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Exxon Valdez Oil Spill Trustee Council

645 G Street, Suite 401, Anchorage, AK 99501-3451 907/278-8012 fax:907/276-7178

MEMORANDUM

TO: Trustee Council Members

FROM: Molly McCammon
Executive Director

RE: Update on GEM Review and Development

DATE: April 7, 2000

NRC Review of GEM Science Program: If the April 5 review draft of the GEM Science Program meets with your approval at your meeting April 7, staff will spend the next week on proofreading, minor editing for improved readability, and final formatting. We plan to send the document to the National Research Council (NRC) about April 17. We have had lengthy discussions with the NRC about their review of this document. Our discussions have resulted in a revised review process and timetable that has three NRC committee meetings (tentatively May, September and November 2000) devoted to review of the draft GEM Science Program, with a peer-reviewed interim report to be delivered to the Trustee Council in February 2001. The committee would use the three meetings to gain an overview of the research and monitoring activities in the spill area to date, be briefed by interested parties in Alaska, and become sufficiently familiar with the content of the draft GEM Science Program to produce an interim report. I should note here that the revised proposal for the NRC still needs review, especially the budget.

NRC Review of GEM Research and Monitoring Plan: In order to begin implementation of GEM in FY 03 (October 1, 2002), we must have a draft Research and Monitoring (R&M) Plan delivered to the NRC in March 2001. The NRC review committee would meet on this plan in April and June of 2001. A final meeting/ report-writing workshop would be held in August 2001 to finalize conclusions and recommendations on both the R&M Plan and the overall GEM program. The final report would be peer-reviewed and delivered to the Trustee Council in November 2001. This would give us about two months to develop, review and approve the first GEM Invitation, scheduled to be issued February 15, 2002.

Development of GEM Research and Monitoring Plan: The Restoration Office is committed to developing a draft R&M Plan, with input from the public, scientists, communities, resource managers and others, by March 2001. The suggested process and timetable for developing the plan is outlined below. It would be most helpful if you and your staff could review this and get back to me by April 20 (the sooner the better) with any comments or suggested changes.

April-May 2000. Restoration Office staff produce first straw R&M Plan working from GEM Science Program, which includes database of existing projects and preliminary list of research and monitoring elements.

June-August 2000. Several focus groups composed of 12-15 scientists, agency managers, stakeholders and public review and comment on straw R&M Plan. Revise straw plan as needed. Also during this period:

PAG Briefing/Input	**July 20, 2000**
Trustee Council Briefing/Input	**August 3, 2000**

September 2000. Make draft R&M Plan available to public, including featuring it in an edition of the Restoration Update newsletter.

October 10-12, 2000. Hold EVOS Annual Workshop (in lieu of a January workshop). Theme will be to complete development of the R&M Plan in both plenary sessions and smaller work groups.

November-December 2000. Distribute draft R&M Plan for public review and comment. Revise plan as needed.

January 15, 2001. Trustee Council approve draft R&M Plan.

February 15, 2001. FY 02 Invitation released. May include GEM transition projects.

March 2001. Submit draft R&M Plan to NRC for review.

cc: Restoration Work Force
Bob Spies, Chief Scientist

mm/raw

Exxon Valdez Oil Spill Trustee Council

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FAX COVER SHEET

TO TRUSTEE COUNCIL MEMBERS

Dave Gibbons
Michele Brown
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also @ 202.208.1481
Frank Rue
Steven Pennoyer
Craig Tillery

FROM: Molly McCammon

DATE: April 6, 2000 TOTAL PAGES: 3

Please forward to the TC member in your office ASAP. This memo relates to the TC teleconference tomorrow.

Thank you

TRUSTEE COUNCIL ALTERNATES

Rob Bosworth
Dan Easton
✓Barry Roth
Bill Hines, Bruce Wright
Alex Swiderski

HARD COPY TO FOLLOW no

FAX SENT BY: Rebecca

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*** MULTI TRANSACTION REPORT ***
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GULF ECOSYSTEM MONITORING

A sentinel monitoring program

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

Review Draft

April 5, 2000

Circulation of this draft for the purposes of review is encouraged. Please direct comments by e-mail, gem@oilspill.state.ak.us, use the mailing address below or call 907-278-8012. Contents not for citation or attribution.

***Exxon Valdez* Oil Spill Trustee Council**

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Contents

EXECUTIVE SUMMARY

Still needs minor tweaking to reflect changes in rest of document

Notes

This document is the foundation for a research and monitoring plan that has yet to be written. The Trustee Council is one-third of the way through a three-year process of developing, reviewing and adopting a research and monitoring plan. Individual research projects to implement the future research and monitoring plan are not to be received by the Trustee Council until April of 2002, and the first implementation projects are to be funded by the Council no earlier than October of 2002.

added

The document is composed of four main sections plus supporting materials. Sections I describes the Gulf of Alaska region and the regional needs for the program. Section II contains the Trustee Council's vision for meeting regional needs, and 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. As such, Section IV attempts to be inclusive of all the biological and physical components of the Gulf of Alaska ecosystem.

Within the northern Gulf of Alaska, including Prince William Sound, Cook Inlet, Kodiak 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 Gulf of Alaska 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 part of the "lungs" of the planet for recycling of oxygen and carbon to and from the atmosphere, habitat for diverse populations of fish and shellfish, marine mammals and seabirds, and a source of beauty and inspiration for those who love nature. As a result of both human influences and natural processes, these important attributes are continually experiencing significant change.

Fifty-four percent of the state's 621,000 permanent residents live within the geographic area of the northern Gulf of Alaska and the nearby population center of the greater Anchorage area. Most of the more than one million tourists that travel to the state visit this region each year. The private sector economy of Alaska depends heavily on extraction of natural resources from this region, primarily petroleum, followed in descending order by fish and shellfish, minerals, and agricultural products, including timber. Crude oil and fuel tanker traffic, increasing tourism and recreational use, expanded road building, and increased commercial and sport fishing pressure are all human activities that could affect the marine resources and ecosystem of the northern Gulf of Alaska. 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 Gulf of Alaska have undergone major changes, especially since the late 1970s. Salmon catches of all species, and especially 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 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 Gulf of Alaska have declined since about 1977, whereas species and populations having access to offshore gulf habitats have generally increased.

> "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."

Understanding the sources of these changes, whether natural or influenced by human activities, requires a solid historical context. This has certainly been the lesson of the 1989 *Exxon Valdez* oil spill, a large-scale ecological disaster, with 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 *Exxon Valdez* Oil Spill 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 Gulf of Alaska.

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 Gulf of Alaska 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.

Obviously 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 in 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 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 Gulf of Alaska. GEM instead, will be focused to a large extent, on key species and ecological processes in the system. These 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 basis for production. 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 then build a matrix of who is monitoring what, where, and when and identify gaps in monitoring these things that are important to us. GEM will fill 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 purposes.

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 the GEM program. 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 Gulf of Alaska ecosystem. One approach is through the use of models, as well as periodic "State of the Gulf" and "State of the North Pacific" workshops, reports and a GEM website. The Trustee Council is committed to public input and outreach as vital components of the long-term GEM program.

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. Knowledge and experience gained during ten years of biological and physical studies on the aftermath of the *Exxon Valdez* oil spill 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 research fund is expected to be in place and functioning by October 2002. The fund 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 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 that would 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 the 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 Gulf of Alaska (Figure 1) and their relationships to one another and the physical environment. Even more important than the science so far assembled may be the improved understanding of the magnitude of our ignorance of physical and biological systems. Today, more than ten years after the *Exxon Valdez* oil spill, although it is reasonably clear that some of the injured natural resources and the services that depend on them have not fully recovered, the fate of others is still not known (Table 1). Of the twenty-six resources and three services reviewed by the Trustee Council in March 1999, only two were categorized as clearly "recovered," while six 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 valued natural resources. Studies are underway to learn more about cutthroat trout, Dolly Varden, Kittlitz's murrelets, and rockfish {EVOSTC 1999 #1400}.

The main concerns about 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

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		
	Pacific Herring		
	Pink Salmon		
	Sea Otter		
	Sediments		
	Sockeye Salmon		
	Subtidal communities		

Injured Services

Injured services condiered to be recovering: Commercial fishing, Passive use, Recreation and tourism, and Subsistence

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

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 losses 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. 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.

As the Trustee Council moves from the restoration program to the Gulf Ecosystem Monitoring program, studies of lingering oil spill injury and recovery will be drawn to a

