographic currents, biological productivity, and the ecological effects of human activities The models cited above mostly address the PWS ecosystem To the extent that these models relate to GEM hypotheses, it may be worthwhile to invest additional resources in further testing and application in PWS or to extend their scope to other areas within the oil-spill region or to the northern GOA more broadly

Although the scientific literature is an effective means of disseminating research results within academic circles, journals are generally not an effective way to share information with natural resource managers and stakeholders, who may lack time, ready access, or training to make use of the information available in technical journals Thus, there is a need to convey the interpreted and synthesized results of monitoring and research projects to managers and stakeholders in a timely, accessible, and understandable manner Lack of an effective mechanism or mechanisms to do so can compromise the success of a program like GEM

Periodic workshops on the "State of the Gulf," and possibly on the "State of the North Pacific," will be another means of reviewing and integrating information across disciplines to achieve greater insight into the status of and trends in the northern GOA ecosystem At such forums, project investigators and others will present results and exchange information for the benefit of scientific participants, but also for the benefit of resource managers, stakeholders, and the public The format will be similar to the annual restoration workshops in the current *Exxon Valdez* Oil Spill (EVOS) program More targeted workshops may also be appropriate

The GEM program should also take an active role in other ecosystem synthesis efforts in the greater North Pacific These include the North Pacific Research Board, the U S Salmon Fund established as part of treaty negotiations with Canada on the Pacific Salmon Treaty, and international research by participants in the North Pacific Marine Science Organization (PICES) Because of the institutions represented on the *Exxon Valdez* Oil Spill Trustee Council (Trustee Council) and guaranteed funding opportunities, the GEM program may be in a unique position to help provide leadership in this realm

III B Coordination

There are many different programs and projects that involve monitoring, research and management of marine resources in the GOA These programs and projects are carried out by government agencies, such as the National Marine Fisheries Service, by universities, such as the University of Alaska, and by international bodies, such as the International Pacific Halibut Commission Among these agencies and institutions, missions, responsibilities, and priorities vary by program and project, yet each of them concerns the study, management or conservation of marine resources in the gulf There is potential for overlap and duplication among these programs and projects, but probably a more serious concern is a lack of coordination and integration, which means foregoing opportunities for increased efficiency, focus, and joint action that would benefit marine resources and stakeholders Thus, there is both need and opportunity for coordination, joint planning and setting of priorities, and sharing of program details such as cruise schedules This also holds true for coordination of efforts in the Bering Sea and the greater North Pacific Building strategic partnerships among institutions and programs will be a key component of GEM Goals are to increase leveraging of funds, improve capacities for research and management, and maximize opportunities to benefit conservation of marine resources in order to serve the common interests of stakeholders

A major contribution of GEM towards the goal of increased coordination of efforts will be the GEM database/matrix of who is doing what, where, and when (Appendix B) Initial feedback has been that active management of this database would be in and of

itself an extremely useful project No entity currently has the responsibility for actively tracking research and monitoring efforts in the GOA Any future GEM database effort should be closely coordinated with other existing efforts

III C Long-term Monitoring

The core of GEM is long-term ecological monitoring Long-term monitoring is necessary to document seasonal, interannual and interdecadal changes in productivity on the shelf and coastal ecosystems of the northern GOA, including PWS, lower Cook Inlet, and the Kodiak Archipelago-Shelikof Strait area Monitoring productivity against the backdrop of long-term ecological change will lead to an understanding of the natural and human influences on the health and productivity of key species of fish and wildlife, and it will improve abilities to distinguish among the causes of change and predict ecological trends In turn, this information can be applied by a variety of resource managers, policy makers, and stakeholders for the use, management and conservation of marine resources

The GOA ecosystem includes a complex network of thousands of species Section IV describes our current understanding of how biological productivity of the northern gulf is influenced by natural and man-made factors It will not be possible for GEM to answer all, or even most, of the questions that could be posed Instead, GEM is likely to be focused, to a large extent, on key species and ecological processes in the system Species and processes would be picked on the basis of ecological importance, human relevance, and their ability to indicate ecosystem disturbance, as well as their importance for understanding the physical and biological bases for productivity

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In designing a monitoring program, it will be important to give some thought to developing indices of ecological performance from data collected by GEM and its correspondent agencies and researchers Annual and seasonal indices related to the "State of the Gulf" should be developed from the types of data relevant to management agencies Observations such as abundance of adult sea lions in standard survey areas, number of humpback whales, levels of contaminants in animal tissue and nutrients in water are specific examples Standards such as desired future conditions, historical conditions, and baseline information over a given time period should be considered when refining monitoring goals In the end, GEM must be justified on what it can teach policy makers, resource managers, and the public about options for directing human behavior toward achieving sustainable resource management goals

Accordingly, the GEM program will continue its work with resource managers, stakeholders, the scientific community and the public to refine a common understanding of which marine resources of the northern gulf are key and what stressors, or potential threats, could affect their overall health The GEM program will then build a matrix of who is monitoring what, where, and when, and work with interested parties to help fill critical information gaps

It is envisioned that the GEM monitoring plan will be considered and re-adopted by the Trustee Council on a regular basis, perhaps every three to five years The monitoring plan will address which species, ecosystem functions, and indicators of human-influenced change to focus on, which hypotheses to test, and which approaches and strategies would be most effective in accomplishing the mission and goals, given the available funding A major challenge will be to determine the appropriate balance between retrospective data analysis and synthesis and active data acquisition, as well as the balance between monitoring for large scale ecological change and more localized effects A preliminary list of areas of interest for possible monitoring is included in Appendix C 1

III D Shorter-term Focused Research

The long-term monitoring component of GEM will be complemented by strategically chosen research projects with relatively short-term goals It is premature to identify specific projects to be carried out in the research component of GEM It is possible, however, to discuss the types of research that likely will be carried out Some of these scientific questions are described in further detail in Appendix C 2

III D 1 Lingering Injury From the Oil Spill

Research specifically related to the effects of the *Exxon Valdez* oil spill may be prominent in the first few years of the GEM program, but the need for this type of research will diminish over time Types of research likely to be conducted include exploring the continuing, low-level effects of hydrocarbon exposure on the survival and reproduction of fish and wildlife resources and the identification of pathways of such exposure General restoration projects that relate directly to restoration of oil spill injury may also be needed in some cases

III D 2 Exploring Questions With or Generated by Monitoring Data

As the effects of EVOS fade and as GEM matures, research projects will increasingly arise from the results and needs to improve the long-term monitoring program Many different types of research may arise by this means Some of this research will involve special analyses and modeling of data obtained through the core monitoring program (including current and retrospective data) and/or other monitoring efforts in the gulf Other projects, such as those exploring mechanisms of change or ecological processes, will require additional work in the field or laboratory

III D 3 Management, Conservation, and Sensitive Areas and Seasons

GEM research may include projects designed to provide information and tools to improve management and conservation of marine resources Examples of this type of research would include improving techniques, tools, or technology for stock assessments of fisheries resources, gathering basic information on species' life histories, genetic stock identification of marine mammal, seabird, or fish populations, and experimental work on the ecological effects of different levels, locations, and seasons of fisheries harvests, and interactions between hatchery and wild salmon

The Trustee Council's habitat protection program has focused on the terrestrial habitat of numerous marine species by protecting about 650,000 acres of upland habitats, including

more than 1,400 miles of shoreline and 300 anadromous fish streams Research carried out as part of GEM can be focused on the identification of sensitive areas and seasons in the marine environment so that this information can be considered in the development of management and conservation strategies in the marine environment

III E Traditional Knowledge, Community Involvement and Local Stewardship

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 Additionally, traditional and local knowledge can provide important observations and insights about changes in the status and health of marine resources (Huntington 1998) The inclusion of appropriate traditional and local knowledge and the involvement of communities in the northern gulf region is appropriate throughout the GEM program Local monitoring, documentation, and stewardship projects must be linked wherever possible with other monitoring, research, and conservation projects under GEM to promote sharing of information and ideas Scientific steering committees, composed of academic, agency and local representatives, can identify and oversee opportunities for productive collaboration A "State of the Gulf" workshop and other forums can bring together a variety of participants in the various aspects of GEM to stimulate discussions and spark new ideas

The actual mechanisms for achieving this goal are under active consideration 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 (Brown-Schwalenberg et al 1998, Huntington in press, Fehr and Hurst 1996, Hansen 1994, Brooke 1993) One approach, the Youth Area Watch, has proven to be an effective and popular means of using schools to involve and educate young people and their home communities in marine research The Alaska Native Harbor Seal Commission uses Trustee Council funds to teach youths and subsistence hunters from spill-area communities how to take biological samples from locally harvested seals The Community Involvement Project contracts with the Chugach Regional Resources Commission to provide local experts in Alaska Native communities who offer advice and feedback to the Trustee Council's restoration program A pilot effort is underway with five of those communities this year to develop a natural resource management plan for each community, identify important resources and potential threats, and design a local monitoring scheme This could develop into a much larger program, similar to that of other tribes across the nation

Other citizen monitoring efforts that are not part of the current Trustee Council program are springing up throughout the spill area Cook Inlet Keeper is spearheading a volunteer water quality monitoring program in Kachemak Bay, and providing training and oversight for similar efforts in the Kenai watershed and the Matanuska-Susitna Valley The Global Learning and Observations to Benefit the Environment (GLOBE) program is targeting high school students as part of an international environmental monitoring effort In other parts of the country, fishing vessels and commercial vessels have been equipped with instruments known as "CTDs" for the temperature, salinity and depth data they log

Similar projects may be developed as part of GEM in coastal communities throughout the oil-spill area Quality control, volunteer versus paid personnel, data management, and integration with existing agency efforts are all issues that would need to be addressed In addition, further thought needs to be given to whether to rely on one comprehensive program, or a loose conglomeration of smaller, more separate efforts

III F Program Administration and Management

By necessity, the administration and management of GEM must be cost efficient Equally important, however, is the need for a high caliber scientific program In addition, there must be public access and accountability in regard to all projects and project results

III F 1 Administration

The GEM program will be administered by a core professional staff that is not directly affiliated with any particular agency, institution, or program, as is currently the case with management of the *Exxon Valdez* Oil Spill Restoration Office An executive director will oversee the financial, program management, 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

III F 2 Competition and Quality

Monitoring and research activities must be of the highest scientific caliber, with participation by the best scientists from a variety of institutions The program should take advantage of different institutions, facilities, and capabilities throughout the region These institutions should contribute expertise, services, and funds toward programs and projects that support GEM's mission

Funds for monitoring and research projects will be awarded on a competitive basis Priority will be given to strategies that involve partnerships Participation by students and local residents will be actively encouraged It is the intent of the Trustee Council not to fund projects that are considered "normal" activities of government agencies

III F 3 Science Management

A senior staff scientist, hired by the executive director and residing in Alaska, will provide in-house scientific counsel and leadership to GEM and the Trustee Council Over time, but probably not initially, the senior scientist may serve as executive director of the Trustee Council The senior scientist will work with the Trustee Council and executive director, in consultation with the scientific community, natural resource agency managers, and stakeholders to plan, implement, and evaluate the long-term program

III F 4 Scientific Peer Review

Independent peer review will be an essential feature of the GEM program, and there are different models for managing this process For example, the process could be managed entirely by the senior staff scientist or it could rely more on the services of a consulting science advisor Regardless, there will be an external *ad hoc* technical review process, the primary purpose of which will be to provide rigorous peer review of the scientific

merits of all monitoring and research proposals and selected reports Such reviews will be sought on a mostly voluntary basis from qualified scientists who are not also carrying out projects funded by the Trustee Council In general, the individuals involved will change as topics, needs, and availabilities change Review functions will be carried out in writing, by telephone, and occasionally on site or in person

From time to time, special review panels will be convened to evaluate and make recommendations about aspects of the program For example, although monitoring projects will be designed on long time scales, they will likely be reviewed at five-year intervals At other times, special panels may meet with project investigators and others to fully explore particular topics, problems or projects Periodic review by an outside entity, such as the National Research Council, may be appropriate

III F 5 Annual Work Plan Process

Starting in FY 2003, the basic process will function on an adaptive management cycle along the lines of the current restoration program This process will likely have the following elements or steps, although this may be modified over time

- A "State of the Gulf" workshop will be held periodically, at which the research and monitoring results during the previous cycle are discussed, information integrated across disciplines, and future needs and opportunities considered Project investigators, selected peer reviewers, resource managers, stakeholders, and the public will be invited to this meeting

- An *Invitation to Submit Proposals*, which will specify the types of proposals that are priorities for consideration in the coming fiscal period, will be issued periodically Research proposals are envisioned to be of finite duration and to have short-term goals (e g , two to five years) Monitoring projects will be evaluated and renewed on longer time scales (e g , once every five years) The *Invitation* will be the vehicle for notifying the scientific community and others that monitoring projects will be considered in a given fiscal year

- Proposals received in response to the *Invitation to Submit Proposals* will be circulated for peer review Peer review comments and recommendations will be summarized and provide a basis for preliminary recommendations on the projects to be included in annual work plans

- The executive director will prepare a draft annual work plan which will be circulated for public review and comment The size of the work plan will depend on the funding level determined by the Trustee Council on an annual basis depending on the success of the GEM fund's investments A policy for how that amount will be calculated is under development Following close of the public comment period, the executive director will prepare final recommendations on the annual work plan for consideration and action by the Trustee Council

- Annual and final reports will be required for all monitoring and research projects, and all such reports will be reviewed to evaluate whether the investigators are making satisfactory progress toward project objectives Selected annual reports may be sent for review by independent peer reviewers, depending on need, the maturity of the project, and other factors All final reports will be sent for independent peer review,

and comments from the independent peer reviewers must be addressed in the final versions of final reports All annual and final reports will be archived at the Alaska Resources Library and Information Service (ARLIS) and affiliated institutions

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

III G Data Management

The current EVOS restoration program does not have an overarching data management strategy or plan, although some individual projects (e g , Sound Ecosystem Assessment) have had sophisticated systems for managing and exchanging data The investigators for each project sponsored by the Trustee Council are responsible for preparing written final reports, which must describe the data obtained in the project and the format of the data, identify the permanent custodian of the data, and indicate the availability of the data The final reports containing the data summaries are available from the Alaska Resources Library and Information Service (ARLIS) With respect to data on hydrocarbons, copies of all such data are reviewed and then archived in a hydrocarbon database maintained at the National Marine Fisheries Service's Auke Bay Laboratory in Juneau, Alaska In addition, it is the policy of the Trustee Council that, consistent with state and federal laws, any data resulting from any project to which the Trustee Council has contributed financially are in the public domain and, as such, must be available to the public

It is absolutely essential that data management needs for GEM be addressed fully before gathering of new long-term monitoring data is initiated To the extent that GEM will incorporate existing data sets, it also is essential that provision is made to seamlessly link existing and new data As preliminary steps, it will be necessary to

- review existing EVOS policies and practices with respect to data management at programmatic and project levels,
- compile detailed information about the location and status of data sets ("metadata") for at least those projects that are likely to be relevant to GEM, and
- assess federal and state agency data management policies and standards, practices, and programs to identify requirements that pertain to GEM and opportunities to address GEM data management needs on a cooperative basis with trustee agencies or other appropriate agencies and institutions

On the basis of these preliminary steps, a draft data management plan and policy will be developed A project led by Dr Charles Falkenberg was initiated in FY 2000 to explore the data management issues described in this section The fundamental aim of a future plan will be to ensure that GEM data, especially long-running streams of monitoring data, will be maintained and archived in ways that are permanent, cost effective, technically appropriate, and readily accessible to scientific users, resource managers, stakeholders, and the public

The GEM data policy will require individual investigators and sponsoring agencies and institutions to turn over all data in electronic formats along with supporting documentation, consistent with applicable data standards, to a custodian agency or institution within an agreed time after the data are obtained, at which point the data will be available to all public users Although different data sets may be archived and

maintained at different agencies or institutions, depending on the subject, it is expected that such data will be available at a central GEM website via Internet links to other websites Implementing the GEM data management plan and policy will likely require the services of a dedicated data manager, perhaps on a shared basis with a trustee agency or other agency or institution

III H Public Information and Involvement

The importance of public participation in the restoration 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 The question is how this should be achieved The existing Public Advisory Group (PAG) has 17 members representing 12 interest groups and the public at large, as well as two ex-officio members from the Alaska Legislature It may be appropriate to change the makeup of the PAG to increase the participation of additional interests and reduce costs It is also possible that public input could be sought without a formal advisory group, although this would require an amendment to the consent decree The Council's current PAG is in the process of reviewing various options for public involvement and will be making a recommendation to the Trustee Council in the next year The Trustee Council will likely seek additional public comment on various alternatives before taking any final action prior to October 2002

The Trustee Council is a public entity subject to the State of Alaska Open Meetings Act and corresponding federal laws All meetings are public and include a formal public comment period A number of additional tools have been developed by the Trustee Council to promote and encourage public input and participation These include newsletters, annual reports, public meetings throughout the spill-affected region, newspaper columns, a series of radio spots, and the Trustee Council's website at www oilspill state ak us

Because the GEM program is envisioned as a much smaller program than the current *Exxon Valdez* oil spill restoration program, at least initially the cost of these outreach efforts has to be considered before decisions are made on which tools should be used to increase public input and participation Additionally, the audience for an outreach program is very broad and includes the greater scientific community both in Alaska and outside the state, Alaska Native villages, many of which lack Internet access, high school and college students, fishers, and federal, state and local government officials Some tools are obviously more appropriate for specific audiences

A major tool for disseminating data and interpreted and synthesized results from GEM projects to the public, stakeholders and the greater scientific community will be a GEM website This site could be along the lines of the Bering Sea and North Pacific Ocean Theme Page, which is maintained by the National Oceanic and Atmospheric Administration This website could provide access to GEM databases and other products (e g , metadata and bibliographies of reports and publications), as well as present and discuss research results, program information, and evolving insights about the northern GOA marine ecosystem Another example of an effective tool for facilitating exchange of data and research is the North Pacific Marine Science Organization (PICES) web site

Notes

IV Scientific Background

IV Introduction

Sections I-III have described the framework for the GEM program and process Section IV describes and organizes the scientific information available to guide the Trustee Council as it develops and implements GEM As such, this background section attempts to be inclusive of all the biological and physical components of the Gulf of Alaska (GOA) ecosystem Please note that this section is not a list of projects to be implemented, nor is it a research and monitoring plan

The first part of the scientific background is a description of a scientific record that spans 260 years Following this, the scientific information is organized into a conceptual foundation that states our current understanding and beliefs about how the elements of the system function to produce birds, fish, shellfish, and mammals and other biological constituents such as phytoplankton and zooplankton

IV A Guidance from Prior Programs

IV A 1 Comprehensive Investigations and Reviews

Antecedents of the GEM program provide guidance A marine science planning document with a broader geographic scope, the Alaska Regional Marine Research Plan (ARMRP) (ARMRB 1993), was prepared under the U S Regional Marine Research Act of 1991 For all marine areas of Alaska, including the GOA, the plan provided five elements that are of interest to the GEM program 1) an overview of the status of marine resources, 2) an inventory and description of current and anticipated marine research, 3) a statement of short- and long-term marine research needs and priorities, 4) an assessment of how the research and monitoring activities under the program take advantage of existing projects, and 5) descriptions, time tables and budgets of research and monitoring to be conducted under the program The current GEM document does not address element five, since that is the ultimate goal of the three-year process of implementation to be completed by October 2002 ARMRP goals express the scientific needs of the region as of 1992, and they are still quite relevant to the GEM effort

- Distinguish between natural and human induced changes in marine ecosystems of the Alaska Region,
- Distinguish between natural and anthropogenic 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 region's water quality and ecosystem health

The Bering Sea has received a good deal of recent attention, especially due to concern over long-term declines in populations of high-profile species such as king and Tanner

crab, Steller sea lions, spectacled eiders, common murres, thick-billed murres, and red-legged and black-legged kittiwakes (DOI-NOAA-ADF&G 1998b) The vision of the federal-state regulatory agencies for the Bering Sea Ecosystem Research Plan (DOI-NOAA-ADF&G 1998a, p 5) is consistent with the mission statement of the Trustee Council (Section II A) "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 plan