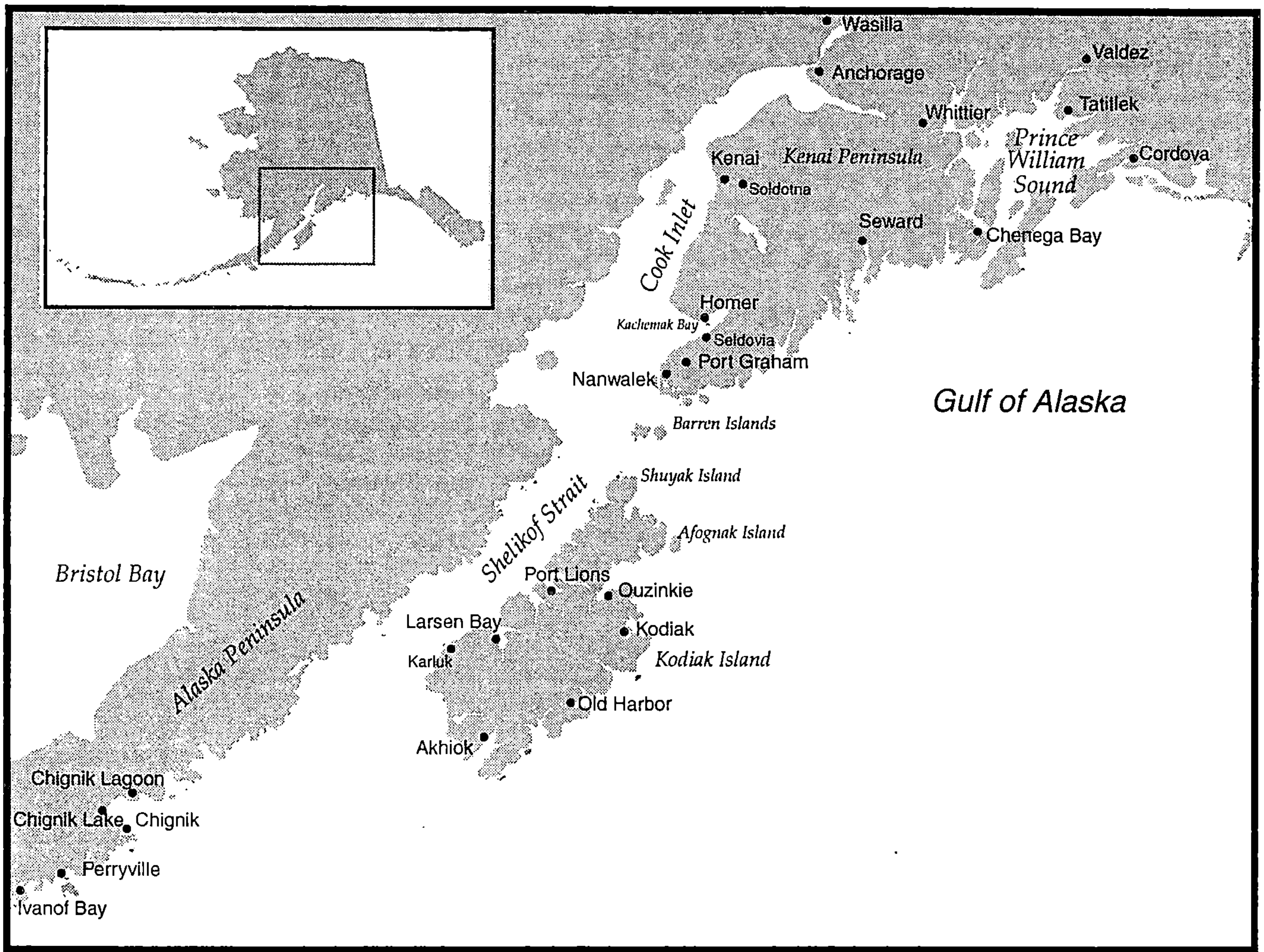

Figure 1. Map of the oil spill area showing the location of communities.

conclusion in the near-term, to be increasingly replaced by long-term environmental monitoring and studies of ecosystem. Studies that permit integration of 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 data provided by long-term environmental monitoring provided by many programs, including GEM.

I. B. Background

On March 24, 1989, the *T/V Exxon Valdez* ran aground on Bligh Reef in Prince William Sound, Alaska, spilling almost eleven 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. The 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 separate and related damage assessment studies.

In 1991 Exxon 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). Under the court-approved terms of the settlement, the *Exxon Valdez* Oil Spill 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, which was adopted by the Trustee Council in 1994. In its Restoration Plan {EVOSTC 1994 #1380}, 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 2001-02. 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 primarily 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 rearing in Prince William Sound. SEA has provided new insights into ocean currents, nutrients, mixing, 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 2001-02 will be to continue monitoring the recovery status of species injured by the oil spill, research factors that may be persisting 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 have also been conducted on key individual species injured by the oil spill. The 1994 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.

As an example, 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 Prince William Sound. 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 Prince William Sound 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. 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 Prince William Sound. Increased biomasses of herring were identified in 1997 and 1998. However, the population has yet to recruit a highly successful 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).

Over $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 is for the period 1990-98, indicates 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, more than three hundred articles had been published in scientific journals in the United States and all over the world, numerous theses and dissertations had been prepared, and hundreds of project reports had been compiled.

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 important for restoration of injured resources. Many species injured by the oil spill nest, feed, molt, winter, and seek shelter in the habitat 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 the 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.

I. C. Socioeconomic Profile

Within the area 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 residents and seasonal transients are relatively small compared to the millions of people outside the Gulf of Alaska 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 Gulf of Alaska 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. Prince William Sound

Prince William Sound lies to the north of the Gulf of Alaska and to the west of Cordova. About 7,000 people live in the Prince William Sound area. The largest communities in Prince William Sound — Cordova, Valdez and Whittier — are all coastal and predominantly non-Native, although Valdez and Cordova are home to Native Village corporations and tribes. Chenega Bay and Tatitlek are 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 Prince William Sound 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 on the banks of Prince William Sound, north of Seward, which is just outside the Sound. A road scheduled for completion in 2000 will allow cars to drive directly to Whittier. Since Whittier is much closer by road to Anchorage than Valdez or Seward, automobile access undoubtedly means increased human use of Prince William Sound.

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. 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. The Prince William Sound Science Center and its Oil Spill Recovery Institute provide a base for scientific research in Cordova. Large oil tankers routinely traverse Prince William Sound and the northern Gulf of Alaska 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 Gulf of Alaska separates Cook Inlet from Prince William Sound. The central peninsula is on the main road system, so much of it is only a few hours by car from the major population centers of Anchorage and Wasilla. About 49,000 people live on the Kenai Peninsula. About two-thirds of the region's population live in the central part of the Kenai Peninsula in the vicinity of 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 groundfish species such as halibut. Marine sports fishing is a major attraction for the tourist industry in Kenai, Seward, and especially in Homer.

The southern Kenai Peninsula contains the cities of Homer and Seldovia and the 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 nearby the western entrance of Prince William Sound. 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 by the Seward Highway and from Kenai, Soldotna and Homer by the Sterling Highway. 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 UAF. Also 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 Corporation operates a State-owned hatchery that produces clams and scallops for a growing aquaculture industry in Prince William Sound and southeastern Alaska.

I. C. 3. Kodiak Island archipelago

The Kodiak Island archipelago lies to the west of the northern Gulf of Alaska. This region includes the city of Kodiak and the six 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 it has long been among the largest ports in the nation for seafood volume or value of landings. Residents of the 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. Commercial timber harvest occurs on Afognak Island, which is north of Kodiak Island. The U.S. Coast Guard Station near Kodiak is a major landowner and employer.

Kodiak also has marine research and fisheries-related facilities. The National Marine Fisheries Service (NMFS) maintains a research facility, 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 maintains support facilities on Kodiak for its many monitoring and research programs on fish and shellfish in the Kodiak and Alaska Peninsula region.

I. C. 4. Alaska Peninsula

The Alaska Peninsula lies to the far west of the northern Gulf of Alaska. 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 a regional salmon-fishing center, while Dutch Harbor, southwest of Perryville and somewhat outside the spill area, is a major center for crab and marine fish. 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 Native. Subsistence on fish and caribou is important to the people who live in Chignik and Chignik Lagoon.

Chignik Lake, Ivanof Bay and Perryville are predominantly 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 at 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, bear, and porcupine.

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 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 resource, 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–Prince William Sound and Cook Inlet. Crude oil pumped from fields on the North Slope has been 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 Prince William Sound. 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, tide, 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 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 disease and resulting closures have devastated the herring fishery.

Within the oil spill area, there are major commercial fisheries on sockeye salmon, pink salmon and Pacific herring. The oil spill area includes portions of the commercial fishing districts of Prince William Sound, Cook Inlet, Kodiak and Chignik. The species fished and the gear type 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 Prince William Sound, 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 Prince William Sound is significantly increased by hatchery sales fish from private nonprofit hatcheries. However, since the spill the earnings of salmon seine fishermen in Prince William Sound 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 Prince William Sound declined from 255 in 1988 to 149 in 1998. The number of salmon gillnetters in Prince William Sound has remained at about 500 over the same period.

Significant commercial sockeye salmon fisheries occur in the Upper Cook Inlet and the Chignik area. The Copper River also supports a major commercial salmon fishery. Although the Copper River is outside of the spill area, it flows into the northern Gulf of Alaska 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 sac, or ovary, 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 Prince William Sound and Cook Inlet was worth about $14 million. However, the Pacific herring fishery in Prince William Sound was closed in 1993 due to a disease outbreak. 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 cancelled.

Seafood processing in the spill area has also 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 — this section added

Salmon hatcheries on the Gulf of Alaska 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 populations. The degree to which the salmon harvests of the Gulf of Alaska depend on hatchery production is also remarkable.

Substantial production of salmon occurs from hatcheries in three areas within the northern Gulf of Alaska, Cook Inlet, Kodiak, and Prince William Sound. In addition, salmon hatchery production has a number of 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 salmonids 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.

Within the northern Gulf of Alaska, Cook Inlet, Kodiak, and Prince William Sound, 56% of the number of 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 in northern Gulf common property salmon harvests were of hatchery origin in 1999. Of the total number of salmon in the State of Alaska common property harvest throughout the Gulf of Alaska in 1999, 25% were estimated to have been of hatchery origin.

Hatchery production of salmon in Prince William Sound 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, by number. 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 #1450}.

added

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. Three-quarters of the pink salmon, 5% of the coho and 12% of the sockeye harvested on the common property fisheries of Cook Inlet in 1999 were from enhancement programs.

Salmon hatcheries in Kodiak produce largely pink salmon, but they also produce chinook, sockeye, coho and chum. Twenty-nine percent of the total number of salmon commercially harvested in Kodiak in 1999 were enhanced fish. Enhanced pink salmon were 34%, enhanced coho were 39%, enhanced sockeye were 18%, and enhanced chum were 15.4% of the total commercial harvest in Kodiak waters in 1999.

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 Gulf of Alaska 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 Prince William Sound {Eggers, Peltz, et al. 1991 #1410}. Other studies have cast doubt on the extent and consequences of the interaction between hatchery and wild pink salmon in Prince William Sound ({Kron 1995 #1420}; {Smoker & Linley 1997 #1430}; {Smoker, Bachen, et al. in press #1440}). 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 Gulf of Alaska 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. The average annual rate of increase over this period was 5%. Between 1990 and 1997, 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 be open for vehicle traffic. The tunnel will improve access to Prince William Sound 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. 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 Prince William Sound.

Charter halibut fishing is an important and growing recreational activity in the oil spill region. In 1998, about 84,000 people were saltwater charter clients 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 Prince William Sound, 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 by charter operations, lodges and outfitters may be contributing to localized depletion of halibut, the North Pacific Fisheries and Management Council recently set halibut charter guideline harvest levels in Southcentral Alaska as well as Southeast Alaska.

I. D. 4. Subsistence

Fifteen predominantly Alaska Native communities (with a total population of about 2,200 people) in the oil spill area rely heavily on harvests of subsistence resources such as fish, shellfish, seals, deer and waterfowl. Many families in other communities also rely on the subsistence resources of the spill area. 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 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 descreased 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 PSP (paralytic shellfish poisoning) in clams outweighed concerns about lingering hydrocarbon contamination from the oil spill.

I. D. 5. Logging

There are no major timber operations in Prince William Sound, but logging continues on Afognak Island. 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 regeneration effort on its land. Logging operations on Port Graham Corporation lands on the southern Kenai Peninsula have finished, 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 an 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. The timber harvest from these lands is estimated to be 125,000 MBF (one thousand board feet) of spruce and hemlock and 410 CCF (one hundred cubic feet) of birch, cottonwood and aspen.

I. D. 6. Small-scale Spills of Toxic Substances _ this section added

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. 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 the Alaska Department of Environmental Conservation 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.

added

Small spills have been caused by a variety of industries, such as the oil and gas industry, timber industry and 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 dedicated to protecting the Cook Inlet watershed.

I. D. 7. Roadbuilding and Urbanization – this section added

Changes in land surface 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. Recently, the Borough 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 from the Alaska Department of Environmental Conservation (ADEC), the Municipality of Anchorage is mapping the impervious surfaces within its area and studying the response of stream macroinvertebrates. Under an EPA 319 grant from ADEC, the USDA Cooperative Extension is also studying the effects of impervious surfaces. A pilot project is planned for the Anchorage area, but, if successful, the methodology may be applied to other areas in the future.

I. E. Global Climate Change

Global climate change is an essential context for development and implementation of the GEM program. Uncertainty over 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 global climate change and to understand its possible roles in biological production in the North Pacific has increased dramatically in the past decade. The climate of the North Pacific is known to change fairly sharply over periods of decades, centuries, and millennia, in concert with climatic processes in other parts of the world, such as the north Atlantic. Some of these changes have been correlated through time with sharp changes in production and relative abundance of species of sea birds, salmon and other fishes, marine mammals, shrimp and crabs (see Section IV). The timing of changes in climate also appear 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 start at the bottom of the food chain and work their way up.

Global climate change is important for understanding how humans impact biological production. Is global climate change solely responsible for the ups and downs of the animal populations humans use and manage? Long-term population declines are apparent in animal populations that depend on the ecosystems of the Gulf of Alaska (GOA) such as cormorants, kittiwakes, fur seals, Steller sea lions, harbor seals, red king crab, and sablefish, among others (see Section IV). Are these declines the result of bottom-up control forced by climate change, or 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, alteration of critical habitat and other human activities, or is it some complex interaction of both? Some populations that show long time trends, up or down, or sharp rapid changes in abundance, are actively managed through harvest restraints, such as fish (salmon, sablefish, pollock, halibut, arrow tooth flounder, Pacific Ocean perch) and marine mammals (seals, sea lions, whales, otters). 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 use and the requirement for sustainable use of natural resources are important concerns for designing GEM. In these contexts it is essential that GEM provide products that are relevant to the needs of resource managers, consumers, and conservationists. The growing demand for recreational, charter, commercial and subsistence harvests of fish and shellfish appears to be driven by growing human population (Section I.C), increasing tourism (Section I.C), and application of existing policy mandates.

Policy mandates for sustainable use of fisheries resources have long been clear, but the overall information required for implementation is rapidly increasing. The Constitution of Alaska (ca. 1959) and the federal Magnuson-Stevens Fisheries Conservation and Management Act (ca. 1976) (FCMA), provide the basic state-federal mandates for sustainable use. Experience over the last decade with an amended FCMA and application of the federal Endangered Species Act (ca. 1973) to marine birds, mammals and formerly commercially exploited fish species has 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 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 fishery management {NPFMC 1999 #600}.

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 increase. Virtually all living marine resources on the continental shelf off Alaska were most probably negatively impacted by international fishing fleets until about 1975. Impacts were not limited to species represented by catches, 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 twentieth 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-1970's and 1980's, steep declines have been noted in the Bering Sea and Gulf of Alaska in populations of fur seal, harbor seal, murres, kittiwakes, and the Aleutian Island pollock. Declines in Steller sea lion were serious enough for the species to be listed under the U.S. 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 understanding functioning of the ecosystem is the role of weather in driving production of marine species, which is known to be important, but poorly understood.

I. G. Marine Habitat Protection

The management and conservation of habitats in the marine environment is not well advanced compared to such efforts in terrestrial environments. For instance, in the oil-spill area the protection of about 650,000 acres of upland habitats by the Trustee Council is in addition to the protections available 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. Note that 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, the Alaska Peninsula and Aleutian Islands. Marine areas containing marine mammal feeding grounds and adjacent to haul-out areas have also been closed to commercial fishing in parts of the Bering Sea, Aleutian Islands and Gulf of Alaska. 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 even 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 Prince William Sound port of Whittier is expected to vastly increase public visitation to northwestern Prince William Sound. 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 and 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 could lead to changes in species composition and productivity in the 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 have indicated that amounts of oil in water that are much smaller than previously thought can accumulate to the point of damage in 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 the less sensitive locations.

Information may not be 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 restoration program'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 freshwater 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 Gulf of Alaska from centers of industry and human population might be expected to protect much of this region from deposition of environmental contaminants. However, there is evidence of wide geographic distribution of persistent organochlorines (DDT, DDE, PCB), organic pollutants and heavy metals in the Arctic and Subarctic regions {Crane & Galasso 1999 #1070}. Measurable amounts of organochlorines have been found in even apparently pristine areas such as the Copper River delta, which forms the eastern boundary of Prince William Sound. A variety of geophysical pathways to bring these materials into the Gulf of Alaska include 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 & Riebsell 2000 #1080} 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 EVOS revealed that some marine mammal-eating transient killer whales sampled in Prince William Sound 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 people 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 Alaskan Natives in coastal communities.

The information available on the distribution and concentrations of contaminants in the northern GOA is limited, as summarized in the Arctic Environmental Atlas {Crane & Galasso 1999 #1070}. 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.

The GEM projects that sample birds, fish or mammals may provide environmental agencies, such as the Alaska Department of Environmental Conservation (ADEC) and the U.S. Environmental Protection Agency (EPA), a relatively low cost means to acquire samples for contaminants testing. GEM may also contribute to coordination of tissue collection from the multitude of small and large sampling efforts on marine animals throughout the GOA which could enhance exisiting 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.

II. Vision for Gem and Northern Gulf of Alaska

II. A. Mission

The original mission of the Trustee Council adopted in 1994 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 1994 Restoration Plan, the mission of the Gulf Ecosystem Monitoring (GEM) program is to "sustain a healthy and biologically diverse marine ecosystem in the northern Gulf of Alaska 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 Gulf of Alaska monitoring and research activities through leveraging of funds, interagency coordination and partnerships; and involve stakeholders in local stewardship by guiding and carrying out the program."

II. B. Goals

GEM has five major programmatic goals in order to accomplish its mission of sustainable use of natural resources within a healthy ecosystem. 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.

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

IDENTIFY research and monitoring gaps currently not provided by existing programs;

LEVERAGE funds from other programs;

PRIORITIZE research and monitoring needs;

SYNTHESIZE research and monitoring to advise in setting priorities; and

TRACK work relevant to understanding biological production in GOA

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 Trustee Council's November 1994 Restoration Plan, the primary focus of the GEM program is within the oil-spill area, the northern GOA, including Prince William Sound, Cook Inlet, Kodiak 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 Gulf of Alaska 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 ecosystems, the Bering Sea and the Arctic Ocean. 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 occupy the habitats in and around the Arctic Ocean, Bering Sea, Gulf of Alaska, and North Pacific Ocean.

II. D. Funding potential

The intent of the Trustee Council is to fund the GEM program beginning in October 2002 with the funds allocated by the Trustee Council 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 {Miller, Frost, et al. 1984 #550} in the U.S. Treasury. However, recent Congressional action (PL 106-113, (1999)) now allows the funds to be invested in accounts outside the U.S. Treasury and CRIS. That change is expected to 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 five percent per annum. Given the past record of the stock market, investment returns of 18-20% and higher are typical. 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 earnings. Assuming a 3% inflation rate, $3.6 million would go towards inflation proofing, with $6 million available to spend. This investment scenario would allow for a stable program over time. The Trustee Council would also have the option of funding a more reduced 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 have the research fund established 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 and/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 were designated by the Governor of Alaska and the President 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, 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 have each appointed a representative in Alaska to serve on the Trustee Council. These 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 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 production."

It has been suggested that at some time in the future a new board or oversight structure could 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 would require changes in law and the applicable court decrees, and it is not anticipated in the near future. Any change in governance would need to be justified.

III. Structure and Approach

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, coordinates GEM efforts with other programs and funding sources, and encourages leveraging funds and developing strategic partnerships. GEMs 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 GEMs 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 3-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 exist or are in advanced stages of development. These models show great promise as a means of integrating large volumes of data in a way that yields 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 Prince William Sound 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 Prince William Sound 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 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 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 Research Organization, PICES. Because of the institutions represented on the 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 Gulf of Alaska. 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 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, Appendix Table 1). 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 Gulf of Alaska. 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 Gulf of Alaska ecosystem is 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 production.

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 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. The GEM process can then proceed to 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 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.

III. D. Shorter-term Focused Research

The long-term monitoring element 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 will likely be carried out.

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. There also may be need to carry out some general restoration projects that relate directly to restoration of oil spill injury.