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

Further, four of the research themes of the Bering Sea — variability and mechanisms in the physical environment, individual species responses, food web dynamics, and contaminants and other introductions — are closely aligned with the basic mission established by the Trustee Council Current research programs for the Bering Sea (DOI-NOAA-ADF&G 1997) often overlap with the programs identified in our database for the GOA (Appendix B)

IV A 2 Scientific Legacy of the Exxon Valdez Oil Spill

Ecological knowledge gained in the decade following the oil spill forms a substantial portion of the foundation of the GEM program The Trustee Council recognized early in the restoration program the need for basic ecological information to evaluate recovery of injured species The recovery status of each affected resource (Table 1) is based to the extent possible on knowledge of the resource's role in the ecosystem The Trustee Council's scientific legacy points toward the need to understand the causes of population trends in individual species of plants and animals through time Understanding the causes of population trends leads to the need to separate human effects from those of climate and interactions with related species

The studies conducted by the trustee agencies and their contractors since 1989 have resulted in over 300 peer reviewed scientific publications, doctoral dissertations and theses A current bibliography of publications sponsored by the Trustee Council is available on the council's website or on request to the Trustee Council In addition to much specific information on the effects of oil on the biota in the spill area, the studies also provide a wealth of ecological information

As a result of the information gathered during individual research projects and three ecosystem-scale interdisciplinary research projects, the scientific legacy of the Trustee Council includes a wide range of information Topics covered by Trustee Council-funded studies include 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, 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 (A compendium of Trustee Council projects by fiscal year,

as well as a complete list of final and annual reports for projects, are available on the council's website or on request to the Trustee Council)

The Sound Ecosystem Assessment (SEA) is the largest of three ecosystem-level projects undertaken by the Trustee Council Over a period of seven years, 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 Final products from SEA have not yet been completed When report writing is complete, SEA is expected to provide information on biological and physical oceanography that could be used by the Alaska Department of Fish and Game in its herring and salmon management programs In this regard, SEA is expected to give managers a set of interacting numerical models capable of simulating the dynamic processes influencing the survival and productivity of juvenile pink salmon and herring in PWS SEA has already provided new observations of ocean currents, nutrient levels, mixing of water masses, salinity, and temperatures The new observations have made possible models of how physical factors influence plant and animal plankton, prey, and predators in the food web

The two other ecological studies are also in the final stages of completion Both are expected to provide information that will be of use to natural resource management agencies The Nearshore Vertebrate Predator (NVP) project is a six-year study of factors limiting recovery of two fish-eating species, river otters and pigeon guillemots, and two invertebrate-eating species, harlequin ducks and sea otters The Alaska Predator Ecosystem Experiment (APEX) is an eight-year study of ecological relations among seabirds and their prey species The NVP project has contributed to understanding of the linkages between terrestrial and marine ecosystems (Section IV D) by studying key species at the interface of these systems The APEX project has contributed understandings of the critical nexus between productivities of marine bird populations and fish species In addition, analysis of food selection by marine birds shows promise of providing abundance estimates for key fish species, such as sand lance and herring

IV B Existing Agency Programs and Projects

Most major information-gathering programs of the GOA (Appendix B) are divisible 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, the U S Department of the Interior and the National Oceanic and Atmospheric Administration's National Marine Fisheries Service are the primary monitoring agencies for macrofauna Sampling efforts for macrofauna are typically focused on the GOA or smaller areas, including PWS, Cook Inlet, Kodiak and the Alaska Peninsula The National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration 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 GOA as part of a larger program The U S Environmental Protection Agency, U S Forest Service, Alaska Department of Environmental Conservation and Alaska Department of Natural Resources 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 These programs have been incorporated into the GEM database (see Appendix B), 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 GOA Appendix D contains a reference list of commonly used acronyms and web site links for these programs and others

IV B 1 U S Department of Commerce, National Oceanic and Atmospheric Administration (NOAA)

National Marine Fisheries Service (NMFS) Major programs include the triennial trawl surveys for groundfish, which are scheduled to become biennial surveys beginning in 2001, annual longline surveys primarily for sablefish and rockfish, and the Ocean Carrying Capacity (OCC) program in the GOA with three cruises a year

Centers responsible for monitoring within NMFS are the Alaska Fisheries Science Center, Northwest Fisheries Science Center, Southwest Fisheries Science Center, and the Alaska Region Salmon and rockfish genetic stock identification are conducted at Auke Bay Laboratory in Juneau, Alaska Fishing vessel observer programs that collect biological information are conducted out of the Alaska Fishery Science Center in Seattle Marine mammal survey programs include the Cook Inlet marine drift and set gillnet observer program, and the Cook Inlet beluga population survey Offshore killer whale surveys in the GOA are conducted by the Southwest Fisheries Science Center as part of a coast-wide program The National Marine Mammal Laboratory and the Office of Protected Resources (OPR) are cooperators with the U S Geological Survey (USGS) and the National Institute of Standards and Technology (NIST) in conducting the National Marine Mammal Health and Stranding Response Program Human uses 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

Oceanic and Atmospheric Research (OAR) OAR is a complex of oceanographic and macrofauna monitoring and evaluation activities that involves NMFS and other NOAA personnel The fisheries oceanography program (FOCI) in the Pacific Marine Environmental Laboratory (PMEL) in Seattle has a project in the Shelikof Strait, between Kodiak and the Alaska Peninsula This and other GOA monitoring projects are conducted by the Resource Assessment and Community Ecology (RACE) program, a division of the Alaska Fisheries Science Center of NMFS PMEL also conducts retrospective fisheries and oceanographic studies and the rescue and dissemination of older data collected by PMEL scientists OAR's Climate Diagnostics Center holds the Comprehensive Ocean-Atmosphere Data Set (COADS) with surface marine data since 1854 OAR also houses Fisheries and Oceanography and Bering Sea Ecosystem Studies Cooperative Institute for Arctic Research (CIFAR) and Sea Grant Some NOAA-sponsored projects, such as U S Global Ocean Ecosystems Dynamics (US GLOBEC), work through CIFAR on funding originating in the National Ocean Service Both CIFAR and Sea Grant support research projects at universities

National Ocean Service (NOS) In cooperation with the National Science Foundation, NOS supports oceanographic research in the GOA, providing about half the support for

the Northeast Pacific subprogram of the US GLOBEC Substantial projects of the GLOBEC program are retrospective analyses and monitoring studies NOS is responsible for the Kachemak Bay Ecological Characterization study NOS also conducts the National Status and Trends Program which currently includes GOA samples in the Mussel Watch contaminants project and which 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)

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, and sea ice information Much of the information is stored at the National Oceanographic Data Center (NODC) and the National Climate Data Center (NCDC) NODC and NCDC 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 a number of United Nations (UN) projects, one of which is the Global Ocean Observing System (GOOS) One element of GOOS uses ships of opportunity to collect global weather and meteorological data

National Weather Service (NWS) NWS has real-time weather and oceanographic data at the National Buoy Data Center, and it cooperates with NODC to provide historical monitoring data NWS programs active in the GOA include the Moored Buoy Program and the Coastal Marine Automated Network (C-MAN)

National Institute of Standards and Technology (NIST) The NIST cooperates with USGS, NMFS, and Office of Protected Resources with the National Biomonitoring Specimen Bank

IV B 2 State of Alaska

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 is a project to describe the nature, status and health of Alaska's waters, and to identify 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 waterbodies," that is, waterbodies that 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 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

The Cook Inlet Information Management and Monitoring System (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 (ADF&G) 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 ADF&G is responsible for the GOA 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 ADF&G has extensive historical information on the distribution of some species of crab and shrimp in the GOA from Southeast Alaska to the Aleutian Islands ADF&G 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 ADF&G 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 ADF&G also conducts genetic research on crabs, some rockfish, herring, and pollock

The ADF&G and cooperating aquaculture associations also collect some physical and biological oceanographic data, such as Kodiak nearshore sea surface temperatures, Kitoi Bay zooplankton biomass (Eggers et al 1991), and PWS zooplankton settled volumes The ADF&G 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 GOA 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 ADF&G marine programs serve to provide information to NOAA programs

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 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

Alaska Department of Community and Economic Development (ADCED) Each year, the 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 Health & Social Services (ADHSS) The Division of Public Health has conducted several retrospective studies of contamination in subsistence foods One study examined 20 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

University of Alaska The university has extensive programs that are relevant to GEM Four federally and state supported programs within the university system are expected to provide 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 Two university units focused primarily on areas related to GEM are covered in more detail below

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 GEM program IMS produced the comprehensive review (Rosenburg 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 GOA, and it currently operates the R/V *Alpha Helix*, a 133-foot research vessel, for the National Science Foundation

International Arctic Research Center (IARC) IARC promotes international collaboration in global change research in the arctic IARC and GEM share a number of common elements In the science plan for IARC, 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 GEM program 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

IV B 3 U S Department of the Interior (DOI)

Fish and Wildlife Service (USFWS) The Alaska Maritime National Wildlife Refuge (AMNWR) monitors ten seabird colonies annually, four of which are in the GOA The

AMNWR also monitors other sites on a periodic basis largely dependent upon availability of funds

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 rip tides, Cook Inlet forage fish and others MMS has funded a varied range of project types for many years

U S Geological Survey, Biological Resources Division (USGS BRD) BRD maintains a seabird database and a pelagic seabird atlas 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 BRD participates as part of a large multiagency suite of projects discussed below In addition to biological programs, USGS has extensive expertise in other areas of interest to GEM, such as long time series of measurements of freshwater runoff, and the capability to produce high-resolution maps of the sea floor (Gardner et al 1998)

Geological Survey, Water Resources Division The Cook Inlet Basin Study Unit, part of the National Water Quality Assessment program (NAWQA), examines trends in water quality over a nine-year period Measurements are made 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

IV B 4 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 GEM are Polar Research, Geosciences, and Biology NSF also contributes funding for GLOBEC, FOCI and other projects of interest to GEM

IV B 5 Environmental Protection Agency (EPA)

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 GEM program is the EPA's Environmental Monitoring and Assessment Program (EMAP), which seeks to fulfill a national mission that is very similar to some elements of GEM's regional charge 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 In addition to having common concerns, the review of the design phase of EMAP by the National Research Council (NRC 1995) is also relevant to GEM

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

IV B 6 U S Forest Service (USFS)

The U S Forest Service (USFS) is an agency of the U S Department of Agriculture that 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 GOA region The Forest Service has extensive experience in watershed analysis and planning for ecosystem-based management (USFS 1997) Extensive experience in developing scientific information relevant to balancing multiple uses of public lands and waters is available for planning monitoring and research

IV B 7 Nongovernmental Organizations

Regional Citizens Advisory Council (RCAC) bodies were established following the 1989 *Exxon 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 The 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 GOA 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 (Mathisen 1972), 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

Cook Inlet Keeper 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 nitrate-nitrogen

Kenai River Sportfishing Association (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

IV B 8 Transboundary Organizations

Transboundary organizations coordinate information-gathering 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

The umbrella transboundary organization for the North Pacific, the North Pacific Marine Science Organization (PICES), was established in 1992 among Canada, People's Republic of China, Japan, Republic of Korea, Russian Federation, and the United States PICES coordinates North Pacific (above 30° 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

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 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

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 33° 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 Taiwan 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

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, but not into the GOA as yet 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 (June 1991) 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

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 is the keeper of 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

IV B 9 Global Climate Change Research

The United States is participating as 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 Ecosystems Dynamics (GLOBEC), World Ocean Circulation Experiment (WOCE), Joint Global Ocean Flux Study (JGOFS), and 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 is the global change program of the International Geosphere-Biosphere Programme (IGBP) of the International Council for Science The IGBP provides an international, inter-disciplinary 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 nearshore 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 GOA 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

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

IV C The Gulf of Alaska Ecosystem

The basic scientific information relevant to GEM crosses many disciplinary boundaries Although roughly organized into meteorology, oceanography and biology, naming these basic areas of scientific study does not exclude others Such disciplines as economics, fisheries, public administration, and many others also contribute to the very large body of scientific information relevant to GEM

Scientific observations for the scientific literature were first recorded in the GOA about 1741 Accounts of exploration in the mid-to-late 18th century were followed rapidly by the commercial records of exploitation starting in the late eighteenth century and continuing to present Records contributed by trained scientists accumulated steadily but slowly from 1741 until the end of the nineteenth century Efforts to apply science to management of exploited wild animal populations, especially fur seals and salmon, started in the late nineteenth century The original observations were formal descriptions and nomenclature for marine mammals and salmon, followed by physical oceanography and cartography

Given the long time span and diversity of available information, it is fortunate that summaries are available in three key reviews (Francis et al 1998, Hood and Zimmerman 1986, Rosenburg 1972) Rosenberg (1972) presents the status of knowledge up to 1970 Hood and Zimmerman (1986) summarize much of the very large volume of scientific data collected in relation to oil and gas exploration during the decade ending about 1982 Efforts to synthesize and focus multidisciplinary data to explain changes in production of birds, fish and mammals are addressed by Francis et al (1998) A fourth source provides a brief review of the most recent work on linkages between meteorology, oceanography and biology in the North Pacific Ocean (Welch and Batten 2000)

Based on the key reviews and the most recently published literature, the following is a synopsis of biological and geophysical aspects of the northern GOA ecosystem, beginning with the geological features that define the oceanic and coastal regimes Next, ocean circulation and how it affects nutrient recycling is described Finally, the physical and chemical processes that set the bounds for productivity and control the transport of organic matter are discussed This sets the stage for the conceptual foundation that is described in the following section

IV C 1 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

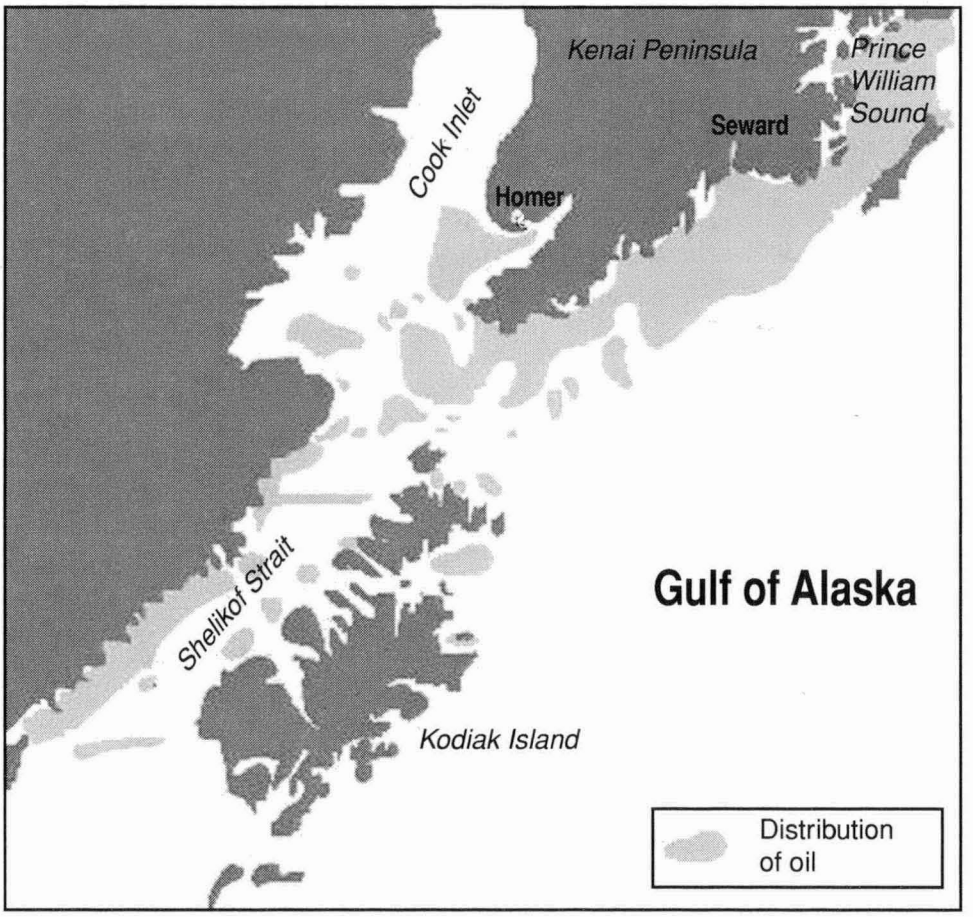

Figure 2. Distribution of oil from the *Exxon Valdez* oil spill.

Charlotte Sound (127° 30' W). Twelve and a half percent of the continental shelf of the U.S. lies within GOA waters (Hood 1986).

The area of the GOA directly affected by the *Exxon Valdez* oil spill (Figure 2) encompasses a broad diversity of terrestrial and aquatic environments. Within terrestrial, freshwater, estuarine, nearshore marine, and offshore marine environments, 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 one of the "lungs" 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 it is a source of beauty and inspiration to those who love natural things.

IV. C. 1. a. Terrestrial Boundaries

The eastern boundary of the GOA is a geologically young, tectonically active area that contains the world's third largest permanent ice field, after Greenland and Antarctica (Figure 3). 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 to largely define the climate of the GOA region. 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 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 south-southwest 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 coast line and islands of the Inside Passage. Major eastern rivers from the south moving north to the perimeter of 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 over 800 independent drainages that are known to support anadromous fish species.