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

Finally, 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 1400 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 1998b). 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. The 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. In press; 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 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 Native communities to provide advice and feedback to the Trustee Councils 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 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 on 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 GEMs 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 to not 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 process, 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 availability 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 5-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 03, 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 periodic State of the Gulf workshop at which the results during the previous cycle are discussed, information is integrated across disciplines, and future needs and opportunities are considered. Project investigators, selected peer reviewers, resource managers, stakeholders, and the public are invited to this meeting.

" A periodic *Invitation to Submit Proposals*, which will specify the types of proposals that are priorities for consideration in the coming fiscal period. Research proposals are envisioned to be of finite duration and to have short-term goals (e.g., 2-5 years). Monitoring projects will be evaluated and renewed on longer time scales (e.g., once every 5 years) and any given *Invitation* may or may not invite proposals for new or ongoing projects. The *Invitation*, however, 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 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 funds investments. A policy for how that amount will be calculated will be determined in the next year. 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 comment by independent peer reviewers, depending on need, the maturity of the project, and other factors. All final reports will be sent for outside 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 peer-reviewed literature are 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 System (ARLIS) at 907-272-7547. 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 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, we will then develop a draft data management plan and policy. A research project under Dr. Charles Falkenberg was initiated in FY 00 to deal with the data management issues issues described in this section. The fundamental aim of the 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 are 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 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 is probably appropriate that the makeup of the PAG be changed to increase the participation of other 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 Councils current Public Advisory Group is currently reviewing various options 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 in the past to promote and encourage public input and participation. These include newsletters, annual reports, public meetings in the spill-affected region, newspaper columns, a series of radio spots, and the Councils website at www.oilspill.state.ak.us.

Since the GEM program is envisioned as a much smaller program than the current *Exxon Valdez* Oil Spill restoration program, the cost of these outreach efforts has to be considered before decisions are made on which tools are the best to increase public input and participation. Additionally, the audiences vary widely and include the greater scientific community both in Alaska and outside the state, Native villages without internet access, high school and college students, fishermen, 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 (www.pmel.noaa.gov/bering), 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 Gulf of Alaska marine ecosystem. Another example of an effective tool for facilitating data exchange of data and research is the North Pacific Marine Science Organization, PICES web site, (http://pices.ios.bc.ca/data/weblist/weblist.htm).

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 the GEM program. As such, the background attempts to be inclusive of all the biological and physical components of the Gulf of Alaska ecosystem. Please note that it is not a list of projects to be implemented, nor is it a research and monitoring plan.

The first part of the scientific context is a description of a scientific record that spans two hundred and sixty years. Following this, the scientific information is organized into a conceptual foundation that states our current understandings 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.

added

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 #10}, was prepared under the U.S. Regional Marine Research Act of 1991. For all marine areas of Alaska, including the Gulf of Alaska, 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 5, since that is the ultimate goal of the three-year process of implementation to be completed by October 1, 2002. ARMRP program goals express the scientific needs of the region as of 1992, and they are still quite relevant to the GEM effort {ARMRB 1993 #10}:

◁ 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.

◁ 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. Concern over long-term declines in populations of high-profile species such as king and tanner crab, Steller sea lion, spectacled eider ducks, common murres, thick-billed murres, red-legged and black-legged kittiwakes {DOI-NOAA-ADF&G 1998b #190}. The vision of the federal-state regulatory agencies of the Bering Sea Ecosystem Research Plan {DOI-NOAA-ADF&G 1998a #180} is consistent with the mission statement of the Trustee Council (see 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." (1998a, p. 5). The basic concepts of the GEM program are also consistent with the overarching hypotheses of the Bering Sea Ecosystem Research Plan draft {DOI-NOAA-ADF&G 1998a #180}:

- 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 Ecosystem Research Plan {DOI-NOAA-ADF&G 1998a #180}, variability and mechanisms in the physical environment, individual species responses, food web dynamics, contaminants and other introductions are closely aligned with the basic mission established by the Trustee Council. Note that current research programs for the Bering Sea {DOI-NOAA-ADF&G 1997 #170} often overlap with the programs identified in our survey for the Gulf of Alaska (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 the need for basic ecological information in evaluating recovery of injured species early in the restoration program. 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 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, PhD dissertations and Master's theses. A current bibliography of publications sponsored by the *Exxon Valdez* Oil Spill Trustee Council is available on the web http://www.oilspill.state.ak.us/Biblio/biblio.htm or on request to the 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 interdisciplinary research programs, the scientific legacy of the Trustee Council includes information of interest to a wide range of interests. Topics covered by 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 Council projects by fiscal year, and a complete list of final and annual reports for projects are available on the web http://www.oilspill.state.ak.us/reports/clusters.htm or on request to the 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 Prince William Sound. 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 rearing in Prince William Sound. 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 project (NVP) 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 program has contributed to understanding of the linkages between terrestrial and marine ecosystems (see section IV.D) by studying key species at the interface of these systems. The APEX program 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 government information gathering programs of the Gulf of Alaska (Appendix B Appendix Table 1) 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).

Biological oceanography most often collects data on small plants and animals, the zooplankton and phytoplankton, and on primary productivity. Primary productivity, often measured as grams of carbon fixed per unit area per unit time, is a basic measure of biological activity. Notably absent are monitoring or assessment programs for large plants, such as kelp and other large marine algae. Sampling efforts for macrofauna are typically focused on the Gulf of Alaska or smaller areas, including Prince William Sound, Cook Inlet, Kodiak and the Alaskan Peninsula, whereas oceanography programs often include the Gulf of Alaska as part of a larger, often global program. ADF&G, Department of Interior and National Oceanic and Atmospheric Administration and its National Marine Fisheries Service, NOAA/NMFS are the primary monitoring agencies for the macrofauna. National Aeronautics and Space Administration, NASA and NOAA's National Ocean Service, NOS, National Environmental Satellite, Data, and Information Service, NESDIS (http://www.ngdc.noaa.gov/seg/hazard/resource/soc/sanesdis.html), National Weather Service, NWS, Oceanic and Atmospheric Research, and OAR (Fisheries Oceanography Investigations, FOCI) are the primary sources of oceanographic data.

The projects presented in Appendix B (Appendix Table 1) are actively collecting data. Inactive projects should be included in the future because they contain considerable valuable historical information relevant to the production of plants and animals in the Gulf of Alaska. A summary of the major programs conducted by the United States, State of Alaska, and transboundary organizations follows.

IV. B. 1. US Department of Commerce, National Oceanic and Atmospheric Administration

National Marine Fisheries Service (http://www.nmfs.gov/): Major programs include the triennial trawl surveys for groundfish, becoming biennial surveys beginning in 2001, annual longline surveys primarily for sablefish and rockfish, and the Ocean Carrying Capacity program in the Gulf of Alaska 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, near 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 fisheries mammals observer program, and the Cook Inlet beluga population survey. Offshore killer whale surveys in the Gulf of Alaska 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 (http://www.nmfs.gov/prot_res/prot_res.html) are cooperators with the U.S. Geological Survey (USGS) (http://www.usgs.gov/) (DOI) and the NIST (http://www.nist.gov/) in conducting the National Marine Mammal Health and Stranding Response Program (http://www.nmfs.gov/prot_res/overview/mmhealth.html) that will be discussed below under multiagency programs. Human uses are monitored through The Fisheries Statistics and Economics Division, which maintains US commercial and recreational fisheries statistical data, such as pounds and dollar value of commercial landings.

Oceanic and Atmospheric Research (http://oar.noaa.gov/): OAR is a complex of oceanographic and macrofauna monitoring and evaluation activities that involves NMFS and other NOAA personnel. The fisheries oceanography program (FOCI) (http://rho.pmel.noaa.gov/card/long/home_page.html) in the Pacific Marine Environmental Laboratory (PMEL) (http://www.pmel.noaa.gov/) in Seattle has an element in the Shelikof Strait, between Kodiak and the Alaska Peninsula. This and other Gulf of Alaska monitoring projects are conducted by the Resource Assessment and Community Ecology (RACE), a division of the Alaska Fisheries Science Center of NMFS. PMEL also conducts retrospective fisheries and oceanographic studies and is involved with Data Rescue.

OAR's Climate Diagnostics Center holds the Comprehensive Ocean-Atmosphere Data Set (COADS) (http://www.cdc.noaa.gov/coads) with surface marine data since 1854. OAR also houses Fisheries and Oceanography and Bering Sea Ecosystem Studies (CIFAR) (http://www.cifar.uaf.edu/fisheries.html) and Sea Grant {Tyler & Kruse 1996 #910} (http://www.nsgo.seagrant.org/). Some NOAA-sponsored US GLOBEC (http://cbl.umces.edu/fogarty/usglobec/) projects work through CIFAR on funding originating in NOS (http://www.nos.noaa.gov/). Both CIFAR and SG support research projects at universities.

National Ocean Service: In cooperation with the National Science Foundation, NOS supports oceanographic research in the Gulf of Alaska, 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 (http://www.state.ak.us/adfg/habitat/geninfo/nerr/kbec/index.htm). NOS also conducts the National Status and Trends Program (http://ccmaserver.nos.noaa.gov/NSandT/New_NSandT.html) which currently includes Gulf of Alaska samples in the Mussel Watch contaminants project and which formerly included the Benthic Surveillance Project in Alaska (http://www.nwfsc.noaa.gov/pubs/tm/tm16/tm16.htm). Specimens are held in the Specimen Banking Project at the National Institute of Standards and Technology (NIST see below).

National Environmental Satellite, Data, and Information Service: NESDIS holds most of the historical information gathered by NOAA agencies, and current satellite oceanographic, buoy data, and sea ice information. Much of the information is stored at the National Oceanographic Data Center (NODC) (http://www.nodc.noaa.gov) and the National Climate Data Center (NCDC) (http://www.ncdc.noaa.gov/). NODC and NCDC cooperate with NASA, the National Weather Service (NWS) (http://www.nws.noaa.gov/), 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 that uses ships of opportunity to collect global weather and meteorological data (see Global Climate Change Research section IV.B.6 below).

National Weather Service: 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 Gulf of Alaska include the Moored Buoy Program and the Coastal Marine Automated Network (C-MAN).