To the west of PWS lie 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 lies 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,

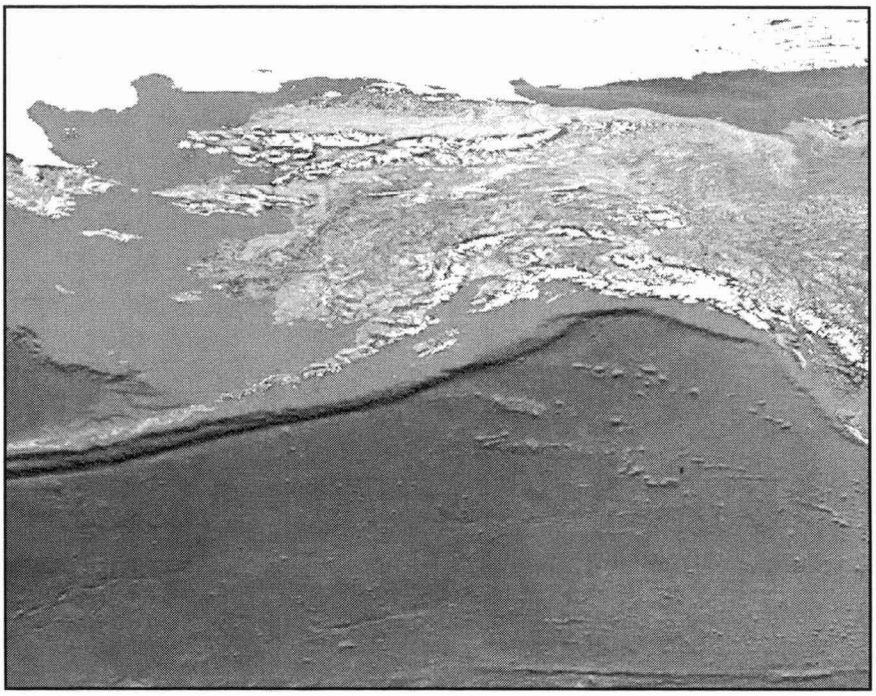

Figure 3. Satellite radar image of the northern Gulf of Alaska. Continental shelf, seamounts, and abyssal plain can be seen in relief. (Composite image from SEAWIFS Remote Sensing satellite, NOAA).

there are only two major river systems on the western coastal boundary of the GOA, the Crescent and the 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, the Red, and the 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

IV C 1 b Coastal Boundaries

The GOA shoreline is bordered by a continental shelf ranging to 200 meters in depth (Figure 3) Extensive and spectacular shoreline has been and is being shaped by plate tectonics and massive glacial activity (Hampton et al 1987) 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 2000 meters, is very broad in the eastern GOA, but it narrows steadily southwestward of Kodiak, becoming only a narrow shoulder above the wall of the 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)

IV C 1 c Marine-Terrestrial Linkages

The role of marine inputs to the watershed phase of regional biogeochemical cycles has been recognized for some time (Mathisen 1972) Marine nutrients are transported to watersheds by anadromous species, such as salmon (Kline Jr et al 1993, Ben-David et al 1998a), by marine feeding land animals, such as river otters (Ben-David et al 1998b) and coastal mink (Ben-David et al 1997a), and by such opportunistic scavengers as riverine mink (Ben-David et al 1997a), wolf (Szepanski et al 1999) and martens (Ben-David et al 1997b) In theory, any terrestrial bird or mammal species that feeds in the marine environment, such as harlequin duck or black-tailed deer, is a pathway to the watersheds for marine nutrients Species that transport marine nutrients play important roles in supporting a wide diversity of other fauna and flora, 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) In studies of a small Alaska stream containing chinook salmon, Piorkowski (1995) supported the hypothesis that salmon carcasses can be important in structuring aquatic food webs In particular, microbial composition and diversity determines the ability of the stream ecosystem to utilize nutrients from salmon carcasses, a principal source of marine nitrogen

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 due to low numbers of salmon entering a watershed (Kline et al 1993, Mathisen 1972, Piorkowski 1995) 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 ecosystem may be retarded in systems that have been denuded of salmon for any length of time (Piorkowski 1995)

Paleoecological studies 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-term trends in climate, and into how to separate the effects of climate from human impacts such as fishing and habitat degradation (Finney 1998)

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)

IV C 1 d Coastal and Ocean Circulation

The flow along the shore over the shelf and slope of the GOA is counterclockwise or cyclonic on average (Reed and Schumacher 1986) The flow over the continental slope consists of the Alaska Current, a relatively broad, diffuse flow in the north and east GOA, and the Alaska Stream, a swift, narrow, western boundary current in the west and northwest GOA (Figure 4) The Alaska Stream continues westward along the southern flank of the Aleutians with portions of it flowing northward into the Bering Sea through the deeper passes intersecting the Aleutian Chain Together these currents comprise the poleward limb of the North Pacific Ocean's subarctic gyre and they provide the oceanic connection between the GOA shelf, Bering Sea, and the Pacific Ocean Reed and Schumacher (1986) suggest that flow in the Alaska Stream is relatively constant year round However, Musgrave et al (1992), Okkonen (1992), and Thomson and Gower (1998) show that sometimes the Alaska Current and Alaska Stream contain large eddies or form prominent meanders that could be important means for exchanging water with the shelf

The shelf is topographically complicated, consisting of submarine canyons that punctuate the shelf break, glacially carved troughs and moraines on the inner shelf, and numerous banks and shoals The coastline is similarly complex, consisting of numerous capes and embayments These features interact with the tidal and subtidal circulation, causing mesoscale flow variability that suggests regions of locally enhanced (or depressed) biological production Many of the submarine canyons extend across the shelf break, which suggests that these might be important pathways for cross-shelf transport

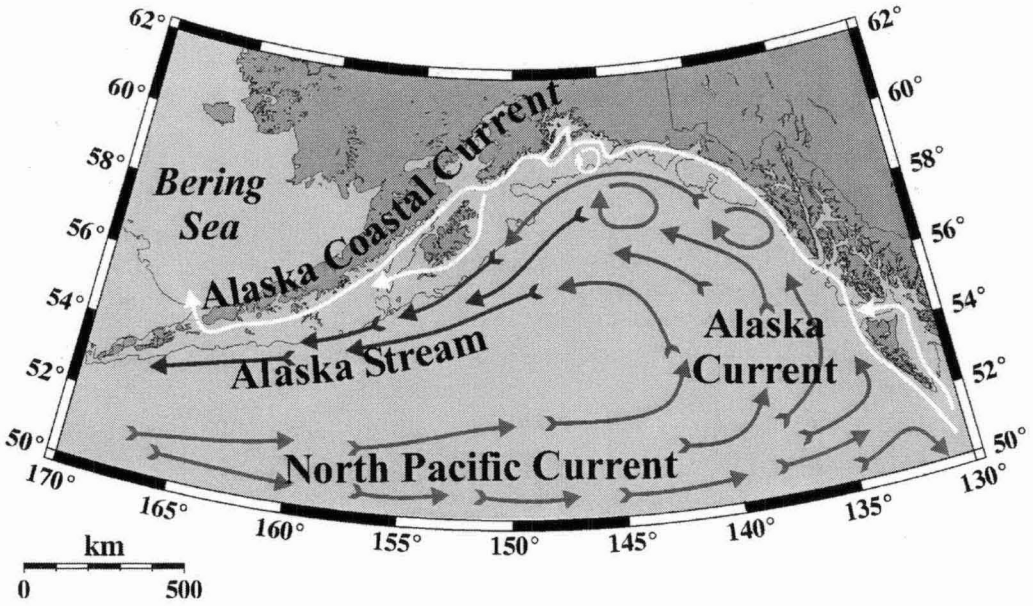

Figure 4. Currents in the Gulf of Alaska. (S. Danielson IMF).

The most striking feature of the shelf circulation is the Alaska Coastal Current (ACC), which is a swift (0.2 - 1.8 m s^{-1}), coastally constrained flow, typically found within 35 km of the coast (Royer 1981b, Stabeno et al., 1994). The offshore boundary of the ACC consists of a front, which might be an important barrier to cross-shelf transport of physical, chemical, and biological properties. This current persists throughout the year and circumscribes the GOA shelf for at least 2500 km from where it originates on the northern British Columbia shelf (or possibly even the Columbia River depending on the season) to where it enters the Bering Sea through Unimak Pass. In contrast to the ACC, the shelf flow between the offshore edge of the coastal current and the shelf break is weaker and more variable (Niebauer et al. 1981). The source of this variability is uncertain, but potential mechanisms include separation of the coastal current as it flows around coastal promontories (Ahlnes et al. 1987), baroclinic instability of the coastal jet (Mysak et al. 1981), flow over topography (Lagerloaf 1983), or meandering of the ACC along the shelf break (Niebauer et al. 1981).

The dynamics of the basin and the shelf are closely coupled to the Aleutian Low pressure system. Storm systems propagate eastward into the GOA and are blocked by the mountain ranges of Alaska and British Columbia. Thus, the regional winds are strong and cyclonic and the precipitation rates are very high. The positive wind-stress curl forces cyclonic circulation in the deep GOA while on the shelf these winds impel an onshore surface Ekman drift and establish a cross-shore pressure gradient that forces the ACC. The high precipitation rates cause an enormous freshwater flux (~20 % larger than the average annual Mississippi River discharge) that feeds the shelf as a "coastal line source" extending from Southeast Alaska to Kodiak Island (Royer 1982). However, the seasonal variability in winds and freshwater discharge is large. Cyclonic (or coastal downwelling favorable) winds are strongest from November through March and feeble or even weakly anticyclonic in summer when the Aleutian Low is displaced by the North Pacific High (Royer 1975, Wilson and Overland 1986). The seasonal runoff cycle exhibits

slightly different phasing from the winds: it is maximum in early fall, decreases rapidly through winter when precipitation is stored as snow, and attains a secondary maximum in spring due to snowmelt (Royer 1982).

The shelf hydrography and circulation vary seasonally and are linked to the annual cycles of wind and freshwater discharge. In late winter, the vertical stratification and the front bounding the ACC are relatively weak. By contrast, in fall the water column is strongly stratified and the offshore front is strong. Measurements by Royer et al. (1979) and Johnson et al. imply that near-surface waters converge from either side of the front. This pattern of cross-shelf circulation would tend to accumulate plankton, which might then attract foraging fish. Moreover, the front and the region inshore of it might be an area of enhanced productivity because entrainment (Royer et al. 1979) and/or frontal instability could resupply the surface layer with nutrients from depth. As shown by Xiong and Royer (1984), deep shelf waters attain maximum salinities in fall and minimum in spring. The source of this high salinity water is the annual intrusion of slope water forced onshore and along the bottom of the shelf by the seasonal relaxation (or reversal) in downwelling (Royer 1975, 1979). Interannual variability in the onshore flux of slope water and/or differences in slope-water properties likely imply similar variability in the onshore flux of nutrients to the GOA shelf.

Farther offshore, the Alaska Current forms the poleward-flowing eastern portion of the North Pacific subarctic gyre and generally follows the upper slope and shelf break. It is broad in the east, but it narrows and strengthens into a western boundary current northeast of Kodiak Island (Figure 4) into the Alaska Stream, the westward flowing portion of the subarctic gyre (Reed and Schumacher 1986). This dominant current system often may have computed velocities in excess of 80 to 100 centimeters/second and net transport in excess of 6 x10^6 m^3/s. This is particularly so near the outer Alaska Peninsula and Aleutian Islands, where sharp salinity decreases inshore generate strong pressure gradients that force swift flows (Reed and Schumacher 1986). Waters from the shelf and basin of the GOA eventually enter the Bering Sea through Unimak Pass and then the Arctic Ocean through the Bering Strait. Thus, the Bering and Chukchi seas are "downstream" ecosystems with respect to the GOA.

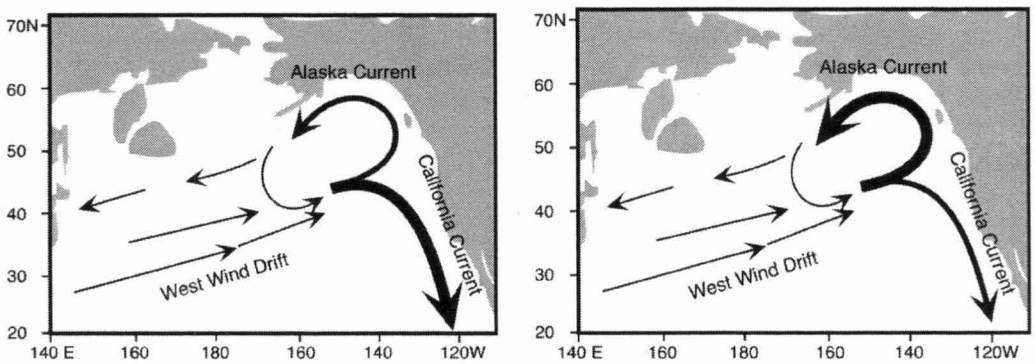

Figure 5. Oceanic circulation patterns in the far eastern Pacific proposed for negative PDO (left) and positive PDO (right). (Hollowed and Wooster, 1992).

With regard to the interannual variability of current flows, it is generally thought that more intense cyclonic activity in the atmosphere will result in stronger flows in the Alaska Gyre and more of the westwind drift will go to the south to the California Current system (Hollowed and Wooster 1992). The proposed decadal scale variation in currents of the northeastern Pacific are shown in Figure 5. Weak flows of the Alaska Current in the eastern gulf have been associated with years of higher-than-normal salinity (Ingraham et al. 1991). Reed and Schumacher (1986) describe a summer 1981 collapse of wind stress in the eastern gulf, which was accompanied by the widespread distribution of warm and relatively fresh surface water. At the same time, wind stress increased in the western gulf, diverting water flowing into the southern gulf more to the northwest. They suggested that such changes, although neither frequently characterized nor well understood, may affect biological processes throughout the region. For example, one would expect the persistence of such conditions to favor water-column stratification, and subsequent depletion of surface water nutrients during the later portion of the summer growing season.

During periods when the winter Aleutian Low Pressure system is more northerly and intense, winds in the eastern GOA are stronger (Emery and Hamilton 1985, Mantua et al. 1997), precipitation is greater, and Ekman transport is greater, which might be expected to influence variability in mixed-layer depth and productivity. However, in the central GOA, mixed layer depth variability in the winter is primarily a consequence of changes in upper-ocean salinity (Freeland et al. 1998).

IV. C. 1. e. Climatic Oscillations

The GOA has a variable and severe climate and is the incubator for the winter storms that sweep across the North America continent via the Aleutian storm track (Wilson and Overland 1986). Three semi-permanent atmospheric pressure regions dominate climate

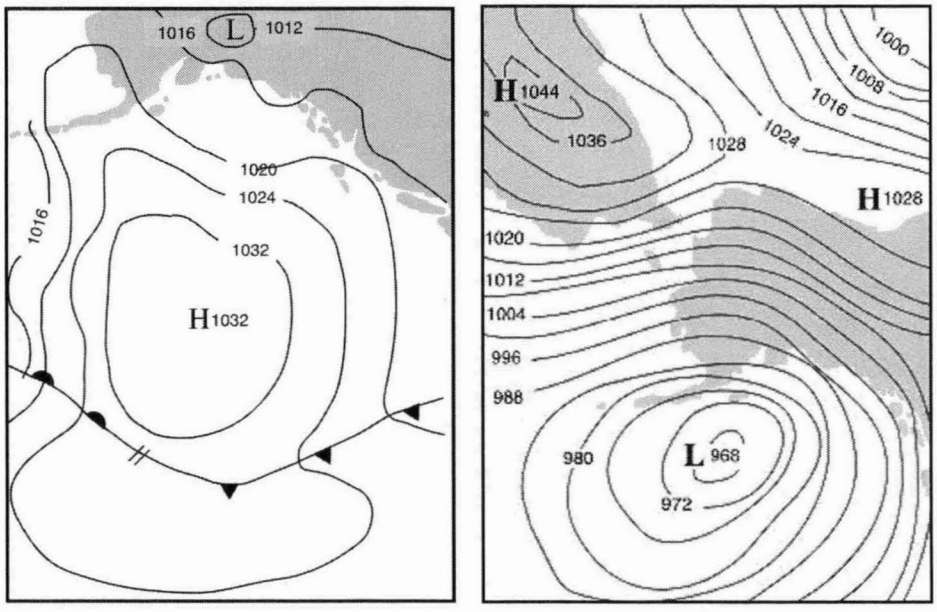

Figure 6. Typical winter (right) and summer (left)examples of the Aleutian low and Siberian high-pressure systems. Contours refer to sea-level pressure in millibars (From Carter).

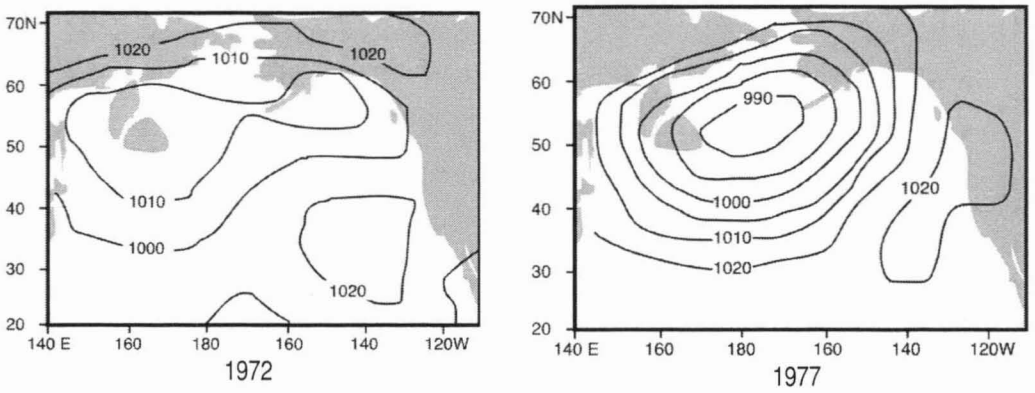

Figure 7. Mean sea-level pressure patterns from the winters of 1972 and 1977 (From Emery and Hamilton, 1985).

in the northern GOA–the Siberian and East Pacific high-pressure systems and the Aleutian Low-pressure system (Figure 6). These have variable, but characteristic, seasonal locations. The Aleutian Low-pressure system averages about 1002 millibars (Favorite et al. 1976), is most intense in winter, and appears to cycle in its average position and intensity with about a 20-25 year period (Rogers 1981, Trenbreth and Hurrel 1994). The North Pacific Oscillation (NPO), as this cycle is called, appears to be a major source of oceanographic and biological variability.

Low-pressure systems or storms frequently arise from the GOA. Although the storm track is well-known, the severe winter weather that comes from the northern GOA is unpredictable on a short-term basis, due to the interplay among the relatively warm air masses over the gulf, the cold continental air masses inland, and the dominating coastal mountains (Alaska, Chugach and Wrangell-St. Elias ranges) in between. These features support blocking high-pressure ridges, which deflect storm tracks to the north and south for periods as long as several weeks, but which have an average persistence of seven to ten days (Treidl et al.). This interplay between eastward moving storm systems and blocking high pressure in winter is quite variable from year to year, but undergoes long-term cycles on or about the same period as the NPO (White and Clark 1975).

Mantua et al. (1997) have calculated the Pacific Decadal Oscillation (PDO) index, which tracks the NPO and is discussed in more detail in Section IV.D.2. The PDO index had strong positive values from 1900 to about 1912, during most of the 1930s and early 1940s, and then again during the late 1970s, 1980s and most of the 1990s. From about 1948 through 1976 and then again for three years in the early 1990s, the PDO was negative (Hare et al. 1999). Figure 7 shows wintertime examples from two climatic regimes: a negative PDO regime example from 1972 and a positive PDO example from 1977. In addition, there is evidence that the Aleutian storm track has shifted to a more southerly position during the twentieth century (Richardson 1936, Klein 1957, Whittaker and Horn 1982, Wilson and Overland 1986). There also is a low-frequency lunar nodal cycle of 18.6 years, possibly working through an enhancement of poleward geostrophic flow (due to differences in seawater density) or increased tidal mixing in its positive phase, as an attractive alternative or complementary hypothesis for external forcing factors (Parker et al. 1995).

IV C 1 f Marine Nutrients and Fertility

The fertility of GOA waters depends on nutrient recycling from depth to the surface layer where plants grow The deep waters of the central GOA have some of the highest concentrations of nutrients and the oldest carbon in the world's oceans (Mantyla and Reid 1983), consistent with lack of deep-water formation in the north Pacific Ocean, slow turnover and trapping of significant amounts of nutrients at depth Intense low-pressure systems and cyclonic circulation in the GOA favor nutrient transport to the surface in the central GOA (Reid 1965), ^{14}C depletion in surface waters (Reeburg and Kipphut 1987), and the presence of low-temperature, high-nutrient water (Sambratto and Lorenzen 1987)

One feature of the Alaska Gyre, also shared with the eastern Tropical Pacific and parts of the Southern Ocean, is that there is apparently no lack of the macronutrients (nitrates, phosphates and silicates) necessary to support phytoplankton growth (Beklemishev 1957, Heinrich 1957) The traditional view has been that grazing by zooplankters was sufficient to prevent phytoplankters from depleting macronutrients (Anderson and Munson 1972) More recent work has explained the surfeit of macronutrients differently in terms of micronutrient (iron) limitation and called lack of macronutrient limitation into question (Freeland et al 1998) Moreover, the question of the extent of limitations imposed on productivity by iron in the GOA is an important and open question (Pahlow and Riebsell 2000) Non-nitrogen and carbon limited growth allows phytoplankton to discriminate against the "heavy" stable isotopes, ^{15}N and ^{13}C, during synthesis of organic matter Organic nitrogen and carbon depleted in ^{15}N and ^{13}C are passed into food chains Thus, zooplankton and fishes from oceanic waters of the gulf are ^{15}N and ^{13}C depleted, compared to those from coastal waters such as PWS that are nutrient limited (Kline 1999a)

Onshore movement of more dense offshore water by winds results in coastal downwelling most of the year Relaxation of these winds during the summer results in slightly favorable conditions for upwelling of deep nutrient-rich water onto the shelf, the supply of which undoubtedly varies from year to year For example, in Resurrection Bay transport of offshore water into the bay occurs mainly during periods of positive upwelling (Heggie and Burrell 1981) In this predominantly downwelling shelf and coastal regime, the extent to which deep-water nutrients reach the more biologically productive nearshore surface waters and the mechanisms that transport it there during most of the year are only sketchily understood Bottom water in coastal fjords appears to be renewed by water originating from shallower than 250 m in the central gulf (Muench and Heggie 1978) Renewal of bottom water in shallow-sill coastal fjords, like Alalik Bay on the outer Kenai Peninsula coast, occurs in spring From near-uniform density throughout the water column in winter, developing density gradients in the fjords in the spring allow denser (from winter cooling and reduced freshwater runoff) shelf water that enters as distinct masses on April tides to sink to the bottom of these fjords Deeper fjords, such as PWS, are renewed in late summer and early fall as relatively warm and saline water originating in the central gulf below 150 m moves onto the shelf under conditions of reduced downwelling and onshore convergence of surface water

Deep water renewal processes were speculated to explain the occurrence of GOA-origin copepods undergoing diapause within PWS (Kline 1999a) Long-term shifts in the deepwater renewal process could thus affect variability in a source of zooplankton

forage for juvenile salmon and other PWS consumers, since it is the offspring of diapausing copepods that form the bulk of subarctic Pacific zooplankton blooms (Miller et al. 1984).