National Institute of Standards and Technology: The NIST cooperates with USGS, NMFS, and OPR with the National Biomonitoring Specimen Bank.

IV. B. 2. State of Alaska

Alaska Department of Environmental Conservation: 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 permittee 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 EPA. ADEC has awarded EPA 319 funds for 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 the 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/Monitoring System, CIIMMS (http://www.dnr.state.ak.us/ssd/ciimms/ciimms_sum2.html), is a project, funded by the Exxon Valdez Oil Spill 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 Alaskan commercially harvested shellfish beaches and shellfish farms for paralytic shellfish poisoning (PSP). The Division also monitors PSP in king crab in Prince William Sound and in Dungeness crab and tanner crab in Prince William Sound, 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: The Division of Commercial Fisheries of ADF&G (http://www.cf.adfg.state.ak.us/cf_home.htm) 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 Gulf of Alaska 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 Gulf of Alaska from southeastern 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 (http://www.pac.dfo-mpo.gc.ca/sci/pbs/pages/NPAFC.htm). The data permit 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.

ADF&G and cooperating regional aquaculture associations also collect some physical and biological oceanographic data, such as Kodiak near shore sea surface temperatures, Kitoi Bay {Eggers, Peltz, et al. 1991 #1410} zooplankton biomass, and Prince William

Sound zooplankton settled volumes. The ADF&G Subsistence Division's Whiskers (http://www.state.ak.us/local/akpages/FISH.GAME/subsist/subhome.htm) database on subsistence harvest of marine mammals is part of a larger NOAA sponsored program. In addition, Wildlife Conservation Division monitors harbor seals in cooperation with NMFS. ADF&G conducts port sampling of groundfish for information about the recreational effort, catch and harvest of rockfish, lingcod and halibut in the northern Gulf of Alaska. This project consists of catch sampling and angler interviews. ADF&G also collects data on subsistence fish and shellfish harvest. Note that most ADF&G marine programs serve to provide information to NOAA programs.

The Sport Fish Division (http://www.state.ak.us/local/akpages/FISH.GAME/sportf/sf_home.htm) conducts port sampling of groundfish for information about the recreational effort, catch and harvest of rockfish, lingcod and halibut in the northern Gulf of Alaska. This project consists of catch sampling and angler interviews. The Subsistence Division collects data on subsistence fish and shellfish harvest. The Habitat Division (http://www.state.ak.us/local/akpages/FISH.GAME/sportf/sf_home.htm) 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.

Alaska Department of Natural Resources (http://www.dnr.state.ak.us/): The Alaska Department of Natural Resources (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 (http://www.dnr.state.ak.us/parks) 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 (http://www.dnr.state.ak.us/mlw) 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 Economic and Community Development: 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 (AVSP)*.

Alaska Department of Health & Social Services: 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; *School of Fisheries and Ocean Sciences* {Piorkowski 1997 #1210}, *Sea Grant Program* {Piorkowski 1997 #1210}, *National Underwater Research Program* {Piorkowski 1997 #1210}, and the

Institute of Social and Economic Research {DOI-NOAA-ADF&G 1997 #170}. Two university units focused primarily on areas related to GEM are covered in more detail below.

Institute of Marine Science (University of Alaska, School of Fisheries and Ocean Sciences): Scientists associated with IMS have compiled much of the historical data relevant to the GEM project. IMS produced the comprehensive review {Rosenberg 1972 #1040} in preparation for the extensive and intensive environmental studies sponsored by the Minerals Management Service in the 1970's {Hood & Zimmerman 1986 #420}. The IMS maintains a historic database of oceanographic measurements from the Gulf of Alaska, and it currently operates the R/V Alpha Helix, a 133-foot research vessel, for the National Science Foundation.

International Arctic Research Center {Piorkowski 1997 #1210} http://www.iarc.uaf.edu/: 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. In the IARC Research Framework, while each of the eight themes is relevant to the GEM program (IARC 2000), four are most compelling: 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. US Department of the Interior

Fish and Wildlife Service (USFWS):The Alaska Maritime National Wildlife Refuge monitors 10 seabird colonies annually, four of which are in the Gulf of Alaska. The AMNWR also monitors other sites on a periodic basis largely dependent upon availability of funds.

Minerals Management Service: 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.

Geological Survey, Biological Resources Division: 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 1970's BRD has an extensive seabird monitoring project at Middleton Island, the MI 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, Butman, et al. 1998 #320}.

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

The National Science Foundation is an independent U.S. federal 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. Within the Polar Research Program area, the Office of Polar Programs disciplinary programs include atmospheric sciences, biological sciences, earth sciences, glaciology, ocean sciences, and social sciences. The Geosciences program area includes atmospheric and ocean sciences. The Biology program area contains a large number of disciplinary programs of potential interest to GEM.

IV. B. 5. Environmental Protection Agency

U.S. Environmental Protection Agency is an independent agency of the U.S. federal government. The mission of the EPA 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 (NRC 1995). The EMAP program is of interest because it 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 NRC (NRC 1995) is also relevant to GEM.

In addition, EPA 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. US Forest Service

The 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 Forest Service conducts occasional surveys of recreational use in Prince William Sound. These surveys are not conducted on a regular basis and are therefore not intended to serve as a long-term monitoring instrument. The US Forest Service also reports on use of campgrounds, visitor centers and other facilities operated by the agency in the Gulf of Alaska region. The Forest Service has extensive experience in watershed analysis and planning for ecosystem-based management {USFS 1997 #1390}. 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 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 Prince William Sound. The Cook Inlet Regional Citizens Advisory Council (RCAC) monitors the environmental impacts of terminals and tankers. The Cook Inlet RCAC's environmental monitoring program includes studies of sediment chemistry, hydrocarbon accumulation, sediment toxicity and ballast water issues. The Prince William Sound Regional Citizens Advisory Council (RCAC) has conducted an environmental monitoring program for the past six years. The Long-Term Environmental Monitoring Project monitors nine sites in Prince William Sound and the Gulf of Alaska 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 #1200}, combustion sources (pyrogenic) and petroleum products or residues from natural coal deposits (petrogenic) hydrocarbons. The Prince William Sound RCAC 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 sampling at the Valdez Marine Terminal and a pilot study on 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, and conductance, bacteria oxidation-reduction potential, macroinvertebrates, ortho-phosphate, apparent color and nitrate-nitrogen.

Kenai River Sportsfishing Association 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 fish management agencies, and volunteers to stabilize and re-vegetate 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 (http://pices.ios.bc.ca/), was established in 1992 among Canada, People's Republic of China, Japan, Republic of Korea, Russian Federation, and the United States of America. 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 (http://pices.ios.bc.ca/data). The long time series data set is a compilation of voluntary submissions from data sources, and it is therefore not exhaustive.

The International Pacific Halibut Commission, IPHC (http://www.iphc.washington.edu/), was the first multinational fishery management organization in the North Pacific. The United States and Canada established it 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, and 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 (http://www.psc.org/Index.htm) {Emery & Hamilton 1985 #210}, 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) (http://www.npafc.org/inpfc/inpfc.html) and its successor, the North Pacific Anadromous Fish Commission, NPAFC (1993) (http://www.npafc.org/) coordinates research and harvest of salmon and other andromous species above latitude 33° N outside the 200-mile zones of the signatories. Signatory nations are the U.S., 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.

Arctic Monitoring and Assessment Programme, AMAP, is an international circumpolar program which seeks to monitor anthropogenic pollutants in all parts of the Arctic environment (http://www.amap.no/). Observations extend into the Bering Sea, but not into the Gulf of Alaska as yet. The nations of Canada, Denmark/Greenland, Iceland, Norway, Sweden, the Soviet Union, and the United States entered into the 'Rovaniemi process' that promotes arctic environmental protection in 1989 at a meeting in Rovaniemi, Finland. 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) (http://arcticcircle.uconn.edu/NatResources/aeps.html). 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 (http://www.psmfc.org/), 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 (http://www.psmfc.org/rmpc/) 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 Climate Change (GLOBEC) (http://www.ccpo.odu.edu/Research/globec_menu.html), World Ocean Circulation Experiment (WOCE) (http://www.soc.soton.ac.uk/OTHERS/woceipo/ipo.html), Joint Global Ocean Flux (JGFOS) (http://ads.smr.uib.no/jgofs/jgofs.htm), and Global Ocean Observing System (GOOS) (http://www.gos.udel.edu/) each rely on the personnel, facilities and finances of the nations and organizations that participate in the transboundary organizations described above in the section on transboundary organizations.

GLOBEC is the global change program of the International Geosphere-Biosphere Programme (IGBP) (http://www.igbp.kva.se/) 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 depends on cross-shelf import of large zooplankton from offshore to nearshore waters (see also section IV. D.2.b). 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 Gulf of Alaska. Another part of IGBP is the Joint Global Ocean Flux (JGFOS), 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) (http://ioc.unesco.org/iyo/) of United Nations Educational Social and Cultural Organization, UNESCO (http://ioc.unesco.org/iocweb/), 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 Metorological 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.

This whole section has been reorganized, starting with a description of the GOA ecosystem

IV. C. The Gulf of Alaska Ecosystem

added

The basic scientific information relevant to GEM crosses a number of disciplinary boundaries. Although roughly organized into meteorology, oceanography and biology, naming these basic areas of scientific study does not exclude others. Disciplines such 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 written scientific literature were first taken in the Gulf of Alaska about 1741. Accounts of exploration in the mid- to late eighteenth 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 {Rosenberg 1972 #1040}{Hood & Zimmerman 1986 #420}{Francis, Hare, et al. 1998 #280}. 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. D.W. & Batten 2000 #1480}).

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

IV. C. 1. The Gulf of Alaska

The Gulf of Alaska, GOA, encompasses watersheds and waters south and east of the of the Alaskan Peninsula from Great Sitkin Island (176 W), North of 52 N to the Canadian mainland on Queen Charlotte Sound (127 30 W). Twelve and a half percent of the continental shelf of the U.S. lies within GOA waters (Hood 1986).