IV. C. 1. g. Plankton and Productivity

Some of the basic conditions for phytoplankton growth in the central GOA, based on data from Ocean Station P, are outlined by Sambratto and Lorenzen (1987). The annual cycle starts in spring when the compensation depth for primary production increases to below 150 m with increasing insolation time and solar incident angle. At the same time, the mean mixed-layer depth, constrained from below by a permanent halocline at 150 to 100 m, rises rapidly between April and May from below 100 m to about 50 m. These changes result in a rapid increase in phytoplankton production in surface waters to between 200 and 800 mg C m^{-2} d^{-1} through the summer, but the actual data to support this estimate of production are limited (Miller et al. 1991). The reported average annual rate of 170 g C $m^{-2}y^{-1}$ is one of the highest in the world's oceans (Welschmeyer et al. 1993). Historical data suggest that nitrate and other macronutrients are not limiting in the area reached by sunlight (photic zone) during the growing season (Dugdale 1967, Hattori and Wada 1972, Miller et al. 1991). It is possible that the GOA may have undergone a change with respect to the role of macronutrient control, based on more recent data (Freeland et al. 1998). The micronutrient iron has been suggested as a limiting factor, but it appears that iron may set the characterisitics of the phytoplankton community but not be limiting *per se* to the dominant small phytoplankton cells that attain a high level of productivity (Miller et al. 1991).

A great deal of uncertainty about primary production is due both to a sparsity of direct measurements and to the fact that chlorophyll-a does not increase much during the annual production cycle (Anderson et al. 1977). Intense grazing during growth and sinking of cells are possible contributing causes (Booth et al. 1993). Recently, Miller et al. (1991) suggested that consideration of the grazing protozoans as an intermediate trophic step

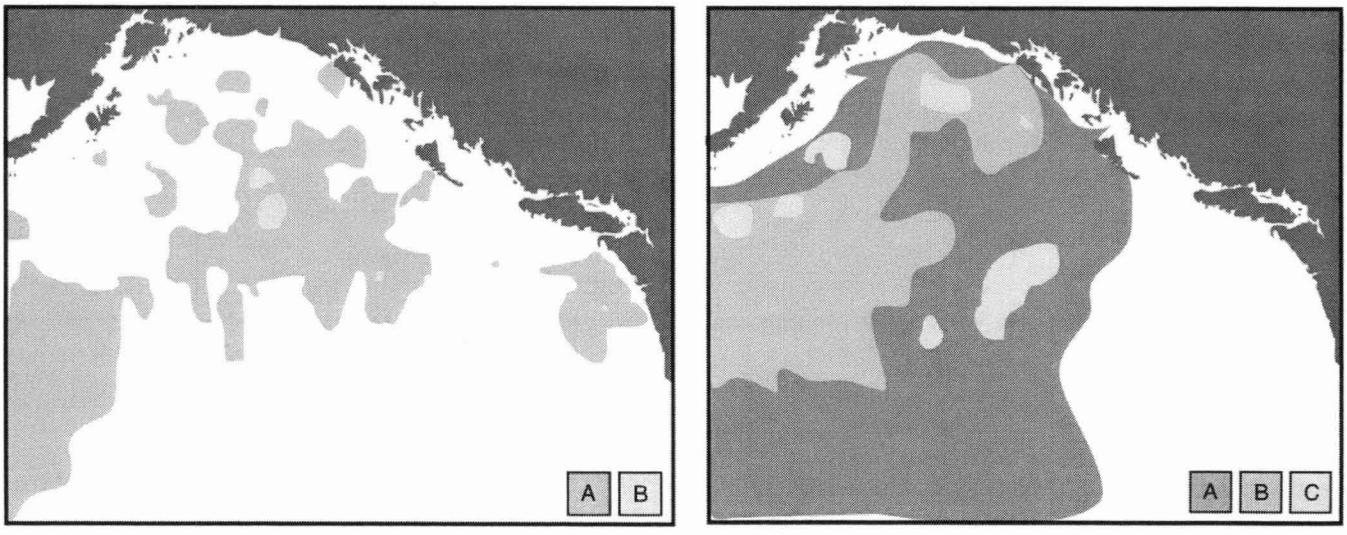

Figure 8. Biomass of plankton for the spring and summer period are contrasted for a negative PDO period (left) and a positive PDO period (right). Box A represents 100-200 g/1000 m^3 zooplankton biomass, Box B represents 201-300 g/m^3, and Box C represents >300 g/m^3.

between phytoplankton and large copepods (Miller et al 1984) could well explain the lack of phytoplankton blooms in the presence of relatively low numbers of large copepods A further iteration of a model that explains productivity in the surface waters of the Alaska Gyre is presented by Miller (1993) Essentially, high productivity is maintained by a shallow mixed layer that persists throughout the year, thereby preventing loss of key organisms out of the photic zone, including the abundant protozoans, which have high enough rates of cellular division to keep up with the phytoplankton populations Ammonia recycled quickly from the micro- and macrozooplanknton to the phytoplankton (mainly flagellates) apparently explains the continuous high concentrations of dissolved nitrate With regard to long-term changes in phytoplankton, integrated measurements of chlorophyll-a over the central North Pacific indicate a general increase after 1977 (Venrick et al 1987)

Annual primary production rates rise from central gulf values of 100 g C m^2 to values greater than 250 on the shelf and values between 150 and 200 g C m^2 in bays, sounds and inlets (Sambratto and Lorenzen 1987) Unlike the oceanic regime offshore, nutrient depletion does occur inshore of the shelf in lower Cook Inlet during the growing season (Chester and Larrance 1981, Larrance and Chester 1979) Unfortunately, the situation with respect to macronutrient limitation of productivity on the GOA shelf is far from clear Results of the Trustee Council-sponsored Sound Ecosystem Assessment (SEA) project include a model of the water column in PWS that has successfully produced the duration and extent of both phytoplankton and zooplankton blooms for several years (Eslinger 1999) Atmosphere-sea-surface interactions in the early spring appear to set the conditions for the remainder of the spring-summer production period Two general outcomes are seen for production 1) warm, quiescent springs have intense but brief phytoplankton blooms and relatively low zooplankton biomass, and 2) colder stormy springs lead to longer phytoplankton blooms and higher zooplankton biomass These two outcomes affect dichotomous carbon isotope ratios in marine biota Quiescent springs result in ^{13}C enrichment while stormy springs result in ^{13}C depletion Primary production shifts thus characterized by $^{13}C/^{12}C$ permeate throughout food chains as evidenced by concomitant isotopic shifts among biota (Kline 1999b)

It is generally thought that the more energetic physical environment on the shelf is responsible for sustaining these high rates of primary production, but coastal convergence and the predominantly downwelling nature of the hydrography limit opportunities for water renewal from the deep GOA Offshore fronts associated with the ACC have been proposed as possibly active in producing enhanced plankton biomass seen at the shelf break It appears that relaxation of coastal winds, local topography (e g , at the entrance to Cook Inlet) interacting with strong tidal currents, and wind events are important factors in within-season nutrient resupply to the photic zone in a system where high freshwater input and long days can produce extended periods of stratification The interplay of these factors throughout the growing season is undoubtedly critical to survival of the many juvenile forms of inshore life dependent on phytoplankton production

Zooplankton productivity in the GOA largely reflects patterns seen or inferred from phytoplankton productivity (Cooney 1987) Thus, productivity of oceanic zooplankton populations may be as high as 30 g C m^2 yr^1 and up to 50 g C m^2 yr^1 on the shelf and in inside waters This production occurs to a large extent in the spring bloom and follows an annual surge in phytoplankton production in the early spring One of the unique

characteristics of North Pacific zooplankton populations is the apparent role of three species of very large copepods–*Neocalanus cristatus*, *N plumchris*, and *Eucalanus bungi*–in transferring large amounts of energy from phytoplankton to higher trophic levels (Cooney 1987, Jeffery Short unpubl) Available evidence led Cooney (1984) to propose that the oceanic copepods are carried by Ekman transport from the open ocean onto the shelf over a large part of the year and may be an important source of organic matter for inshore organisms He estimated that the advected biomass from March to November of each year was $10x10^6$ metric tons in the GOA, considerably higher than the $2x10^6$ metric tons estimated from production on the shelf in the ACC The discovery that stable isotope signatures diagnostic for offshore carbon are found and vary in juvenile fishes of PWS provided evidence that this process takes place and vary in effect from year to year (Kline 1999a) With regard to interannual variability, Brodeur et al (1996) found long-term fluctuations in zooplankton biomass that displayed maximal values on a 10+ year frequency In Figure 8 biomass of plankton for the spring and summer period are contrasted for a negative PDO and a positive PDO, and it can be seen that zooplankton biomass was much greater during the positive PDO

Nonetheless, it is important to bear in mind that primary and secondary productivity measurements in the GOA are few (Reeburg and Kipphut 1987) A truly engaging enigma of the GOA shelf is how it can sustain its apparent high productivity in the face of physical features that should inhibit productivity Physical features that should limit productivity in the gulf include a deep shelf, input of a high volume of low-nutrient freshwater via coastal discharge onto the shelf, and a shelf that is subjected to downwelling winds throughout most of the year In the face of such apparent inconsistency between the physical circumstances of the gulf and reported high productivities, it is reasonable to be skeptical of how representative the reported values actually are It is possible that there are not enough values in time and space to resolve the nature of seasonal productivities on the GOA shelf

Even so, corroborating data on GOA nekton also indicate that this group of organisms was more abundant after about 1978 Both these observations are consistent with calculations by Polivina et al (1995), indicating that the reduction of the mixed-layer depth and increase of surface temperatures in the GOA would allow a doubling of pelagic production With more to eat, it is not surprising that survival and catches of Pacific salmon in the Alaska Gyre have increased so strongly since the late 1970s (Hare et al 1999, Mantua et al 1997, Pearcy 1992) At the same time, there are indications that inshore production has been declining in many locations

There is little known about decadal-scale changes in inshore rates of primary production, but there are efforts underway to compile what data does exist (David Mackas, pers comm) While the very favorable production regime for salmon in the central gulf was occurring, many, but not all, nearshore seabird and harbor seal colonies were in decline (Hatch et al 1993, Piatt and Anderson 1996) This was apparent in PWS, especially in data on black-legged kittiwakes from southern PWS (Irons 1996) One compelling contrast from adjacent Cook Inlet was the decline over the last 20 years in seabirds at Chisik Island, while seabirds at Gull Island in Kachemak Bay were increasing during this period (Figure 9) High rates of nutrient supply from deep water enabled by exceptionally strong, topographically focused, tidal-induced mixing in lower Cook Inlet and, at the same time, increased nutrient-poor freshwater inflows through upper Cook

Inlet might explain these different regional 20-year trends in seabird abundance Other long-term trends that may impact biological productivity are the continuing increase of average surface-water temperatures in the North Pacific and an apparently greater frequency of strong *El Niño* events in recent years

IV C 1 h Benthos

The GOA sea bottom supports a diverse community of bacteria, fungi, algae, some higher plants, invertebrates and fishes It varies with changes in substrate characteristics, depth, temperature, light and food supply (Feder and Jewett 1987, O'Clair and Zimmerman 1987) Primary production occurs in intertidal and shallow subtidal communities Benthic algal production is locally important in inshore areas of the northeastern Pacific Productivity estimates for the northeastern GOA for large kelps *Nereocystis* and *Laminaria* species range as high as 37 4-71 9 kg/m^2/yr wet weight for PWS to 2 1 kg/m^2/yr wet weight for shallow intertidal *Fucus* and *Rhodymenia* spp in lower Cook Inlet, and 0-0 4 kg/m^2/yr for deep subtidal areas containing *Agarum* and *Callophyllis* Wherever physical conditions are suitable to permit benthic algae to flourish, benthic algal production is very important to maintaining nearshore communities Nonetheless, current information indicates the majority of primary production in the GOA occurs in phytoplankton

The communities of the shelf bottom and shallow subtidal and intertidal environments support thousands of different species that recycle nutrients and carbon and participate in important geochemical cycles for trace substances Climatic forcing may influence the nearshore-bottom communities in several ways, including through nutrients, larvae and food Long time series data necessary to address these questions are available primarily for commercially utilized species of fish, crabs and molluscs (Hollowed and Wooster 1995, Zheng and Kruse in press) Data on the geology and biology of the benthos are also available from work preparatory to oil exploration in the Aleutian Islands, Alaska Peninsula, Kodiak Island, Cook Inlet, and northeastern GOA (OCSEAP 1990) The above references to climate-mediated changes in production regimes to changes in transport of organic matter apply to all these communities, whether they are at the bottom of the central GOA or in the intertidal zone of Cook Inlet In addition, terrestrially mediated changes wrought by climate change, such as differences in the amount, timing and volume of freshwater discharge, sediment loads, and winter temperatures, would be expected to affect intertidal and nearshore communities

For the offshore seabed and its associated resources (e g , epibenthic fish, crabs and shrimp), one might expect that changes in biological production in the surface-mixed layer, such as described earlier, might result in changes in the amount of organic matter reaching the sea floor Between 1989 and 1996, a decline in the supply of particulate organic carbon to the abyssal eastern North Pacific has been reported (Smith and Kaufman 1999) Also, variations in cyclonic circulation in the GOA and, therefore, in surface Ekman divergence and the associated advection of plankton might change the amount of organic matter delivered to shelf communities Mechanisms underlying the radical changes in the biological composition of nearshore communities in the GOA in the late 1970s and early 1980s (Piatt and Anderson 1996) are not known It is possible, however, that the supply of organic matter to the shelf might have changed and this could have contributed to changes in seabed communities

Many inshore communities have populations that rely on only occasional recruitment of successful age classes The interplay of annually variable food supplies and currents may play significant roles in the success of larval production and their return to suitable habitats for the adult life stages It may be, for example, that offshore loss of propagules is constrained when the ACC stays close to the coast

Sediments are also a major repository for organic matter and contaminants from human activity and may capture the history of climatic and geochemical events in the overlying waters The intertidal zone, though very narrow, is a productive and unique component of the GOA ecosystem that feeds a variety of important populations, including people Unfortunately, there appears to be no long-term program among scientific agencies for collecting data on intertidal community composition in the northern GOA

IV C 2 Status and Changes in Fish and Shellfish, Birds and Mammals

IV C 2 a Fish and Shellfish

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, numerous species of shrimp and crab, five species of Pacific salmon, Pacific cod, Pacific halibut, sablefish, herring, rockfish, pollock, flatfishes, scallops and other invertebrates Among the most important of the GOA groundfish species, exploitable pollock populations in 1999 were estimated at 738,000 metric tons (mt), down from a peak of about three million mt in 1982 (Witherell 1999) Annual numbers of two-year-old pollock entering the fishable population (recruitment) from 1981-1987 were erratic and usually lower than recruitments estimated in 1977-1980 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 600,000-950,000 mt estimated for 1978-1999 Annual recruitments of GOA Pacific cod have been relatively stable since 1978, with exceptionally large numbers of three-year old recruits appearing in 1980 and 1998 Biomass of the dominant flat fish 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 By comparison, the exploitable biomass of another flatfish, the highly prized Pacific halibut, in 1999 was estimated at 258,000 mt, which is above average for 1974-1999 (Witherell 1999) Exploitable biomass of Pacific halibut was also increasing from 1974-1988, after which it declined slightly As a possible consequence of climate change and/or fishing, the status of crab populations (discussed below) is relatively poor in comparison to the groundfish populations

Both salmon and groundfish populations in the northeastern Pacific appear to vary in concert with features of climate, but the responses appear to be different (Francis et al 1998) Groundfish recruitments follow a cycle with a roughly ten-year period that is closely related to the *El Niño* Southern Oscillation (ENSO) (Hollowed and Wooster 1992), whereas salmon abundance changes sharply at intervals of 20-25 years in concert with the Pacific Decadal Oscillation (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 Since the groundfish species described by Hollowed and Wooster (1992,

1995) were mostly winter spawners, Zheng and Kruse (in press) 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)

Since the climatic regime shift in 1978, pollock and other cod-like fish have dramatically increased and maintained high population levels, replacing shrimp in nearshore waters as the dominant group of organisms caught in mid-water trawls on the shelf (Piatt, J F and Anderson 1996) Pacific halibut appear to undergo decadal-scale changes in recruitment, which have been correlated with both the 18 6-year lunar nodal tide cycle (Parker et al 1995) and the PDO There also is a reported coincidence of size-at-age data for Pacific herring with this same cycle (Ware 1991) The patterns are not as clear with herring, but the populations tend to be dominated by the occasional strong year class and show considerable variability in landings over the years

In a recently completed study of time-series data on recruitment for 15 crab stocks in the Bering Sea, Aleutian Islands and GOA, time trends in seven of 15 crab stocks are significantly correlated with time series of the strength of Aleutian Low climate regimes (Zheng and Kruse in press) 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 15 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 red king crab brood strength 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 (in press) 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 to 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 due to the distribution of the different sea bottom types 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 (in press) 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 *Thalassiosira* 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 (Rosenkrantz 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 (Rosenkrantz 1999)

Species not commercially harvested are less well studied than commercially harvested species, such as Tanner crab For example, since 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 Some information on changes of forage fish comes from sampling the diets of colony nesting seabirds and the stomach contents of Pacific halibut, as well as from many years of mid-water trawls around Kodiak Island and on the Alaska Peninsula (Piatt and Anderson 1996) Data from the latter study indicated, for instance, that capelin nearly disappeared from the northern GOA shelf in the early 1980s The evidence that climate (i e , the PDO index) is significantly correlated with fisheries for Pacific salmon in the GOA is very strong (Hare et al 1999), with dramatic increases after the strong shift to a positive PDO index in the late 1970s In addition, analysis of the eastern GOA data on fishes showed that many flatfish stocks increased following the 1977 PDO shift, but several dominant groundfish stocks did not (e g , Atka mackerel, Pacific cod, Pacific hake and walleye pollock) (Francis et al 1998) With fisheries accounting for up to 25% of the energy produced by coastal shelf and upwelling systems on a worldwide basis (Pauly and Christensen 1995), the sustainability of gulf fisheries must be put in the context of climate change

IV C 2 b Seabirds

The GOA supports large aggregations of colony nesting seabirds 26 species contributed to an estimated total of eight million birds in 1987 in the GOA (DeGange and Sanger 1987) In addition, the large estuarine habitats in Cook Inlet and the Copper River Delta are critically important for migrating shorebirds in the spring (Senner 1999) During the summer breeding season, colonial sea birds aggregate at about 800 different colonies around the periphery of the GOA (DeGange and Sanger 1987) to feed on the plankton, nekton, and mainly the forage fishes living in the coastal and shelf environment It is well known that the general fertility of various marine systems is reflected in the abundance and productivity of seabirds that nest and reproduce nearby (Furness and Camphuysen 1997, Phillips et al 1996)

Seabirds also provide an easily accessible source of tissues (e g , eggs and feathers) that integrate changes in the availability of some contaminants and abundances of stable isotopes of carbon and nitrogen in the food web Gulf seabirds consume more than one million metric tons of marine organisms each breeding season Because different seabird species feed in different ways (e g , black-legged kittiwakes feed at the surface and common murres dive deeply), their distributions and productivity can give indications of the distribution and availability of their prey

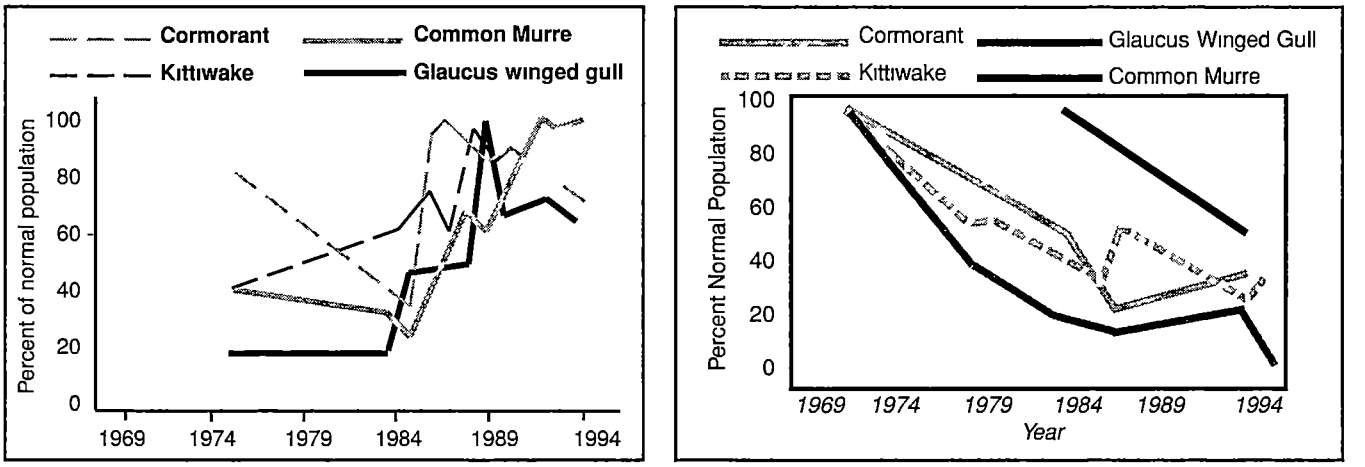

Figure 9 Long term decline of seabirds at Chisik Island, Cook Inlet (right) and increase at Gull Island, Outer Cook Inlet (left) (Piatt and Anderson, 1996)

While the very favorable production regime for salmon in the central gulf was occurring, many, but not all, nearshore seabird colonies were in decline (Hatch et al 1993, Piatt and Anderson 1996) (Figure 9) This was apparent in Price William Sound, especially in data on black-legged kittiwakes from the southern sound (Irons 1996) An exception to the widespread decline of nearshore seabirds is found at Gull Island in Kachemak Bay, lower Cook Inlet, where populations were apparently increasing during this period (Piatt, unpubl) This exception to the widespread downward regional trend in lower Cook Inlet may point to an opportunity to identify the oceanographic conditions that support seabird productivity that are lacking in the other areas

IV C 2 c Marine Mammals

Three groups of marine mammals occur in the northern GOA, cetaceans (whales and dolphins), pinnipeds (seals, sea lions and walrus) and the mustelids (sea otter) One species, the Steller sea cow, was extirpated about 1768 (Hood and Zimmerman 1986) The loss of the sea cow is relevant to GEM in that it signals the beginning of the extensive alteration of trophic structure in the GOA as a result of human harvest of marine mammals (Scheffer 1972) As the largest recent herbivore to have grazed on nearshore macroalgae, the sea cow was undoubtedly an important component in the nearshore portion of the ecosystem Most species of marine mammals experienced some level of commercial harvest starting in 1741, when Vitus Bering explored the Bering Sea and northern GOA region and laid claim to it for Russia

Continuing concern about past alteration of trophic structure in the GOA and its consequences for contemporary trophic structure is well warranted Six species of large baleen whales inhabit the gulf blue, fin, sei, humpback, gray, and Pacific right (Calkins 1987) Numbers of each of the great baleen whale species have been radically reduced at some point between about 1845 and the imposition of protection by the International Whaling Commission in 1966 (Calkins 1987) Numbers of the blue whale and the Pacific right whale are now at the point where these species are unlikely to be factors in the trophic structure of the GOA Sei whales are notable in that their numbers were severely

depleted relatively recently, between 1963 and 1966 Although sei whales eat mostly zooplankton, they are known to feed opportunistically on a wide range of forage and commercial fish species, including smelt, sand lance, capelin and pollock

Recovery of populations of large, potentially piscivorous (fish-eating) whale species leads to concern about future alteration of the trophic structure of the gulf in ways that could directly impact human harvests of salmon and herring Gray whale populations have recovered to what may be pre-exploitation levels Grays are piscivorous as they travel through the GOA, but consumption rates are unknown When feeding on a combination of benthic and pelagic invertebrates, the consumption rate of an adult gray whale is 1,200 kg per day (Calkins 1987) Recent growth in numbers of humpback whales, which were radically reduced in population size prior to 1966 (Scheffer 1972), has important implications for trophic structure and fisheries management Humpbacks at times feed heavily on fish, including herring and juvenile salmon

Concern about future alteration of trophic structure is in part due to the fact that the harvest of many marine mammals, including the great baleen whales and sperm whale, has been sharply reduced in GOA waters during the last third of the 20th century, although some low levels of harvest for some species still occurs Some species of great whales, such as gray and sperm, have responded to the cessation of harvest by increasing their numbers, while others have not Given the diverse foraging strategies of cetaceans in general, the rates of recovery of these apex predators from heavy exploitation could offer insights into many different aspects of trophic structure and trophic dynamics of the GOA and North Pacific

Some species of pinnipeds, such as the northern elephant seals, have increased dramatically during recent decades Even with cessation of most harvests, however, such other pinniped species as fur seals, Steller sea lions, and harbor seals have undergone dramatic declines coincident with changes in oceanography, forage fish and seabird populations in the GOA over the past 20 years Harbor seals should be considered candidates for long-term monitoring since they have relatively small geographic ranges and do not appear to sharply limit composition of prey species within their range Harbor seal diet studies, including trophic status, may provide means of detecting changes in the trophic structure and dynamics of the nearshore marine environment

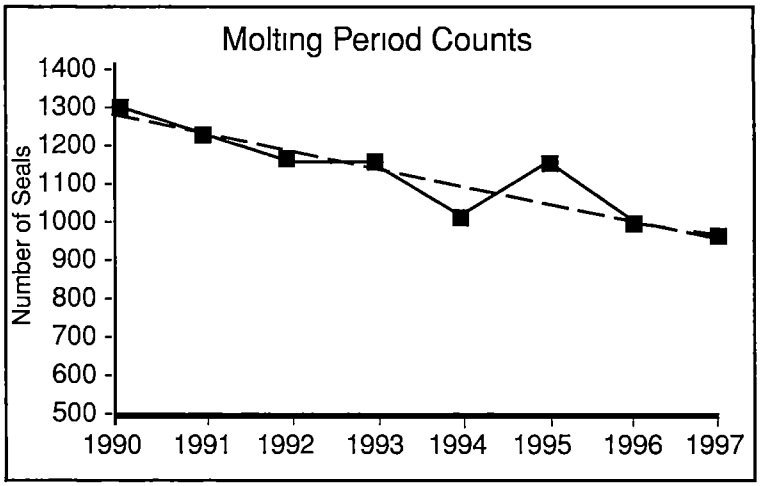

Figure 10 Population trend of molting seals in Prince William Sound (Frost, 1998)

Sea otters, very nearly extirpated from the North Pacific by 1900, also have benefited from the near-cessation of human harvest Since that time the species has increased dramatically throughout most of Alaska, and has itself precipitated profound changes in the structure and function of coastal marine communities of less than 100 m depth During the past decade, large declines in sea otter abundance have been noted in the central Aleutian Islands, although the exact extent of the decline is unknown One hypothesis

advanced to explain the decline involves killer whales using otters as a replacement for the now rare pinnipeds (seals and sea lions)

Northern fur seals have been in steep decline in the Bering Sea and their decline may be related to conditions in the GOA (Trites 1992) Although food limitations in the Bering Sea may not be limiting population growth, food limitations in the Aleutians and in the GOA may be creating a population growth bottleneck by causing high mortalities of juveniles during migrations The bottleneck hypothesis of fur seal abundance control (Trites 1992) illustrates one of many ecological connections between the Bering Sea and the GOA Steep declines in harbor seals in the GOA have been documented in and around Kodiak Island 1956-1976 (Pitcher 1990) and in PWS throughout the 1990s (Figure 10) (Frost et al 1998)

Concepts on control of marine mammal populations focus on food limitation and hunting or other human removals Steller sea lions, now listed under the federal Endangered Species Act, have declined steeply starting in the early 1970s, particularly in the Aleutian Islands (Trites 1992) Current hypotheses on limitation of Steller sea lion abundance center on food limitation, possibly due to competition with humans for prey species, but there is no conclusive information with respect to the role of fisheries in causing food limitation for Steller sea lions (Bowen et al 1999) The possibility remains that climate change and its effect on species composition of prey species plays an important role in regulating marine mammal populations

IV D Conceptual Foundation for the Gulf of Alaska Ecosystem

IV D 1 Rationale

A conceptual foundation of how biological production and diversity vary in the GOA in response to natural and anthropogenic forces is necessary to organize thinking about the ecosystem and how it functions As such, it is not a prescription for actions to be taken by the Trustee Council Rather, the conceptual foundation advises the Trustee Council regarding the ecological context for future decisions that set priorities for research and monitoring activities By use of the conceptual foundation, each specific project considered for implementation of the GEM program may be understood in relation to other projects and the functions and components of the ecosystem it addresses

Recent syntheses have advanced the understanding of processes upon which the production of marine birds, fish and marine mammals may depend, and with which the conceptual foundation is concerned As development of the GEM program progresses, we expect to advance understanding of the basis for production of representative species of birds, fish and mammals The remaining contexts for designing the plan relate to the human needs served by the Trustee Council through policy and management objectives In this way, the conceptual foundation provides a substantial part of the context for developing the research and monitoring plan by suggesting key processes and species for study

The conceptual foundation will change as more information accumulates, since it is a starting place for understanding the system Some parts of the conceptual foundation will stand the test of time as they are verified through further work in GEM and elsewhere Other portions will be rejected or modified based on reinterpretations of existing data or

insights from new data The future states of the ecosystem might not be anticipated based on past experience, as happened following the regime shift in the late 1970s Therefore, using the principles of adaptive management, the conceptual foundation may be continually refined and revised to reflect our understanding of the ecosystem

Developing testable hypotheses based on the conceptual foundation is important to serve the purposes of GEM, but nonetheless, hypothesis-driven research is effective in direct proportion to the presence of long-term monitoring observations Capturing ecological change will necessitate yearly measures of the critical parameters to capture any superannual natural cycles and detect trends in anthropogenic influences

IV D 2 The conceptual foundation

The GEM program is concerned with both the productivity and population levels of birds, fish, shellfish and mammals in the watersheds and waters of the GOA Under the conceptual foundation, the direct effects of and interactions among related natural and human factors are thought to control the productivity of these species Their population levels are thought to be controlled primarily by food, habitat and removals

The conceptual foundation of the GOA ecosystem links or couples the variation in productivity of many of the birds, fish, shellfish and mammals in the gulf to the amount of food produced at the front associated with the continental shelf break and its subsequent distribution (Figures 11 and 12) There appear to be two major fronts one at the shelf break, that is, the transition between offshore and shelf water masses, and a second one that represents a transition from outer shelf water mass to the more shoreward and fresher waters of the Alaska Coastal Current These fronts are highly dynamic areas thought to be important for food production because of movement of nutrient-rich waters toward the surface (upwellings) or toward the bottom (downwellings) On the surface, long lines or "rips"of debris or foam may identify some fronts Other fronts are marked by water of differing colors on either side Changes in production of break-coupled species may depend on primary production at the shelf break and on mechanisms that distribute the carbon and nutrients produced at the shelf break towards inshore areas

The factors that control populations—primarily food, habitat and removals—are also an important component of the conceptual foundation The amount of food available is greatly influenced by events at the shelf break, and the extent of inshore water stratification The amount of habitat available is determined by geophysical processes, such as climate, and by human activities that degrade habitat, such as pollution, and that destroy habitat, such as logging, road building and other aspects of urbanization Harvest removals include human harvests, as well as natural causes such as starvation and non-human predators Note that these key factors are interactive, since, for example, degraded habitat may produce less food or unsuitable food Key factors are also related, since removals can determine the amount of food available at a location

In general, the basic source of food, primary productivity, is thought to be controlled through the influence of climate and other geophysical processes on plant species composition, temperature, light and the availability of macronutrients, such as nitrate, phosphate, and silicate, and micronutrients, such as reduced iron In the GOA, four climatological cycles or trends may act alone or in combination to change annual primary productivity the ENSO (*El Niño-La Niña*) phenomena with 3- to 7-year oscillations, the

PDO with a 20- to 30-year oscillation, the lunar tidal node with an 18 6-year period, and the long-term trend of global warming

Although the three other phenomena are also important, the conceptual foundation centers around the PDO as the primary force affecting changes in the productivity of the GOA The physical mechanisms through which the lunar tidal node on biological production may be expressed are not as apparent or extensively elaborated as are those of the PDO (Parker et al 1995, Royer 1993) For purposes of this conceptual foundation, we assume confluence in the effects of the PDO and lunar cycle on production in order to avoid specifying which of these explanations (or both) are significantly affecting the ecosystem

The PDO is a set of atmospheric circumstances resulting from the location and intensity of the winter-time Aleutian Low pressure system The PDO changes, or oscillates, between positive and negative states (Figures 11 and 12) In decades of positive PDOs, below normal sea surface 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 Under these conditions, break-coupled species (primarily offshore grazers, such as salmon and some seabirds) do well Although influenced by the amount of removals by humans, the increases in adult salmon during a positive PDO generally return larger amounts of nitrogen to natal streams, resulting in increased production of break-coupled species of plants and animals in the watersheds

In decades of negative PDOs, the opposite sea surface temperature and pressure patterns occur The GOA is cooler and less windy with less precipitation As a consequence, non-break-coupled species (primarily inshore grazers, such as some seabirds, herring and seals) thrive

Figure 11 shows in detail the physics of the positive PDO, starting with the northerly movement and intensification of the winter-time Aleutian Low pressure system with the following interrelated changes

1 Acceleration of cyclonic motion in the Alaska subarctic gyre and increased shoreward surface water transport, specifically in the Alaska Current,

2 Increased mid-gyre upwelling of deep, nutrient-rich water to the ocean surface,

3 Entrainment of more of the west wind drift northward into the GOA Gyre via the Alaska Current, rather than into the California Current system to the south,

4 Deepened winter-time mixing of the surface layer in the central gulf,

5 Warmer surface water temperatures and increased heat flux to the atmosphere,

6 Increased precipitation and coastal runoff, increase in organic carbon and anthropogenic contaminants inputs,

7 Decreased surface water salinity, especially nearshore,

8 Increased winds and Ekman transport from the central gulf shoreward,

9 Increases in the intensity of the Alaska Coastal Current due to increased baroclinic and wind-driven transport,

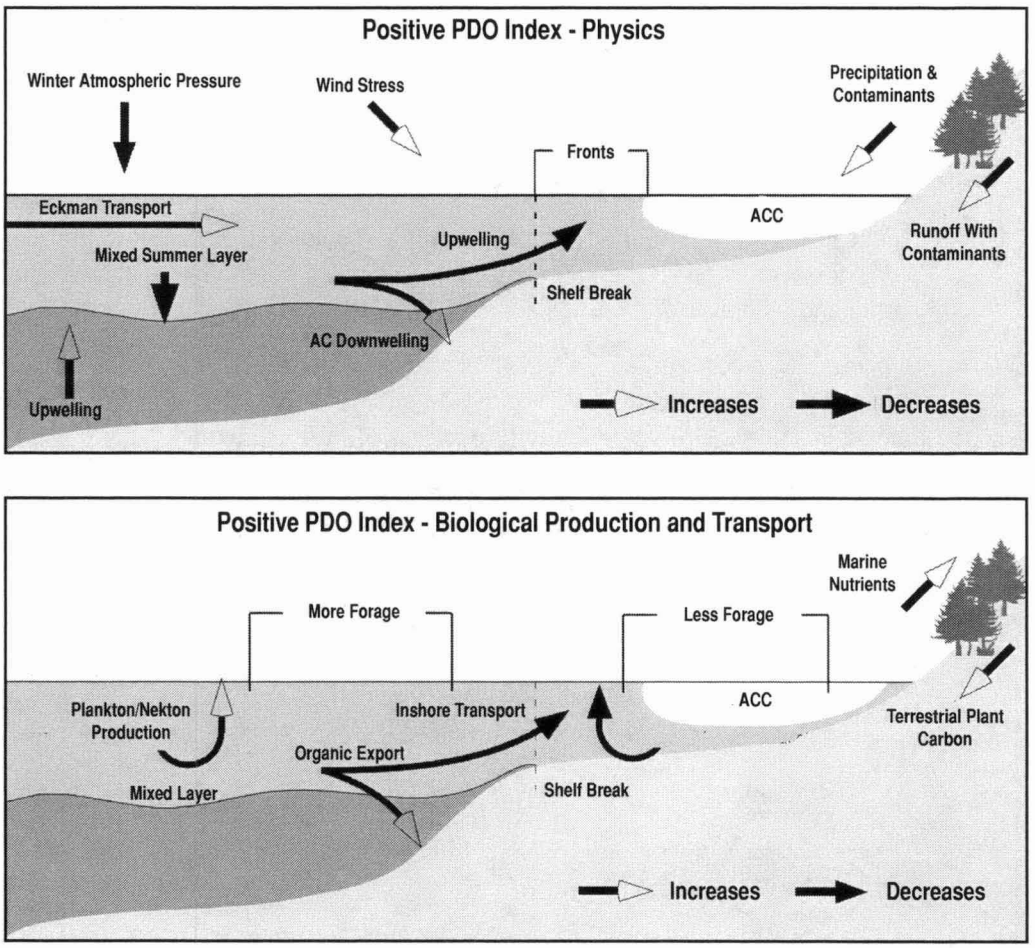

Figure 11. Schematic of physical processes during the winter in a positive PDO climatic regime in the Gulf of Alaska from offshore to inshore areas showing the Alaska Current (AC) and the Alaska Coastal Current (ACC).