The area of the GOA directly affected by the *Exxon Valdez* oil spill encompasses a broad diversity of terrestrial and aquatic environments (GOA ecosystem, Figure 4). 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.

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 to 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 5). 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

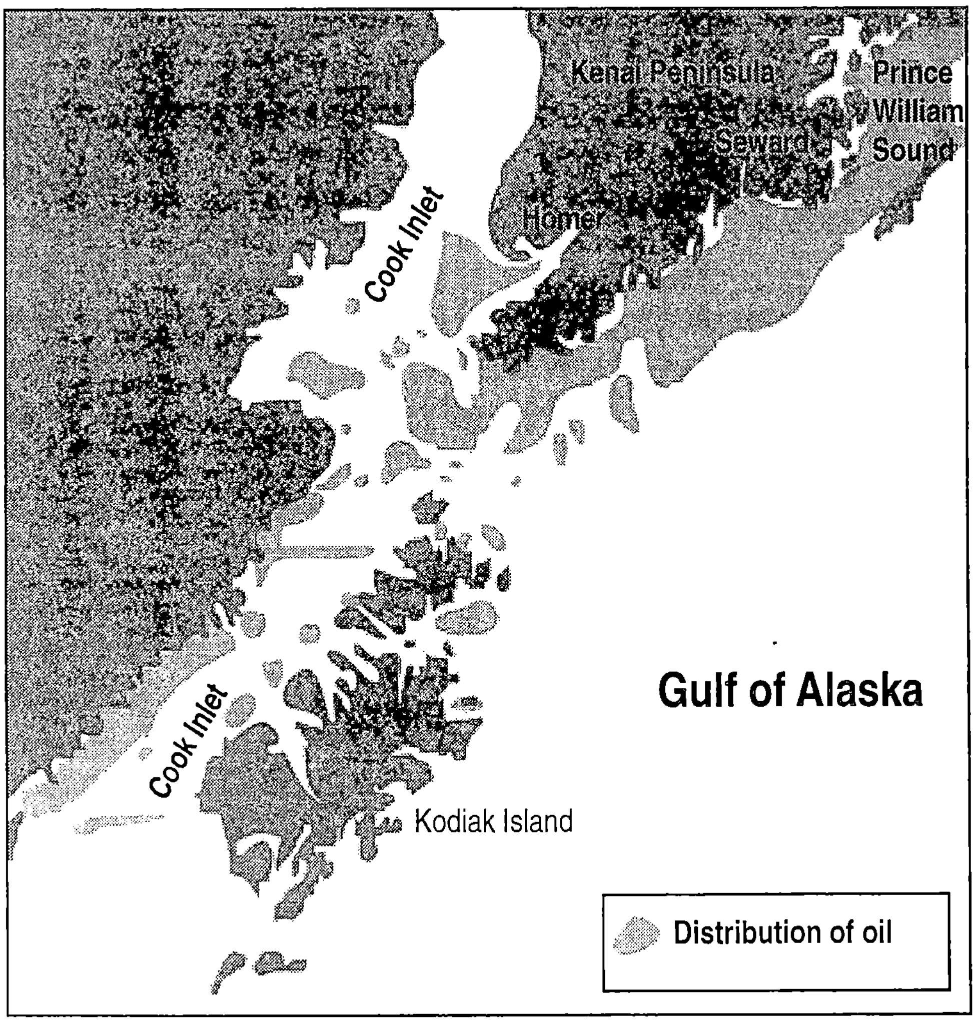

Figure 4. Distribution of oil from the *Exxon Valdez* oil spill.

the eastern boundary mountains trap weather systems from the west to largely define the climate of the GOA region (see Figure 5 and Figure 6). From the southeastern GOA limit (52 N at landfall) moving north, the eastern GOA headwater mountain ranges and height (ft) of the highest peaks are the Pacific Coast (10,290), St. Elias (18,000), and Wrangell (16,390). Northern boundary mountain ranges from east to west are the Chugach (13,176), Talkeetna (8,800) and Alaska (20,320). 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).

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 Prince William Sound 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 Prince William Sound proper has no major river systems, it does have over eight hundred independent drainages that are known to support andromous fish species.

To the west of Prince William Sound 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 Prince William Sound, 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, Denali (Mt McKinley). Moving southwest down the Alaska Peninsula, there are only two major river systems on

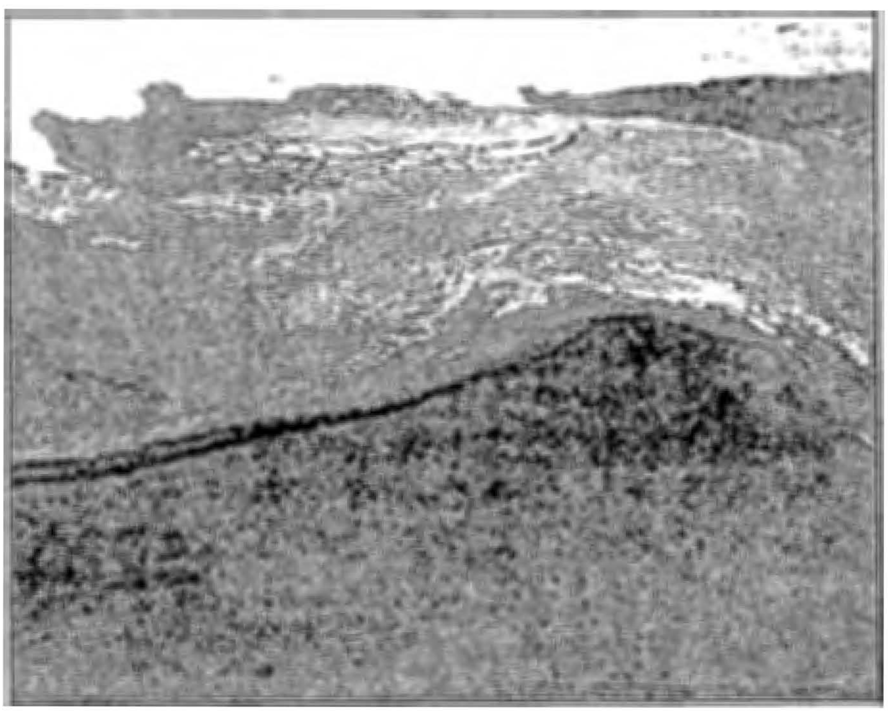

Figure 5. Satellite radar image of the northern Gulf of Alaska. Continental shelf, seamounts, and abyssal plain can be seen in relief. (Composite image from SEAWIFS Remote Sensing satellite, NOAA).

the western coastal boundary of the GOA, the Crescent and the Chignik, although many small coastal watersheds connected to the Gulf of Alaska 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 5). Extensive and spectacular shoreline has been and is being shaped by plate tectonics and massive glacial activity ({Hampton, Carlson, et al. 1987 #340}). 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 (Figure 5). The continental shelf is incised by extensive valleys or canyons ({Carlson, Burns, et al. 1982 #100}) that may be important in cross-shelf water movement, and by very large areas of drowned glacial moraines and slumped sediments ({Molnia 1981 #570}).

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 #1200}. 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, Bowyer, et al. 1998b #1130}, coastal mink {Ben-David. M., Hanley, et al. 1997a #1100}, and by opportunistic scavengers such as riverine mink {Ben-David. M., Hanley, et al. 1997a #1100}, wolf ({Szepanski, Ben-David, et al. 1999 #1220}) and martens {Ben-David, Flynn, et al. 1997b #1110}. In theory, any terrestrial bird or mammal species, such as harlequin duck or blacktailed deer, that feeds in the marine environment 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, aquatic and riparian plants (Bilby et al. 1996, Piorkowski 1997, Ben-David et al. 1998a; 1998b). In studies of a small Alaskan stream containing chinook salmon, Piorkowski (1997) 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 {Piorkowski 1997 #1210}.

The role of marine nutrients in watersheds is important 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 Jr. et al. 1993, Mathisen 1972, Piorkowski 1997) 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 1997 #1210}.

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 are expected to 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, Talbot, et al. 1996 #1190}. 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 Alaskan ecosystems have shown the feasibility and potential importance of such measures (Kline Jr. et al. 1990, Kline Jr. et al. 1993, Mathisen 1972, Piorkowski 1997; 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 & Schumacher 1986 #720}). The flow over the continental slope consists of the Alaska Current, a relatively broad, diffuse flow in the north and east GOA, and the Alaskan Stream, a swift, narrow, western boundary current in the west and northwest GOA (Figure 6). 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 Alaskan Stream is relatively constant year round. However, Musgrave et al. (1992), Okkonen (1992), Thomson and Gower (1998) show that sometimes the Alaskan Current and Stream contains large eddies or forms 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 shelfbreak, 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 the subtidal circulation

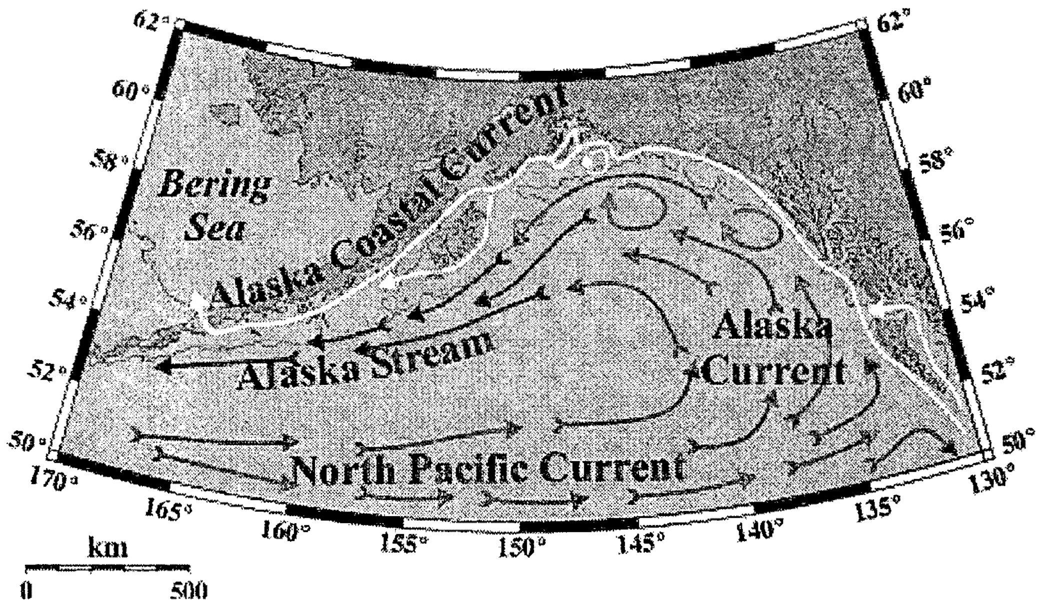

Figure 6. Currents in the Gulf of Alaska. (S. Danielson IMF).

causing mesoscale flow variability that suggest regions of locally enhanced (or depressed) biological production. Many of the submarine canyons extend across the shelfbreak which suggests that these might be important pathways for cross-shelf transport.

The most striking feature of the shelf circulation is the Alaska Coastal Current, which is a swift (0.2 - 1.8 m s^{-1}), coastally constrained flow, typically found within 35 km of the coast, ({Royer 1981b #780}; {Johnson, Royer, et al. 1988 #1260}; Stabeno et al., 1994). The offshore boundary of the Alaska Coastal Current consists of a front (Figure 11 and 12) 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 some 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 coastal current, the shelf flow between the offshore edge of the coastal current and the shelfbreak is weaker and more variable {Niebauer, Roberts, et al. 1981 #1290}. The source of this variability is uncertain, but potential mechanisms include separation of the coastal current as it flows around coastal promontories {Ahlnes, Royer, et al. 1987 #1090}; baroclinic instability of the coastal jet ({Mysak, Muench, et al. 1981 #1280}) flow over topography ({Lagerloaf 1983 #1460}) or meandering of the Alaska Current along the shelfbreak {Niebauer, Roberts, et al. 1981 #1290}.

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 Alaska Coastal Current. 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 #790}. 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 #1340}; 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 #790}.

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. {Johnson, Royer, et al. 1988 #1260} 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, Hansen, et al. 1979 #1350} 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 #1340}; {Royer 1979 #770}). 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 6) into the Alaska Stream, the westward flowing portion of the subarctic gyre ({Reed & Schumacher 1986 #720}). This dominant current system often may have computed velocities in excess of 80 to 100 centimeters/second and net transport in excess of 6×10^6 m^3/s. This is particularly so near the outer Alaskan Peninsula and Aleutian Islands, where sharp salinity decreases inshore generate strong pressure gradients that force swift flows ({Reed & Schumacher 1986 #720}). Waters from the shelf and basin of the Gulf of Alaska eventually enter the Bering Sea and Arctic Ocean through the Bering Strait. Thus the Bering and Chukchi seas are "downstream" ecosystems with respect to the Gulf of Alaska.

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 California Current system {Hollowed & Wooster 1992 #400}. The proposed decadal scale variation in. currents of the northeastern Pacific are shown in Figure 7. Weak flows of the Alaska Currents in the eastern gulf have been associated with years of higher-than-normal salinity {Ingraham, Reed, et al. 1991 #430}. 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 in to the southern gulf more to the northwest. They

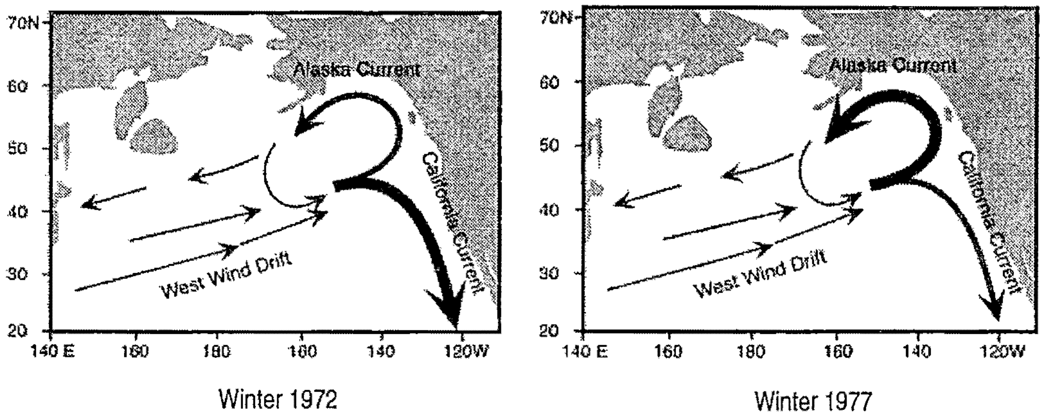

Figure 7. Oceanic circulation patterns in the far eastern Pacific proposed for negative PDO (top) and positive PDO (bottom). (Hollowed and Wooster, 1992).

suggested that such changes, although not 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 NPO favors a more intense, northerly position of the winter Aleutian Low Pressure system, winds in the eastern GOA are stronger {Emery & Hamilton 1985 #210}{Mantua, Hare, et al. 1997 #500}, there is more precipitation and Ekman transport is greater, which might be expected to influence variability in mixed layer depth and productivity. However, in the central Gulf of Alaska, mixed layer depth variability in the winter is primarily a consequence of changes in upper ocean salinity {Freeland, Denman, et al. 1998 #1230}.

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 & Overland 1987 #980}. Three semi-permanent atmospheric pressure regions dominate climate in the northern GOA—the Siberian and East Pacific high-pressure systems and the Aleutian low-pressure system (Figure 8). These have variable, but characteristic, seasonal locations. The Aleutian low pressure system averages about 1002 millibars {Favorite, Dodimead, et al. 1976 #250}, is most intense in winter, and appears to cycle in its average position and intensity with about a 20-25 year period {Rogers 1981 #760}{Trenbreth & Hurrel 1994 #890}. 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 particularly 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 7-10 days (Treidl et al., 1981). This interplay between eastward moving storm systems

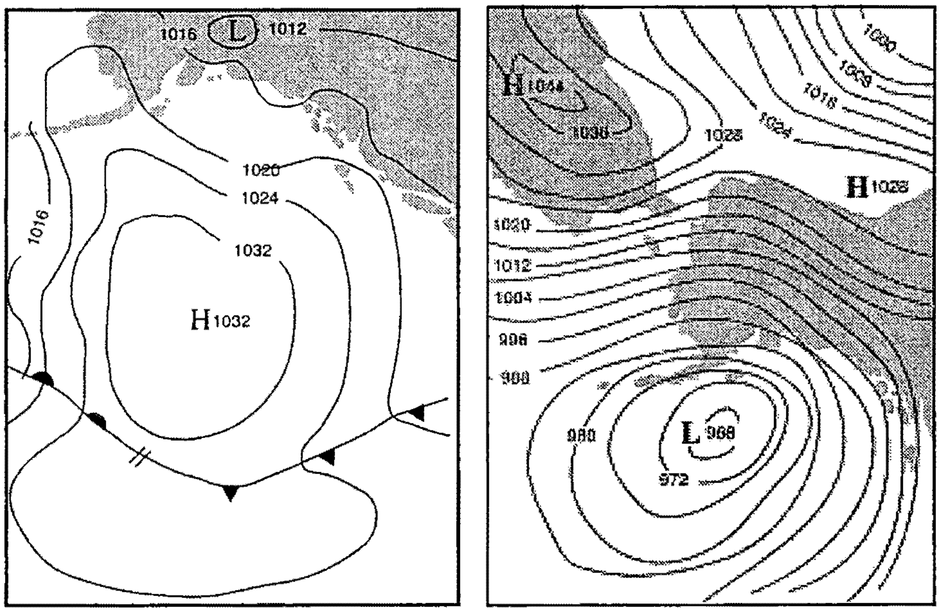

Figure 8. Typical winter (right) and summer (left)examples of the Aleutian low and Siberian high-pressure systems. Contours refer to sea-level pressure in millibars. (From Carter).

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 & Clark 1975 #970}.

Mantua et al. (1997) have calculated the Pacific Decadal Oscillation (PDO) index, which tracks the NPO. 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 the PDO was negative and then again for 3 years in the early 1990s {Hare, Mantua, et al. 1999 #350}. Figure 9 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 this century ({Richardson 1936 #750}; {Klein 1957 #450}; {Reitan 1974 #740}; {Whittaker & Horn

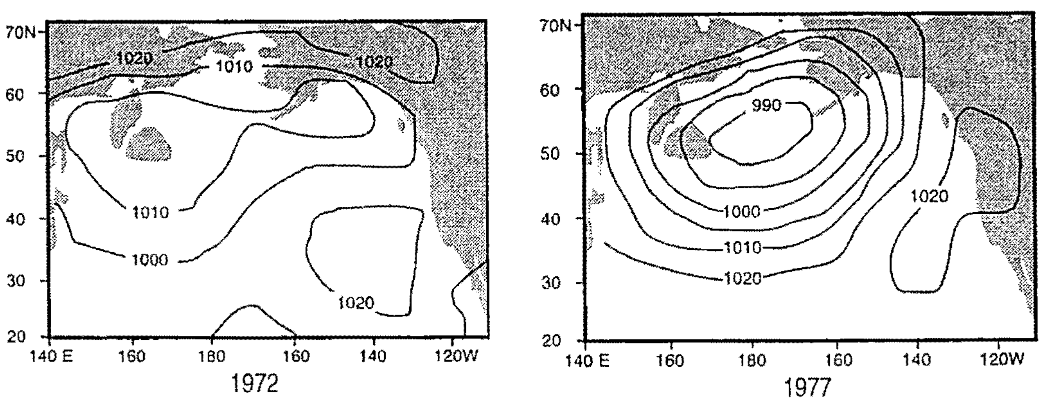

Figure 9. Mean sea-level pressure patterns from the winters of 1972 and 1977. (From Emery and Hamilton, 1985).

1982 #960}; and {Wilson & Overland 1987 #980}). 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, Royer, et al. 1995 #630}.