10. Deepening of the Alaska Coastal Current nearshore; and

11. Increased downwelling of the shoreward-driven surface water from the central gulf.

During the spring and summer a positive PDO period is characterized by the following biological differences:

1. The mixed layer in the central gulf rises rapidly and is shallower due to greater warming and greater stratification of the surface water;

2. Phytoplankton production is greater in the gulf and at the shelf break;

3. There are greater production and standing crops of zooplankton and nekton, including salmon, in the gulf and at the shelf break;

4. More food is available on a year-round basis for pelagic-feeding fish, such as salmon, in the offshelf and in the central gyre and the effective habitat for salmon is expanded through a larger portion of the gulf;

5. Organic matter originating in the gulf is carried shoreward by Ekman transport in much greater quantities, and then is downwelled more strongly before reaching the coast;

6. There are increased supplies of organic matter to the benthic communities in the outer shelf and slope from downwelled saline surface water;

7. Changes in the distribution of organic matter and water temperature on the shelf and slope force changes in the abundance and species composition of the benthic, epibenthic and pelagic communities;

8. Deepening freshwater influence and greater density stratification of inshore waters limit opportunities for bottom water renewal in enclosed coastal water bodies and to the inner shelf, but may be modulated by patterns of in-season winds;

9. Offshore downwelling fronts, less nutrient replenishment and stronger surface water stratification result in a lower exogenous supply and lower endogenous plankton production in nearshore waters;

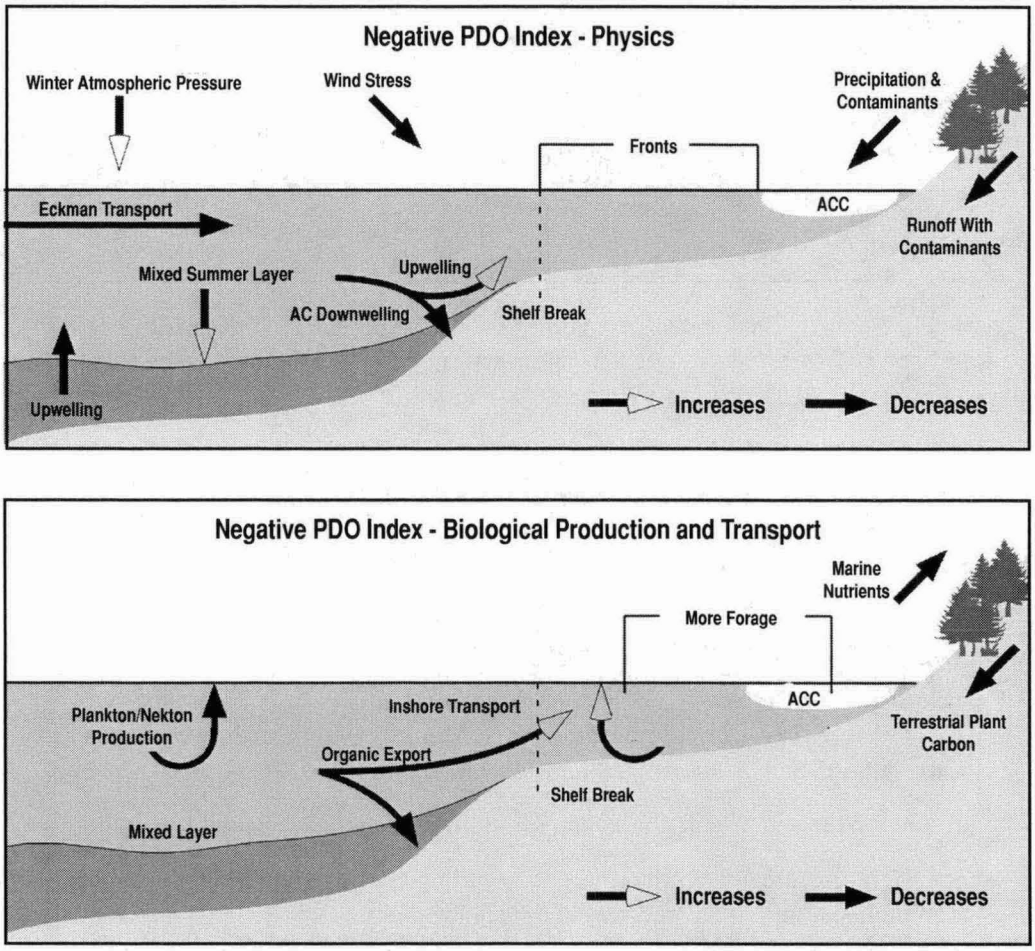

Figure 12. Schematic of physical processes during the winter in a negative PDO climatic regime in the Gulf of Alaska from offshore to inshore areas showing the Alaska Current (AC) and the Alaska Coastal Current (ACC).

10 Forage fish dependent on endogenous inshore production have less to eat and decline, especially fat-rich species whose populations depend on high levels of inshore production,

11 Forage-fish predators, such as harbor seals, sea lions and many sea bird species decline to the extent to which they depend on inshore production and cannot trophically access downwelled offshore production,

12 Fish predators, such as resident killer whales, which depend on offshore production (e g , energy passed trophically through salmon) increase in abundance, and

13 Marine mammal predators, such as transient killer whales, undergo declines

The physics and biology of a negative PDO can generally be described as the inverse of a positive PDO

IV D 3 Discussion

The conceptual foundation is a mechanistic explanation of how the largest climate signal, the PDO, could cause positive and negative biological changes in the abundances and productivities of some species of birds, fish, shellfish and mammals, and why some species show no apparent relation to the climate signals so far described It is assumed that the effects of ENSO cycles and the long-term global warming evident throughout the Pacific will interact in potentially complex ways with PDO cycles to bring about change in biological systems It is also assumed that anthropogenic effects due to harvest levels and methods, degradation of water quality, growing concentrations of contaminants, and habitat loss and degradation will become increasingly important as agents of biological change Accordingly, the conceptual foundation will be changed to accommodate the circumstances created by these natural and anthropogenic agents of change As new insights accumulate, the current conceptual foundation will be expanded, modified or perhaps discarded

Much of the conceptual foundation already appears in the literature, as described in Section IV C , but it also contains a number of new ideas The proposed inshore-offshore inverse production regimes and the transport and fate of the organic matter produced in response to the PDO have not been proposed previously The production regimes are described in the context of a physically coherent ocean-climate model that generally agrees with population trends in higher trophic-level organisms (e g , salmon, seabirds and harbor seals) Specifically, bottom-up controlled food webs in the two regimes respond to climate in generally opposite ways, with positive PDO (e g 1978-1990) indices being associated with greater offshore production (i e , production offshore of the shelf break) and weaker inshore production and negative PDO indices (e g 1948-1977) being associated with greater inshore production (i e , production inshore of the shelf break and on land) and weaker offshore production

The fate of offshore production during the two regimes is key, with shoreward-transported organic production being downwelled more strongly onto the shelf break and outer shelf during the positive PDO index period During the negative PDO index period there is less offshore production transported shoreward, but more organic production can reach the inner shelf and enclosed water bodies due to less downwelling, less water stratification, and more frequent opportunities for shoaling of offshore water derived

from the central gulf onto the inner shelf

The conceptional foundation proposes that the separation between onshore and offshore production regimes occurs between the fronts associated with the shelf break and the ACC (Figures 11 and 12) The "ring of plankton" often seen near the shelf break may be a manifestation, in part, of transported, downwelled organic matter from the gulf that accumulates near the shelf (Cooney 1987) The fate of this organic matter during different climate regimes is key to the oscillations in the concept being proposed here It is recognized that productivity of inshore plankton and nekton is generally higher than offshore productivity on an areal basis However, trapping and accumulation of organic matter produced near the shelf break over a very large area of the central gulf presents a potent source of nourishment for animals on the shelf and slope environments In fact, this source of nourishment is probably larger than the total inshore production of organic matter Cooney (1984, 1987) calculated that shoreward-advected zooplankton in the upper 50 m during the convergence season (October through April) was approximately $10x10^6$ metric tons This compares to $2x10^6$ metric tons produced in the ACC, a five-fold difference The fate of this material may have potent implications for seabirds and juvenile fish that can access it

Recently a mechanistic hypothesis has been advanced to explain the decadal scale variation in eastern North Pacific salmon stocks (Gargett 1997) Gargett proposes that increased precipitation in coastal areas during positive PDOs makes the water column more stable and that this increased stability promotes greater primary production — the "optimal stability window" Polovina et al (1995) have proposed a similar hypothesis for the central GOA, and this ultimately results in more salmon production This hypothesis is based on the assumption that greater water column stability enhances retention of phytoplankton without sacrificing the nutrient supply necessary for the higher rate of primary production

The "optimal stability window" hypothesis is closely related to what is proposed here, with several differences First, because of the tendency for waters of the ACC to become nutrient limited, our model proposes that increased water column stability during positive PDOs will result in net production decreases inshore, in contrast to the increases expected in the central GOA Second, while Gargett proposes that greater salmon production results from favorable productivity in coastal waters, where many salmonids spend their first year at sea, our model would explain abundant food on the outer shelf either as a result of onshore transport of offshore production, i e Cooney's ring of zooplankton production or enhanced production at the shelf break Resolving which, if either, of these two models, the one presented here or Gargett's, is correct depends on knowing the origin of the carbon available to salmon on the shelf Offshore versus inshore carbon may be distinguished in juvenile salmon using natural stable isotope abundance measurements (Kline 1999a) If the source of increased carbon during a positive PDO is due to onshore transport or shelf-break production rather than production within the ACC, then juvenile salmon would have access to the imported production before it is lost to downwelling near the shelf break Unfortunately it does not appear that there are enough data available to distinguish which model may be more accurate

In addition to biological production models based on water column stability and bottom-up control of higher trophic levels, there are the direct effects of water temperature on the physiology of the organism that could alter trophic dynamics, or the geographic range of important organisms For example, Welch (1998) has proposed that global climate warming could drastically restrict the range of sockeye salmon in the next several decades

V Literature Cited

Ahlnes, K , T C Royer, and T H George 1987 Multipole dipole eddies in the Alaska Coastal Current detected with Landsat thematic mapper data Journal of Geophysical Research (92) 13041-13047

Anderson, G C R K Lam, B C Booth, and J M Glass 1977 A description and numerical analysis of the factors affecting the processes of production in the Gulf of Alaska final report Research Unit 58 Environmental Assessment of the Alaska Continental Shelf, Annual Reports of Principal Investigators for the Year ending March 1977 (Receptors, fish, littoral, benthos)

Anderson, G C and R E Munson 1972 Primary productivity studies using merchant vessels in the North Pacific Ocean pp 245-251 *in* A Y Takenoti, editor Biological Oceanography of the Northern North Pacific Ocean Idemitsu Shoten Tokyo, Japan

ARMRB 1993 Alaska Regional Marine Research Board, Alaska Research Plan University of Alaska Fairbanks Alaska Regional Marine Research Board School of Fisheries and Ocean Sciences

Beklemishev, A E 1957 The spatial relationships of marine zoo- and phytoplankton Trudy Institute Okeanologii Akademii Nauk USSR SSSR 20 253-378

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(7) 2567-2571

Ben-David, M , R W Flynn, and D M Schell 1997b Annual and seasonal changes in diets of martens evidence from stable isotope analysis Oecologia (111) 280-291

Ben-David, M , T A Hanley, D R Klein, and D M Schell 1997a Seasonal changes in diets of coastal and riverine mink the role of spawning Pacific salmon Canadian Journal of Zoology (75) 803-811

Ben-David M T A Hanley, and D M Schell 1998a Fertilization of terrestrial vegetation by spawning Pacific salmon the role of flooding and predator activity Oikos (83) 47-55

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 (53) 164-173

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

Bowen et al 1999 Report of the Independent Review of the Scientific Bases for the 3 December 1998 Biological Opinion Regarding Interactions between Steller Sea Lions and Bering Sea and Gulf of Alaska Pollock Fisheries Anchorage, AK North Pacific Fishery Management Council

Brodeur R D , B W Frost, S R Hare, R C Francis and W J Ingraham Jr 1996 Interannual variations in zooplankton biomass in the Gulf of Alaska and covariation with California current zooplankton biomass California Cooperative Oceanic Fisheries Investigations Reports (37) 80-100

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, H P Huntington, and H Short 1998 Traditional knowledge and environmental recovery experiences from the *Exxon Valdez* oil spill Bridging Traditional Ecological Knowledge and Ecosystem Science 1998 Aug Flagstaff AZ

Calkins D 1987 Marine mammals pp 527-558 *in* D W Hood and S T Zimmerman, editors The Gulf of Alaska, Physical Environment and Biological Processes OAD, National Oceanic and Atmospheric Administration, Department of Commerce US Printing Office Washington, D C

Carlson, P R , T R Burns, B F Molnia, and W C Schwab 1982 Submarine valleys in the northeast Gulf of Alaska characteristics and probable origin Marine Geology 47 217-242

Chester A J and J D Larrance 1981 Composition and vertical flux of organic matter in a large Alaskan estuary Estuaries 4 42-54

Cooney, R T 1984 Some thoughts on the Alaska coastal current as a feeding habitat for juvenile salmon pp 256-258 *in* W C Pearcy, editor The Influence of Ocean Conditions on the Production of Salmonids in the North Pacific Volume ORESU-W-83-001 Sea Grant Program, Oregon State University, Corvallis, Oregon

Cooney R T 1987 Zooplankton pp 285-303 *in* D W Hood and S T Zimmerman editors The Gulf of Alaska Physical Environment and Biological Processes OAD, National Oceanic and Atmospheric Administration, Department of Commerce, US Printing Office, Washington, D C

Crane, K and J L Galasso 1999 Arctic environmental atlas U S Naval Research Laboratory, Office of Naval Research, Washington, D C

DeGange, A R and G A Sanger 1987 Marine birds pp 479-526 *in* D W Hood and S T Zimmerman editors The Gulf of Alaska, Physical Environment and Biological Processes OAD, National Oceanic and Atmospheric Administration, Department of Commerce, US Printing Office Washington, D C

DOI-NOAA-ADF&G (U S Department of the Interior, National Oceanic and Atmospheric Administration, Alaska Department of Fish and Game) 1997 Bering Sea Ecosystem Workshop Report Anchorage AK December 4-5, 1997 Juneau, AK ADF&G, Commercial Fisheries Division

DOI-NOAA-ADF&G (U S Department of the Interior National Oceanic and Atmospheric Administration, Alaska Department of Fish and Game) 1998a Draft Bering Sea Ecosystem Research Plan Juneau, AK ADF&G, Commercial Fisheries Division

DOI-NOAA-ADF&G (U S Department of the Interior, National Oceanic and Atmospheric Administration Alaska Department of Fish and Game) 1998b Bering Sea Ecosystem - A Call to Action Juneau, AK ADF&G Commercial Fisheries Division

Dugdale, R C 1967 Nutrient limitation in the sea dynamics identification and significance Limnology and Oceanography (12) 685-695

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(C1) 857-868

Eslinger D 1999 Biophysical modeling and validation through remote sensing, in Sound Ecosystem Assessment (SEA)-An integrated science plan for the restoration of injured species in Prince William Sound Final Report for Project 99320 Anchorage AK *Exxon Valdez* Oil Spill Restoration Office

EVOSTC (*Exxon Valdez* Oil Spill Trustee Council) 1994 *Exxon Valdez* Oil Spill Restoration Plan Anchorage AK *Exxon Valdez* Oil Spill Restoration Office

EVOSTC (*Exxon Valdez* Oil Spill Trustee Council) 1999 *Exxon Valdez* Oil Spill Restoration Plan, Update on Injured Resources and Services Anchorage, AK *Exxon Valdez* Oil Spill Restoration Office

Favorite, F, A J Dodimead, and K Nasu 1976 Oceanography of the subarctic Pacific region 1960-71 International North Pacific Fisheries Commission Bulletin No 33 187

Feder H M and S C Jewett 1987 The subtidal benthos pp 347-398 *in* D W Hood and S T Zimmerman, editors The Gulf of Alaska Physical Environment and Biological Processes OAD, National Oceanic and Atmospheric Administration, Department of Commerce, US Printing Office, Washington, D C

Fehr, A and W Hurst 1996 A seminar on two ways of knowing indigenous and scientific knowledge Inuvik, NWT Aurora Research Institute

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) 1-21

Freeland, H J, K L Denman, C S Wong, F Whitney, and R Jacques 1998 Evidence of change in the winter mixed layer in the northeast Pacific Ocean Deep-Sea Research (44) 2117-2129

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 Restoration Project 97064, Annual Report Anchorage, Alaska *Exxon Valdez* Oil Spill Restoration Office

Furness, R W and C J Camphuysen 1997 Seabirds as monitors of the marine environment ICES Journal of Marine Science (54) 726-737

Gardner, J V, P K Butman, L A Mayer, and J H Clarke 1998 Mapping U S continental shelves enabled by high resolution multibeam systems, advances in data processing, USGS begins systematic mapping program Sea Technology (June) 10-17

Gargett, A 1997 Optimal stability window A mechanism underlying decadal fluctuations in north Pacific salmon stocks Fisheries Oceanography (6) 109-117

Hampton, M A, P R Carlson, and H J Lee 1987 Geomorphology, sediment and sedimentary processes pp 93-143 *in* D W Hood and S T Zimmerman, editors The Gulf of Alaska, Physical Environment and Biological Processes OAD, National Oceanic and Atmospheric Administration, Department of Commerce, US Printing Office, Washington, D C

Hansen, B (editor) 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)

Hare, S R, N J Mantua, and R C Francis 1999 Inverse production regimes Alaska and west coast Pacific salmon Fisheries (24) 6-14

Hatch, S A, G V Byrd, D B Irons, and G L Hunt 1993 Status and ecology of kittiwakes in the North Pacific Ocean pp 140-153 *in* K Vermeer, 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 Canada

Hattori, A and E Wada 1972 Assimilation of inorganic nitrogen in the euphotic layer of the north Pacific Ocean pp 279-287 *in* A Y Takenoti, editor Biological Oceanography of the North Pacific Ocean Idemitsu Shoten, Tokyo, Japan

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 1957 The breeding and development of the dominant copepods in the Bering Sea Trudy Vsesoyuznogo Gidrobiologicheskogo Obshchest VA (8) 143-162

Hollowed, A B and W S Wooster 1992 Variability of winter ocean conditions and strong year classes of Northeast Pacific groundfish pp 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 pp 373-385 *in* R J Beamish, editor Climate Change and Northern Fish Populations Canadian Special Publication of Fisheries and Aquatic Sciences ed Volume 121

Hood, D W and S T Zimmerman editors 1986 The Gulf of Alaska physical environment and biological resources OAD, National Oceanic and Atmospheric Administration Department of Commerce, US Printing Office Washington, D C

Huntington, H P 1992 Wildlife management and subsistence hunting in Alaska Volume xvii Belhaven Press, London, England 177

Huntington, H P 1998 Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge Arctic (51) 3

Huntington H P in press Using traditional ecological knowledge in science methods and applications Ecological Applications (10) 5

Ingraham Jr W J R K Reed J D Schumacher and S A Macklin 1991 Circulation variability in the Gulf of Alaska EOS, Transactions of the American Geophysical Union 72(24) 257-264

Irons D B 1996 Size and productivity of black-legged kittiwake colonies in Prince William Sound before and after the *Exxon Valdez* oil spill pp 738-747 *in* S D Rice, R B Spies, D A Wolf, and B A Wright, editors Proceedings of the *Exxon Valdez* Oil Spill Symposium American Fisheries Society Symposium

Johnson, W R , T C Royer, and J L Luick 1988 On the seasonal variability of the Alaska Coastal Current Journal of Geophysical Research (93) 12423-12437

Klein, W H 1957 Principal tracks and mean frequencies of cyclones and anti-cyclones in the northern hemisphere Research Paper Number 40 Washington, D C US Weather Bureau US Government Printing Office

Kline Jr T C 1999a Temporal and spatial variability of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ in pelagic biota of Prince William Sound Alaska Canadian Journal of Fisheries and Aquatic Sciences 56 (Suppl 1) 94-117

Kline Jr , T C 1999b Carbon and nitrogen isotopes in Prince William Sound pelagic biota annual shift a tool for monitoring changes in oceanographic forcing pp 87-95 in Ecosystem Approaches for Fisheries Management Alaska Sea Grant College Program Report No 99-01 Fairbanks University of Alaska

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 ^{15}N and ^{13}C evidence in the Kvichak River watershed Bristol Bay, Southwestern, Alaska Canadian Journal of Fisheries and Aquatic Sciences (50) 2350-2365

Kron, T 1995 Prince William Sound salmon enhancement programs and considerations relative to wild stocks pp 49-52 *in* M R Collie and J P McVey editors Interactions Between Cultured

Species and Naturally Occurring Species in the Environment Proceedings of the Twenty-second U S -Japan Aquaculture Panel Symposium U S Japan Cooperative Program in Natural Resources (UJNR) Technical Report No 22 Alaska Sea Grant Report AK-95-03 University of Alaska Sea Grant College Program Fairbanks, AK

Lagerloaf, G 1983 Topographically controlled flow around a deep trough transecting the shelf off Kodiak Island, Alaska Journal of Physical Oceanography 13 139-146

Larrance, J D and A J Chester 1979 Source, composition and flux of organic detritus in lower Cook Inlet, Outer Continental Shelf Environmental Assessment Program Final Reports of Principal Investigators

Mackas D, personal communcation Institute of Ocean Sciences, Sidney, British Columbia, Canada

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, C I Malayang, 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

Mantua, N J , S R Hare Y Zhang, J M Wallace, and R C Francis 1997 A Pacific interdecadal climate oscillation with impacts on salmon production Bulletin of the American Meterological Society (78) 1069-1079

Mantyla and Reid 1983 Abyssal characteristics of the world ocean waters Deep-Sea Research (30) 805-833

Mathisen, O A 1972 Biogenic enrichment of sockeye salmon lakes and stock productivity Verhandlungen Der Internationalen Vereinigung Fur Theoretische and Angewandte Limnologie (18) 1089-1095

Memorandum of agreement and consent decree, United States of America v State of Alaska, A91-081 CIV (U S District Court, District of Alaska 1991)

Miller C B 1993 Pelagic production processes in the subarctic Pacific Progress in Oceanography (32) 1-15

Miller, C B , B W Frost, H P Batchelder M J Clemons, and R E Conway 1984 Life histories of large, grazing copepods in a subarctic ocean gyre *Neocalanus plumchrus*, *Neocalanus cristatus*, and *Eucalanus bungii* Progress in Oceanography (13201-243)

Miller, C B , B W Frost, P A Wheeler, M R Landry, N Welschmeyer, and T M Powell 1991 Ecological dynamics in the subarctic Pacific, possibly iron limited system Limnology and Oceanography (36) 1600-1615

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

Muench, R D and D T Heggie 1978 Deep water exchange in Alaskan subarctic fjords pp 239-267 *in* B Kjerfve, editor Estuarine Transport Processes B Baruch Institute for Marine Biology and Coastal Research University of South Carolina Press, Columbia, SC

Musgrave, D T Weingartner, and T C Royer 1992 Circulation and hydrography in the northwestern Gulf of Alaska Deep-Sea Research (39) 1499-1519

Mysak L R D Muench, and J D Schumacher 1981 Baroclinic instability in a downstream varying channel Shelikof Strait, Alaska Journal of Physical Oceanography (11) 950-969

Niebauer, H J , J Roberts, and T C Royer 1981 Shelf break circulation in the northern Gulf of Alaska Journal of Geophysical Research (86) 4021-4033

NPFMC 1999 North Pacific Fishery Management Council Appendix D Preliminary Ecosystem Considerations for 2000 Groundfish Plan Teams Annual SAFE Reports P Livingston, editor Anchorage, AK North Pacific Fishery Management Council

O'Clair, C and S T Zimmerman 1987 Biogeography and ecology of the intertidal and shallow subtidal communities pp 305-346 *in* D W Hood and S T Zimmerman, editors The Gulf of Alaska, Physical Environment and Biological Processes OAD, National Oceanic and Atmospheric Administration, Department of Commerce, US Printing Office, Washington, D C

OCSEAP 1990 Outer Continental Shelf Environmental Assessment Program Comprehensive Bibliography Anchorage, AK U S Department of the Interior Minerals Management Service

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

Pahlow, M and U Riebsell 2000 Temporal trends in deep ocean Redfield ratios Science (287) 831-833

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 Canadian Special Publication of Fisheries and Aquatic Sciences (121) 447-458

Pauly, D and V Christensen 1995 Primary production required to sustain global fisheries Nature (374) 255-257

Pearcy, W G 1992 Ocean ecology of North Pacific salmonids p 179 Washington Sea Grant Program, University of Washington Press

Phillips, R A , R G W Caldow, and R W Furness 1996 The influence of food availability on the breeding effort and reproductive success of Arctic *skuas Stercorarius parasticus Ibis* (138) 410-419

Piatt, J F unpublished National Biological Survey, Alaska Science Center, Anchorage, AK

Piatt, J F and P Anderson 1996 Response of common murres to the *Exxon Valdez* oil spill and long-term changes in the Gulf of Alaska marine ecosystem pp 720-737 *in* S D Rice R B Spies, D A Wolf, and B A Wright, editors Proceedings of the *Exxon Valdez* Oil Spill Symposium American Fisheries Society

Piorkowski R J 1995 Ecological effects of spawning salmon on several southcentral Alaskan streams University of Alaska Fairbanks, AK

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

Polivina 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

Reeburg W S and G W Kipphut 1987 Chemical distributions and signals in the Gulf of Alaska, its coastal margins and estuaries pp 77-91 *in* D W Hood and S T Zimmerman editors The Gulf of Alaska Physical Environment and Biological Processes OAD, National Oceanic and Atmospheric Administration Department of Commerce, US Printing Office, Washington, D C

Reed R K and J D Schumacher 1986 Physical oceanography pp 57-75 *in* D W Hood and S T Zimmerman, editors The Gulf of Alaska Physical Environment and Biological Processes OAD, National Oceanic and Atmospheric Administration, Department of Commerce, US Printing Office Washington D C

Reid Jr J L 1965 Intermediate waters of the Pacific Ocean The Johns Hopkins Oceanographic Studies

Reitan, C H 1974 Frequency of cyclones and cyclogenesis for North America Monthly Weather Review (102) 861-868

Richardson, R W 1936 Winter air-mass convergence over the North Pacific Monthly Weather Review (64) 199-203

Rogers, J C 1981 The North Pacific oscillation Journal of Climatology (1) 39-57

Rosenburg, D H editor 1972 A review of the oceanography and renewable resources of the northern Gulf of Alaska University of Alaska, Institute of Marine Science, Fairbanks, AK

Rosenkrantz G 1999 Statistical modeling of tanner crab recruitment Thesis University of Alaska Fairbanks AK

Royer, T C 1975 Seasonal variations of waters in the northern Gulf of Alaska Deep-Sea Research (22) 403-416

Royer, T C 1979 On the effect of precipitation and runoff on coastal circulation in the Gulf of Alaska Journal of Physical Oceanography (9) 555-563

Royer T C 1981b Baroclinic transport in the Gulf of Alaska Part II A freshwater-driven coastal current Journal of Marine Research (39) 251-266

Royer, T C 1982 Coastal freshwater discharge in the northeast Pacific Journal of Geophysical Research (87C) 2011-2021

Royer, T C 1993 High-latitude oceanic variability associated with the 18 6 year nodal tide Journal of Geophysical Research (98) 4639-4644

Royer T C D V Hansen, and D J 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

Sambratto, R N and C J Lorenzen 1987 Phytoplankton and primary production pp 249-282 *in* D W Hood and S T Zimmerman editors The Gulf of Alaska, Physical Environment and Biological Processes OAD, National Oceanic and Atmospheric Administration Department of Commerce US Printing Office, Washington D C

Scheffer V B 1972 Marine mammals in the Gulf of Alaska pp 175-208 *in* D H Rosenburg, editor A Review of the Oceanography and Renewable Resources of the Northern Gulf of Alaska Report R72-73 University of Alaska Institute of Marine Science Fairbanks AK

Senner S 1999 Converging north dunlins and western sandpipers on the Copper River Delta pp 135-148 *in* K P Able, editor Gatherings of Angels Migrating Birds and Their Ecology Comstock Books, Ithaca NY

Short J W unpublished National Oceanic and Atmospheric Administration National Marine Fisheries, Auke Bay Laboratory Juneau, AK

Smith Jr , K L and R S Kaufman 1999 Long-term discrepancy between food supply and oxygen demand in the deep eastern North Pacific Science (284) 1174-1177

Smoker, W W, B A Bachen G Freitag, H J Geiger, and T J Linley in press Ocean ranching enhancement of salmon production in Alaska Proceedings of the Conference on Sustainable Fisheries Victoria 1993 CRC Press

Smoker, W W and T J Linley 1997 Are Prince William Sound salmon hatcheries a fool's bargain? Alaska Fishery Research Bulletin 4 75-78

SSRT (Sound Science Review Team) 1999 Science Plan Cordova, AK Alaska Department of Fish and Game

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

Thomson, R E and J F R Gower 1998 A basin scale oceanic instability event in the Gulf of Alaska Journal of Geophysical Research (103) 3033-3040

Treidl, R A E C Birch, and P Sajecki Blocking action in the northern hemisphere a climatological study Atmosphere-Ocean (19) 1-23

Trenbreth, K E and J W Hurrel 1994 Decadal atmospheric-ocean variations in the Pacific Climate Dynamics (9) 303-319

Trites, A W 1992 Northern fur seals why have they declined? Aquatic Mammals (18) 3-18

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 AK-SG-96-02 512-543

USFS (US Forest Service) 1997 Northwest Forest Plan, an ecosystem management approach, watersheds communities, and people Portland OR USDA Forest Service Pacific Northwest Research Station

Venrick, E L, J A McGowan D R Cayan and T L Hayward 1987 Climate and chlorophyll-a long-term trends in the central north Pacific Ocean Science (238) 70-72

Ware, D M 1991 Climate predators and prey behavior of a linked oscillating system pp 279-291 *in* T Kawasaki, S Tanaka, Y Toba, and A Tanaguchi, editors Long-term Variability of Pelagic Fish Populations and Their Environments Pergamon Press, Tokyo, Japan

Welch, D W and S D Batten 2000 Climate change global warming and the PICES mandate - The need for improved monitoring PICES Press 8(1) 24-27

Welch D W, Y Ishida, K Nagasawa and J P Eveson 1998 Thermal limits on the ocean distribution of steelhead trout (Oncorhynchus mykiss) *in* D W Welch, D M Eggers K Wakabayashi and V I Karpenko, editors Assessment and status of Pacific Rim salmonid stocks Vancouver, Canada North Pacific Anadromous Fish Commission

Welschmeyer N A 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

White, W B and N E Clark 1975 Development of blocking ridge activity over the central north Pacific Journal of the Atmospheric Sciences (32) 489-502

Whittaker, L M and L H Horn 1982 Atlas of Northern Hemisphere extratropical cyclonicactivity, 1958-1977 Madison WI Department of Meteorology University of Wisconsin

Wilson, J G and J E Overland 1986 Meteorology pp 31-54 *in* D W Hood and S T Zimmerman, editors The Gulf of Alaska, Physical Environment and Biological Processes OAD, National Oceanic and Atmospheric Administration, Department of Commerce, US Printing Office, Washington, D C

Witherell, D 1999 Status and trends of principal groundfish and shellfish stocks in the Alaska exclusive economic zone, 1999 Anchorage, AK North Pacific Fishery Management Council

Xiong, Q and T C Royer 1984 Coastal temperature and salinity observations in the northern Gulf of Alaska, 1970-1982 Journal of Geophysical Research (89) 8061-8068

Zheng, J and G H Kruse In press Recruitment patterns of Alaskan crabs and relationships to decadal shifts in climate and physical oceanography ICES Journal of Marine Science (56)

Appendix A Text of the Resolution of the Trustee Council

RESOLUTION
of the
Exxon Valdez Oil Spill Trustee Council
concerning the
Restoration Reserve and Long-term Restoration Needs

WHEREAS, in November 1994, following an extensive public process, the *Exxon Valdez* Oil Spill Trustee Council ("Trustee Council") adopted the *Restoration Plan* to guide a comprehensive and balanced program to restore resources and services injured by the oil spill,

WHEREAS, since that time the Trustee Council has used the *Restoration Plan* to guide development of the annual work plans as well as the acquisition and protection of large and small habitat parcels important to the long-term recovery of injured resources and services,

WHEREAS, the *Restoration Plan* identified a series of large parcel purchases and the Trustee Council has been successful in obtaining habitat protection agreements with willing-seller landowners to provide protection for approximately 635,000 acres,

WHEREAS, the *Restoration Plan* recognized that complete recovery from the oil spill would not occur for decades and that through long-term observation and, as needed, restoration actions, injured resources and services could be fully restored,

WHEREAS, the *Restoration Plan* specifically recognized establishment of the Restoration Reserve to provide a secure source of funding for restoration into the future beyond the last annual payment from the Exxon Corporation,

WHEREAS, the Trustee Council has sponsored an extensive public involvement process to provide opportunity for comment on possible future uses of the Restoration Reserve including public meetings in communities throughout the spill impact region and also in Anchorage, Fairbanks and Juneau,

WHEREAS, a large volume of public comment regarding the Restoration Reserve has been solicited and received urging a wide range of uses for remaining settlement funds including a strong showing of support for additional habitat protection efforts as well as research and other restoration efforts,

WHEREAS, numerous Native tribal members and other community residents from the spill area have indicated a strong interest in continued support for community-based efforts consistent with those that have been previously funded by the Trustee Council such as subsistence restoration, Traditional Ecological Knowledge, youth area watch, cooperative management, and local stewardship efforts,

WHEREAS, the Public Advisory Group (PAG) has reviewed and discussed long-term restoration needs and use of the Restoration Reserve at considerable length and the views of the PAG members have been communicated to the Trustee Council,

WHEREAS, upon consideration of the restoration mission as provided by the settlement and the *Restoration Plan*, past restoration program efforts and accomplishments, public comments received by the Trustee Council, the views of the Public Advisory Group members, and the most current information regarding the status of recovery of the resources and services injured by the oil spill, the Trustee Council has identified substantial and continuing long-term restoration needs,

WHEREAS, full recovery of many injured resources and services is not yet complete and long-term restoration, conservation and improved management of these resources and services will require a substantial on-going investment to improve our understanding of the biology and marine and coastal ecosystems that support the resources as well as the people of the spill region,

WHEREAS, prudent use of the natural resources of the spill area without unduly impacting their recovery requires increased knowledge of critical ecological information about the northern Gulf of Alaska that can only be provided through a long-term research and monitoring program,

WHEREAS, together with scientific research and monitoring, a continuing commitment to habitat protection and general restoration actions, where appropriate, will help ensure the full recovery of injured resources and services,

WHEREAS, consistent with the *Restoration Plan*, restoration needs identified by the Trustee Council require a long-term comprehensive and balanced approach that includes a complementary commitment to scientific research and monitoring, applied science to inform and improve the management of injured resources and services, continued general restoration activities where appropriate, support for community-based efforts to restore and enhance injured resources and services, and protection for additional key habitats,

WHEREAS, by October 2002, as a result of the past and anticipated future deposits into the Restoration Reserve, it is estimated that the principal and interest in the reserve, together with remaining unobligated settlement funds, will be approximately $170 million unless, prior to that time, on-going negotiations concerning the Karluk and Sturgeon rivers and adjacent lands or other potential habitat transactions result in habitat acquisition agreements that obligates some of these funds,

WHEREAS, absent such additional acquisition agreements, $170 million is the total of the funds estimated to be available to support long-term restoration based on projected investment returns allowable through the Court Registry under its existing authority and thus reasonably anticipated as available for restoration purposes by the Trustee Council starting with FY 2003 ("estimated funds remaining on October 1, 2002"), and

WHEREAS, the limits of the existing investment authority of the Trustee Council have resulted in the loss of millions of dollars in potential earnings that would have been available to effectively address restoration needs in the future and support a comprehensive program that maintains its value over time, and it is necessary that the limits on the investment authority for the joint settlement funds be amended by Congress if we are to optimize our potential restoration program,

THEREFORE BE IT RESOLVED, that the Trustee Council has determined that recovery from the *Exxon Valdez* oil spill remains incomplete and there is need for

establishing at this time a continuing long-term, comprehensive and balanced restoration program consistent with the *Restoration Plan*,

BE IT FURTHER RESOLVED, that funds in the Restoration Reserve and other remaining unobligated settlement funds available on October 1, 2002 (for expenditure starting in FY 2003) be allocated in the following manner consistent with the "Outline of Action Under Existing Authority" dated 3/1/99 attached to this resolution

$55 million of the estimated funds remaining on October 1, 2002 and the associated earnings thereafter will be managed as a long-term funding source with a significant proportion of these funds to be used for small parcel habitat protection and it is recognized that any funding that may be authorized for purchase of lands along or adjacent to the Karluk or Sturgeon rivers or other potential habitat acquisitions would be made from within this allocation, and

The remaining balance of funds on October 1, 2002 will be managed so that the annual earnings, estimated at approximately 5% per year, will be used to fund annual work plans that include a combination of research, monitoring, and general restoration including those kinds of community-based restoration efforts consistent with efforts that have been previously funded by the Trustee Council, such as subsistence restoration, Traditional Ecological Knowledge, Youth Area Watch, cooperative management, and local stewardship efforts, as well as local community participation in ongoing research efforts,

BE IT FURTHER RESOLVED, that the Restoration Office and the Chief Scientist, under the direction of the Executive Director, shall begin to develop a long-term research and monitoring program for the spill region that will inform and promote the full recovery and restoration, conservation and improved management of spill-area resources, and

BE IT FURTHER RESOLVED, that it is the intent of the Trustee Council that this long-term reserve for research, monitoring and general restoration be designed to ensure the conservation and protection of marine and coastal resources, ecosystems, and habitats in order to aid in the overall recovery of those resources injured by the *Exxon Valdez* oil spill and the long-term health and viability of the spill area marine environment,

BE IT FURTHER RESOLVED, that in developing a long-term restoration research, monitoring and general restoration program for the spill region, the Executive Director shall solicit the views of the Public Advisory Group, community facilitators, resource management agencies, researchers and other public interests as well as coordinate restoration program efforts with other marine research initiatives including the North Pacific Research Board,

BE IT FURTHER RESOLVED, that the Executive Director shall work with the Alaska Congressional delegation and appropriate State and federal agencies to obtain the necessary investment authority to increase the earnings on remaining settlement funds, so that the Trustee Council will be able to conduct an effective restoration program that maintains its value over time, and

BE IT FURTHER RESOLVED, that in developing long-term implementation options for consideration by the Trustee Council, the Executive Director shall

investigate possible establishment of new or modified governance structures to implement long-term restoration efforts,

explore alternative methods to ensure meaningful public participation in restoration decisions, and

report back to the Trustee Council by September 1, 1999 regarding these efforts

Adopted this 1st day of March, 1999, in Anchorage, Alaska

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3/9/99 final

Appendix B Description of the GEM Database

In June 1999, the Restoration Office began to develop a database of monitoring, survey and retrospective projects in the northern Gulf of Alaska The purpose of the database is to identify major sources of data germane to the Gulf Ecosystem Monitoring (GEM) program

As of April 2000, the database has information on 240 projects Most of these projects have been funded or conducted by government agencies Major projects in this database are summarized in the following table The summary of projects is not exhaustive The PICES web site (http //pices ios bc ca/data/weblist/weblist html), the Report of the Bering Sea Ecosystem Workshop (DOI-NOAA-ADF&G 1997), and Bering Sea and North Pacific Ocean Theme Page (www pmel noaa gov/bering) may be consulted for a more extensive listing of projects

Each project in the database falls into one or more of the following categories oceanography, macrofauna, and human use Each record includes a description of the project, the name and contact information for the principal investigator, the type of data gathered and analysis conducted, the locations of sampling stations, beginning and ending dates, rough estimates of funding, and instructions for accessing the data generated by the project

The database includes many projects that collect primary data Examples include meteorological and oceanographic data from satellites or buoys Other projects use this data or retrospective data to study an issue of interest to the GEM Still other projects compile data into catalogues or databases Examples of such compilations are the Coded Wire Tag Database, the Pacific Seabird Monitoring Database, and the Beringian Seabird Catalogue

In addition to refining entries on these projects, the Restoration Office is contacting private foundations and other nongovernmental organizations for information about projects they have sponsored or conducted The database will be available on the Trustee Council's web page in the future

Appendix Table 1: Selected information-gathering programs in the Gulf of Alaska

Agency/Program	Data	Coverage in Gulf of Alaska
Oceanography		
GLOBEC / Gulf of Alaska Monitoring Program	Vertical CTD-chlorophyll-PAR profiles ADCP, fluorescence, sea surface temperature and salinity, nutrients, chlorophyll pigments, oxygen isotope ratios and zooplankton 1997-2000	Seward Line Transect Cape Fairfield Line Transect
GLOBEC / Northeast Pacific Retrospective Studies	Analysis of retrospective data sets to document the link between climate and ocean variability and population variability 1998-2005	Full coverage
NASA / Earth Observing System (EOS)	Sea surface temperature, phytoplankton, dissolved organic matter wind fields ocean surface Since 1996	Full satellite coverage
NOAA, NASA / Advanced Very High Resolution Radiometer (AVHRR)	Sea surface temperature 1985-1999	Full satellite coverage
NOAA / Moored Buoy Program	Wave height, dominant wave period, atmospheric pressure, pressure tendency, air temperature, and water temperature	Gulf of Alaska 56° N 148° W North PWS 60° N 146W° South PWS 60° N 146° W
NOAA / Coastal-Marine Automated Network (C-MAN)	Wind direction, speed, and gust, atmospheric pressure, air temperature Since early 1980s	Bligh Reef Light, Five Finger, Middle Rock and Potato Point
NOAA / Fisheries Oceanography Coordinated Investigations (FOCI)	Salinity, temperature, currents and fluorescence, nutrients, chlorophyll, microzooplankton atmospheric variables, sediments Since 1984	Shelikof Strait
Macrofauna		
IPHC / Assessment of Pacific Halibut Stock	Age, length, catch, effort, sex, sexual maturity of Pacific halibut Research surveys since 1925	Pacific halibut range
NOAA / Ocean Carrying Capacity / North Pacific Ocean Salmon Ecology	Ocean migrations, abundance and movement patterns, stock identification, genetics, growth condition, diet Research cruises since 1995	Full coverage
NOAA / Sablefish Longline Surveys	Annual surveys of sablefish Also data on rockfish Since 1979	Full coverage

Agency/Program	Data	Coverage in Gulf of Alaska
ADFG / Salmon Escapement Counts	Enumeration of returning adult salmon Data since early 1900s	Salmon streams throughout the Gulf of Alaska region
ADFG / Surveys	Age, weight, length, AWL, sex, abundance and distribution for herring, shellfish, and other species Since 1980	Full coverage
ADFG / Fish Pathology Disease History Database	Disease histories of salmon, trout, herring, clams, and other fish and shellfish Since 1973	Full coverage
ADFG / Coded Wire Tagging	Identification of a particular stock from a particular year Since the early 1970s	Primarily salmon hatcheries a few wild fish programs
NOAA / Marine Mammal Stock Assessments	Stock assessments for sea lions, harbor seals, various whales, and porpoises Since 1995	Full coverage
DOI / Beringian Seabird Colony Catalog	Breeding population size species composition and location Data since the late 1800s	Seabird colonies throughout Alaska
DOI / Alaska Seabird Inventory and Monitoring Plan	Population, nesting productivity and timing, prey use growth rates survival Since 1970s	10 different sites annually on the Alaska Maritime NWR
Human Use		
NOAA / National Status and Trends Program / Mussel Watch Project	Contaminants in sediments and bivalve mollusks including PAHs and PCBs Since 1986	Cook Inlet, Kodiak Island PWS
NOAA / National Status and Trends Program / National Benthic Surveillance	Chemical concentrations in the livers of bottom-dwelling fish 1984-1993	Prince William Sound
DOI / Alaska Marine Mammals Tissue Archiving Project	Heavy metals PAHs organic pollutants and other contaminants Since 1987	Full coverage

Appendix Table 1 Selected information gathering programs in the Gulf of Alaska

Appendix C Elements of Research and Monitoring

The following areas of interest for long-term monitoring and supporting research represent an initial effort upon which to build a detailed plan The monitoring areas and questions are by no means exhaustive or exclusive They are intended to serve as a starting point for developing the Gulf Ecosystem Monitoring (GEM) research and monitoring plan, which is scheduled for implementation in October 2002

The monitoring areas and questions were assembled from past programs and research projects, and contributed by scientists and other members of the public

Appendix C 1 Long-term Monitoring

A central focus of the GEM program is a core of long-term measurements funded by a variety of entities including GEM that is sufficient to track ecosystem changes in processes and species of interest on the scale of decades At the same time, GEM seeks shorter-term research to clarify functional relationships within the ecosystem so that the monitoring programs may be changed in response to new information and management needs There will always be a dynamic balance between the need for continuity and for making the monitoring program most reflective of our latest understanding of how the system functions and where, when and how it is best measured

It needs to be emphasized that GEM is unlikely to directly support the bulk of the monitoring necessary to track ecosystem changes in processes and species of interest on the scale of decades The approach recommended here is to 1) determine the best hypotheses to explain the interaction of physical, biological and anthropogenic processes to produce species of interest, and what data are presently being gathered to evaluate these hypotheses, 2) conduct statistical and logistical research to determine the monitoring opportunities where GEM may most efficiently contribute to evaluating top hypotheses, 3) leverage GEM funding using the logistic and financial support provided by existing agencies, 4) craft a program of monitoring and related research that is appropriate to the cash flow expected from the Trustee Council's endowment, and 5) periodically review and modify the program

The following are suggested as areas of interest in no particular order Again, GEM is not expected to fund all or even most of the items identified Where other programs are not now fully addressing these areas, there should be opportunities for the GEM monitoring program to contribute

Appendix C 1 a Inshore Benthic and Intertidal Communities

To monitor annual abundance and productivity of selected subtidal and intertidal organisms, such as clams, polychaetes, and crustaceans, at locations in Prince William Sound, Kodiak and lower Cook Inlet Relate retention and transport phenomena to larval supply and recruitment Possible cooperating agencies/programs Minerals Management Service (MMS), Prince William Sound and Cook Inlet Regional Citizens Advisory Councils (RCACs)

Appendix C 1 b Apex Predators

To monitor seabird colony attendance at intervals of perhaps every four years and chick productivity as often as every year at established U S Fish and Wildlife Service (USFWS) Gulf of Alaska (GOA) index colony sites (e g , Barren Islands) within the spill area for at least common murres and black-legged kittiwakes Also monitor total seabird guild composition and abundance at major index sites Occasional at-sea counts of seabirds Possible cooperating agencies/programs U S Geological Survey Biological Resources Division (USGS/BRD), USFWS/Alaska Maritime National Wildlife Refuge Seabird Monitoring Program, Global Ocean Ecosystems Dynamics (GLOBEC), MMS

To conduct regular periodic surveys of harbor seal molting at select sites across the northern GOA coast (e g , Prince William Sound, outer Kenai coast, Cook Inlet, Kodiak) accompanied by biological studies to assess body condition and other factors likely to be indicative of population status Possible cooperating agencies/programs National Marine Fisheries Service (NMFS), Alaska Department of Fish and Game (ADF&G), National Park Service (NPS), University of Alaska, Fairbanks (UAF)

It will be important to continue periodic monitoring and further understanding of how and possibly why some species of predators fluctuate in abundance Sea otters and killer whales are possible candidates, and currently ecosystem trophic modeling may point towards one of these species as an important ecosystem component Possible cooperating agencies/programs USGS BRD, NMFS, USFWS, ADF&G

Appendix C 1 c Climate

To measure intensity and location of the winter Aleutian Low pressure system, wind speed and direction, air temperature and relative humidity at several key sites, precipitation and coastal freshwater input to the GOA Possible cooperating agencies/programs the National Oceanic and Atmospheric Administration (NOAA) (buoy system, National Weather Service), National Center for Atmospheric Research, USGS coastal stream gauge data, use of existing local precipitation and air temperature records

Appendix C 1 d Physical Oceanography

To measure strength, location and variation of Alaska Current, Alaska Stream and Alaska Coastal Current at key sites, variation in the circulation of Prince William Sound and lower Cook Inlet (including eddy formation), the upwelling index along the whole gulf coast, synoptic sea surface temperatures periodically throughout the study area and salinity/temperature/density profiles or sections to depth at selected sites Possible cooperating agencies/programs NOAA (Coastal Ocean Program, Ocean Carrying Capacity program), Fisheries Oceanography Investigations (FOCI), buoy data, Coastwatch Remote Sensing Program, National Science Foundation Snow and Ice Data Center, Canadian GLOBEC, US GLOBEC, UAF (GAK line), MMS

Appendix C 1 e Chemical Oceanography

To measure NO_3, PO_4 and iron concentrations and selected tracers (e g , isotope tracers) at key locations and times in the GOA, on the shelf and in Cook Inlet and Prince William Sound Possible cooperating agencies/programs UAF

To measure concentrations of PCBs, DDT and other persistent organic chemicals in mussels and tissues of apex predators Possible cooperating agencies/programs NOAA National Status and Trends Program–Mussel Watch, NMFS Seattle Laboratory, Prince William Sound and Cook Inlet RCACs

Appendix C 1 f Biological Oceanography

To characterize chlorophyll-a (continuous) and primary productivity at key sites in the gulf, on the shelf, in Prince William Sound and Cook Inlet, to obtain synoptic views of sea surface chlorophyll-a Possible cooperating agencies/programs NOAA/NMFS (FOCI, Coast Watch), Department of Fisheries and Oceans (DFO) Canada, National Aeronautics and Space Administration (NASA), UAF, Prince William Sound Aquaculture Corporation (PWSAC)

To measure zooplankton settled volume at inshore sites within Prince William Sound, Cook Inlet and Kodiak, and zooplankton hydroacoustic biomass and net plankton on the shelf and adjacent waters at key times Collections are expected to include icthyoplankton and larvae of important macroinvertebrates Sample subsets to be analyzed for species composition Periodic modeling of bloom dynamics Possible cooperating agencies/programs PWSAC, US GLOBEC, Canadian GLOBEC

Appendix C 1 g Nekton Including Forage Fish

To make estimates of biomass and species composition by hydroacoustic and net sampling on the shelf and within Prince William Sound and Cook Inlet at key sites and times Possible cooperating agencies/programs US GLOBEC, UAF, FOCI, NOAA/NMFS

To monitor halibut and Pacific cod stomach contents in Cook Inlet and other possible regions, seabird diets in Prince William Sound and Cook Inlet (summer), juvenile herring in Prince William Sound Conduct hydroacoustic and net sampling at key shelf sites Develop an index of species composition and relative species composition and relative abundance of forage fishes Measure carbon and nitrogen stable isotopes and fatty acids of herring and other forage fish on shelf and in Prince William Sound and Cook Inlet Perform biophysical modeling to help predict herring and pollock stock composition and size Possible cooperating agencies/programs ADF&G, NOAA/NMFS, MMS

To obtain commercial catch statistics and stock assessment data for salmon, herring, pollock, sablefish, Pacific cod, rockfish, and other species, including crabs and shrimp, in Prince William Sound, Kodiak, and Cook Inlet When available, supplement with additional data from sport and subsistence harvests Possible cooperating agencies/programs ADF&G, NOAA/NMFS

Appendix C 1 h Resource Consumption

To monitor harvest levels of all species including incidental take (by-catch) and removals of species by human activities such as timber harvest, land development, and point and non-point source pollution Provide information supportive of resource management agencies' actions Possible cooperating agencies/programs ADF&G, Alaska Department of Natural Resources (ADNR), Alaska Department of Transportation (ADOT), U S Environmental Protection Agency (EPA), NMFS

Appendix C 1 i Habitat Degradation

To monitor indicators of human use including proportion of lands and waters in productive habitats out of total land and water bases, extent of habitat fragmentation as measured by condition of migration corridors, number of miles of roads, and human population density Provide information supportive of resource management agencies' actions Possible cooperating agencies/programs Alaska Department of Environmental Conservation (ADEC), ADF&G, ADNR, ADOT, EPA, NOAA, USGS, USFWS, U S Forest Service (USFS)

Appendix C 1 j Pollution

To monitor indicators of human use including water quality (salinity, dissolved oxygen, pH, bacteria levels), harmful algal blooms, PSP, amnesiac shellfish poisoning (ASP), and point source (e g , organochlorines, heavy metals) and non-point source (e g , temperature, turbidity) pollutants Relate trends in indicators to ecosystem functioning and health, and correct for the effects of climate Provide information supportive of resource management agencies' actions Possible cooperating agencies/programs ADEC, ADF&G, ADNR, ADOT, EPA, NOAA, USGS, USFWS, USFS

Appendix C 2 Scientific Questions

In the context of the conceptual foundation described in Section IV and the preliminary long-term monitoring areas of interest above, the following scientific questions are meant to capture some of the main uncertainties in how fluctuations in the GOA ecosystem influence the distribution and abundance of valued organisms The questions do not attempt to capture the entire scope of potential monitoring and research projects, but rather, they address discrete aspects of the conceptual foundation and are related to one another There are other questions that could be posed and other ways to frame the uncertainties, so this should be considered an initial effort

Appendix C 2 a 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 onshore-offshore 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?

Appendix C 2 b 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 Prince William Sound, 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 Prince William Sound, 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?

h What are the relative contributions of the net plankton, microheterotrophs, and bacteria in the overall energy budget of the ecosystem?

i 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?

Appendix C 2 c 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?

i 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?

Appendix C 2 d Benthic and Intertidal Communities

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?

Appendix C 2 e 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?

Appendix C 2 f Anthropogenic and Natural Contaminants

a What are the concentrations of bioaccumulated anthropogenic chemicals in the coastal and shelf organisms?

b What is the loss rate of residual *Exxon 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?

Appendix D Acronyms and Links

ABC Acceptable Biological Catch
AC Alaska Current
ACC Alaska Coastal Current
ADCED Alaska Department of Community and Economic Development
ADEC Alaska Department of Environmental Conservation
ADF&G Alaska Department of Fish and Game
Division of Commercial Fisheries http //www cf adfg state ak us/cf_home htm
Division of Habitat http //www state ak us/local/akpages/FISH GAME/habitat/habhome htm
Division of Subsistence http //www state ak us/local/akpages/FISH GAME/subsist/subhome htm
Division of Sport Fish http //www state ak us/local/akpages/FISH GAME/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 Alaska Department of Transportation
AEPS Arctic Environmental Protection Strategy
http //arcticcircle uconn edu/NatResources/aeps html
AMAP Arctic Monitoring and Assessment Programme
http //www amap no/
AMMTAP Alaska Marine Mammals Tissue Archival Project
AMNWR Alaska Maritime National Wildlife Refuge
APEX Alaska Predator Ecosystem Experiment
ARLIS Alaska Resources Library and Information Service
ARMRB Alaska Regional Marine Research Board
ARMRP Alaska Regional Marine Research Plan
ASP Amnesiac Shellfish Poisoning
ATV All terrain vehicle
AVSP Alaska Visitor Statistics Program
AWQ Division of Air and Water Quality, ADEC
BRD Biological Resources Division
CCF One hundred cubic feet
CDQ Community Development Quota
CIRCAC Cook Inlet Regional Citizens Advisory Council
CIFAR Cooperative Institute for Arctic Research
http //www cifar uaf edu/fisheries html
CIIMMS Cook Inlet Information Management and Monitoring System
http //www dnr state ak us/ssd/ciimms/ciimms_sum2 html
C-MAN Coastal Marine Automated Network
COADS Comprehensive Ocean-Atmosphere Data Set
http //www cdc noaa gov/coads
COP Coastal Ocean Program
CTD Conductivity temperature versus depth
CRIS Court Registry Investment System
CRP Comprehensive Rationalization Program
CSCOR Center for Sponsored Coastal Ocean Research
CVOA Catcher Vessel Operational Area

DDE Dichlorodiphenyldichloroethylene
DDT Dichlorodiphenyltrichloroethane
DFO Department of Fisheries and Oceans, Canada
DOI U S Department of the Interior
EA/RIR Environmental Assessment/Regulatory Impact Review
EEZ Exclusive Economic Zone
EFH Essential Fish Habitat
EMAP Environmental Monitoring and Assessment Program
ENSO El Nino Southern Oscillation
EPA U S Environmental Protection Agency
EVOS *Exxon Valdez* Oil Spill
http //www oilspill state ak us html
Bibliography http //www oilspill state ak us/Biblio/biblio htm
Final and Annual Reports http //www oilspill state ak us/reports/clusters htm
FMP Fishery Management Plan
FOCI Fisheries Oceanography Investigations
http //rho pmel noaa gov/card/long/home_page html
FY Fiscal Year
GAK Gulf of Alaska
GEM Gulf Ecosystem Monitoring
GHL Guideline Harvest Level
GLOBE Global Learning and Observations to Benefit the Environment
GLOBEC Global Climate Change
http //www ccpo odu edu/Research/globec_menu html
GOA Gulf of Alaska
GOOS Global Ocean Observing System
http //www gos udel edu
HAPC Habitat Areas of Particular Concern
IARC International Arctic Research Center, University of Alaska
http //www iarc uaf edu/
IBQ Individual Bycatch Quota
IFQ Individual Fishing Quota
IGBP International Geosphere-Biosphere Programme
http //www igbp kva se/
IMS Institute of Marine Science, University of Alaska
INPFC International North Pacific Fisheries Commission
http //www npafc org/inpfc/inpfc html
IOC Intergovernmental Oceanographic Commission
http //ioc unesco org/iyo/
IPHC International Pacific Halibut Commission
http //www iphc washington edu/
IPSFC International Pacific Salmon Fishing Commission
IRFA Initial Regulatory Flexibility Analysis
IRIU Improved Retention/Improved Utilization
ITAC Initial Total Allowable Catch
JGOFS Joint Global Ocean Flux Study
http //ads smr uib no/jgofs/jgofs htm
Kachemak Bay Ecological Characterization study
http //www state ak us/adfg/habitat/geninfo/nerr/kbec/index htm

KRSA Kenai River Sportfishing Association
LAMP Local Area Management Plan
LLP License Limitation Program
MBF One thousand board feet
MMPA Marine Mammal Protection Act
MMS Minerals Management Service
NPS National Park Service
MSFCMA Magnuson-Stevens Fishery Conservation and Management Act
MRB Maximum Retainable Bycatch
MSY Maximum Sustainable Yield
mt Metric tons
National Status and Trends Program
http //ccmaserver nos noaa gov/NSandT/New_NSandT html
NASA National Aeronautics and Space Administration
NAWQA National Water Quality Assessment Program
NCAR National Center for Atmospheric Research
NCDC National Climate Data Center
http //www ncdc noaa gov/
NERR National Estuarine Research Reserve
NESDIS National Environmental Satellite, Data, and Information Service
NIST National Institute of Standards and Technology
http //www nist gov/
NMFS National Marine Fisheries Service
http //www nmfs gov/
National Marine Mammal Health and Stranding Response Program
http //www nmfs gov/prot_res/overview/mmhealth html
NOAA National Oceanic and Atmospheric Administration
NODC National Oceanographic Data Center
http //www nodc noaa gov
NOS National Ocean Service
http //www nos noaa gov/
NPAFC North Pacific Anadromous Fish Commission
http //www npafc org
http //www pac dfo-mpo gc ca/sci/pbs/pages/NPAFC htm
NPFMC North Pacific Fishery Management Council
NPDES National Pollution Discharge Elimination System
NPO North Pacific Oscillation
NRC National Research Council
NSF National Science Foundation
NVP Nearshore Vertebrate Predator project
NWS National Weather Service
http //www nws noaa gov/
OAR Oceanic and Atmospheric Research
http //oar noaa gov/
OCC Ocean Carrying Capacity
OCSEAP Outer Continental Shelf Environmental Assessment Program
OPA 90 Oil Pollution Act of 1990
OPR Office of Protected Resources
http //www nmfs gov/prot_res/prot_res html

OY Optimum yield
PAG Public Advisory Group
PAH Polyaromatic hydrocarbons
PCB Polychlorinated biphenyls
PDO Pacific Decadal Oscillation
PICES North Pacific Marine Science Organization (not an acronym)
http //pices ios bc ca/
PICES Technical Committee on Data Exchange http //pices ios bc ca/data
PICES Data Bases http //pices ios bc ca/data/weblist/weblist htm
PMEL Pacific Marine Environmental Laboratory
http //www pmel noaa gov/
PMEL Bering Sea and North Pacific Ocean Theme Page www pmel noaa gov/bering
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 psmfc org/rmpc
PSP Paralytic Shellfish Poisoning
PWS Prince William Sound
PWSAC Prince William Sound Aquaculture Corporation
PWSRCAC Prince William Sound Regional Citizens Advisory Council
RACE Resource Assessment and Community Ecology
RCAC Regional Citizens Advisory Council
RCRA Resource Conservation and Recovery Act
SAFE Stock Assessment and Fishery Evaluation Document
SEA Sound Ecosystem Assessment
SG Sea Grant
http //www nsgo seagrant org/
Specimen Banking Project
http //www nwfsc noaa gov/pubs/tm/tm16/tm16 htm
SSC Scientific and Statistical Committee
STAMP Seabird Tissue Archival Monitoring Project
TAC Total allowable catch
UAA University of Alaska, Anchorage
UAF University of Alaska, Fairbanks
UN United Nations
UNESCO United Nations Educational Social and Cultural Organization
http //ioc unesco org/iocweb/
USDA U S Department of Agriculture
USFS U S Forest Service
USGS U S Geological Survey
http //www usgs gov/
US GLOBEC U S Global Ocean Ecosystems Dynamics
http //cbl umces edu/fogarty/usglobec/
VBA Vessel Bycatch Accounting
VIP Vessel Incentive Program
WOCE World Ocean Circulation Experiment
http //www soc soton ac uk/OTHERS/woceipo/ipo html

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