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 & Reid 1983 #510}, 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 #730}; ^{14}C depletion in surface waters {Reeburg & Kipphut 1987 #710}; and presence of low-temperature, high-nutrient water {Sambratto & Lorenzen 1987 #820}.

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 {Heinrich 1957 #390}{Beklemishev 1957 #40}. The traditional view has been that grazing by zooplankters was sufficient to prevent phytoplankters from depleting macronutrients ({Anderson & Munson 1972 #1240}). 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, Denman, et al. 1998 #1230}. Moreover, the question of the extent of limitations imposed on productivity by iron in the GOA is an important and open question {Pahlow & Riebsell 2000 #1080}. 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 to a greater extent than otherwise. Organic nitrogen and carbon depleted in ^{15}N and ^{13}C is 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 Prince William Sound that are nutrient limited {Kline 1999a #460}.

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 & Burrell 1981 #380}. 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 & Heggie 1978 #580}. Renewal of bottom water in shallow-sill coastal fjords, like Aialik 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 conjectured to explain the occurrence of GOA-origin copepods undergoing diapause within Prince William Sound {Kline 1999a #460}. Long-term shifts in the deepwater renewal process could thus effect variability in a source of zooplankton forage for juvenile salmon and other Prince William Sound consumers since it is the offspring of diapausing copepods that form the bulk of subarctic Pacific zooplankton blooms {Miller, Frost, et al. 1984 #550}.

IV. C. 1. g. Plankton and Productivity

Some of the basic conditions for phytoplankton growth in the central GOA, based on 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, Frost, et al. 1991 #560}. The reported average annual rate of 170 g $Cm^{-2}y^{-1}$ is one of the highest in the world oceans ({Welschmeyer, Strom, et al. 1993 #950}). Historical data suggest that nitrate and other macronutrients are not limiting in the photic zone (i.e., that area reached by sunlight) during the growing season {Dugdale 1967 #200}{Hattori & Wada 1972 #370}{Miller, Frost, et al. 1991 #560}. It is possible that GOA may have undergone a change with respect to the role of macronutrient control, based on more recent data {Freeland, Denman, et al. 1998 #1230}.

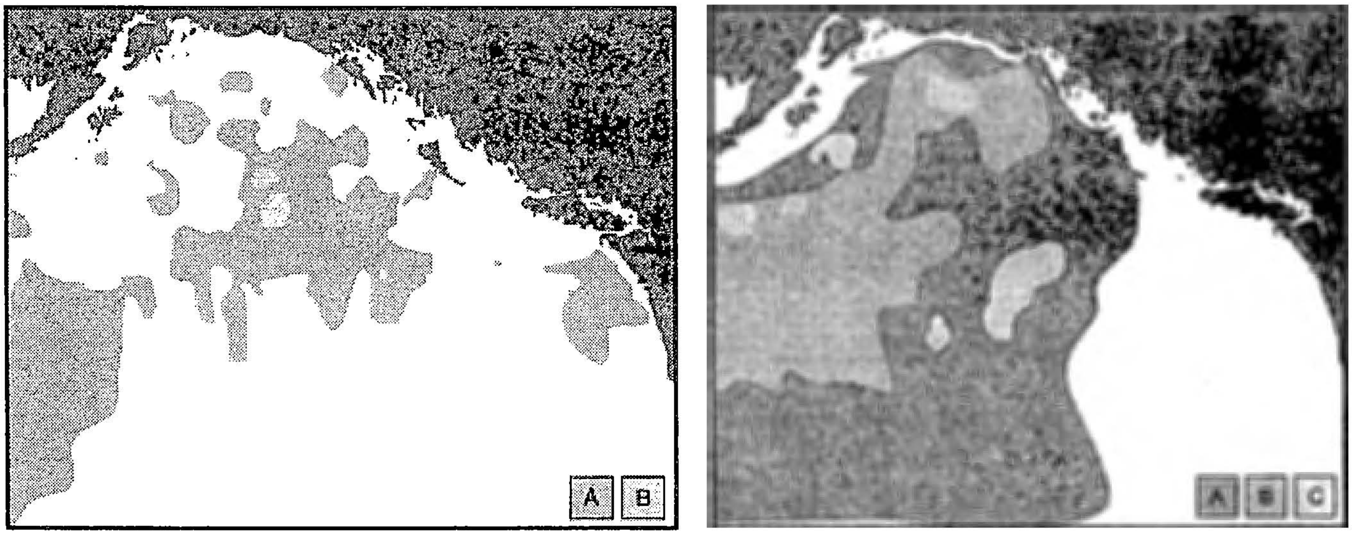

Figure 10. Biomass of plankton for the spring and summer period are contrasted for a negative PDO period (left) and a positive PDO period (right). Box A represents 100-200 g/1000 m^3 zooplankton biomass, Box B represents 201-300 g/m^3, and Box C represents >300 g/m^3.

The micronutrient, iron, has been suggested as 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 phytoplanton cells that attain a high level of productivity {Miller, Frost, et al. 1991 #560}.

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, Lam, et al. 1977 #20}—intense grazing during growth and sinking of cells are possible contributing causes {Booth, Lewin, et al. 1993 #50}. Recently, Miller et al. (1991) suggested that consideration of the grazing protozoans as an intermediate between phytoplankton and large {Miller, Frost, et al. 1984 #550} copepods 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. Apparently, ammonia recycled quickly from the micro- and macrozooplanknton to the phytoplankton (mainly flagellates), 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, McGowan, et al. 1987 #930}.

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 & Lorenzen 1987 #820}. Unlike the oceanic regime offshore, nutrient depletion does occur inshore of the shelf in lower Cook Inlet during the growing season {Larrance & Chester 1979 #490}{Chester & Larrance 1981 #110}. Unfortunately, the situation with respect to macronutrient limitation of productivity on the GOA shelf is far from clear. Results of the EVOS-sponsored Sound Ecosystem Assessment project (SEA) project include a model of the water column in Prince William Sound that has successfully produced the duration and extent of both phytoplankton and zooplankton blooms for several years {Eslinger 1999 #240}. 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 effect 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 #470}.

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 predominately downwelling nature of the hydrography limit opportunities for water renewal from the deep GOA. Offshore fronts associated with the Alaska Coastal Current 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 #150}. 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 transfering large amounts of energy from phytoplankton to higher trophic levels ({Cooney 1987 #150}; Jeffery W. Short unpubl.). Available evidence led Cooney (1984) to postulate 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 estimated $2x10^6$ metric tons estimated from production on the shelf in the Alaska Coastal Current. The discovery that stable isotope signatures diagnostic for offshore carbon is found and also varies in juvenile fishes of Prince William Sound provided evidence that this process takes place and varies in effect from year to year {Kline 1999a #460}. 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 10 biomass of plankton for the spring and summer period are contrasted for a negative PDO period and a positive PDO period, and it can be seen that zooplankton biomass was much greater during the period.

Nonetheless, it is important to bear in mind that primary and secondary productivity measurements in the GOA are few {Reeburg & Kipphut 1987 #710}. A truly engaging enigma of the Gulf of Alaska 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 productiyities, 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 also was more abundant after about 1978. Both these observations are consistent with calculations by Polivinia 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 {Pearcy 1992 #650}{Hare, Mantua, et al. 1999 #350}{Mantua, Hare, et al. 1997 #500}. 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 that does exist (David Mackas, personal communication). 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 {Piatt & Anderson 1996 #670}{Hatch, Byrd, et al. 1993 #360}. This was apparent in PWS, especially in data on black-legged kittiwakes from southern PWS {Irons 1996 #440}. 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 2). 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 well 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, and it varies with changes in substrate characteristics, depth, temperature, light and food supply {O'Clair & Zimmerman 1987 #610}{Feder & Jewett 1987 #260}. 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 NE Gulf of Alaska for large kelps (*Nereocystis* and *Laminaria* spp. range as high as 37.4-71.9 kg/m^2 /yr wet weight for Prince William Sound, 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*. This productivity is very important to maintaining nearshore communities in the areas where it occurs, however 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 & Wooster 1995 #410}; {Zheng & Kruse In press #1000}). Data on the geology and biology of the benthos are also available from work preparatory to oil exploration in the Aleutians Islands and Alaska Peninsula, Kodiak, Cook Inlet, and northeastern Gulf of Alaska {OCSEAP 1990 #620}. The above references to climate-mediated changes in production regimes and 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 & Kaufman 1999 #850}. 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 & Anderson 1996 #670} 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 Alaska Coastal Current 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 of 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 Gulf of Alaska have been among the world's richest in the second half of the twentieth 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 3 million mt in 1982 {Witherell 1999 #990}. Annual numbers of two-year old pollock entering the fishable population (recruitment) from 1981 to 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 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 that were in 1977 and 1995. Biomass of the dominant flat fish in the GOA, the arrowtooth flounder is approaching 2 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 is estimated at 258,000 mt, which is above average for 1974 - 1999 {Witherell 1999 #990}. Exploitable biomass of Pacific halibut was also increasing 1974 – 1988, after which it declined slightly. As possible consequences of climate change and/or fishing, the status of crab populations (discussed below) are relatively poor in comparison to the groundfish populations.

Both salmon and groundfish populations in the northeast Pacific appear to vary in concert with features of climate, but the responses appear to be different {Francis, Hare, et al. 1998 #280}. Groundfish recruitments follow a cycle with a roughly ten year period that is closely related to the El Nino Southern Oscillation (ENSO) {Hollowed & Wooster 1992 #400}, whereas salmon abundance changes sharply at intervals of 20 –25 years in concert with the Pacific Decadal Oscillation (PDO) {Brodeur, Frost, et al. 1996 #70}. The ENSO and the PDO were shown to be independent of one another {Mantua, Hare, et al. 1997 #500}. The opposite responses of groundfish/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 of 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 fish and other animals are discussed further below, and in a recent review paper {Francis, Hare, et al. 1998 #280}.

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 & Anderson 1996 #670}. Pacific halibut appear to undergo decadal-scale changes in recruitment, which have been correlated with both the 18.6-y lunar nodal tide cycle {Parker, Royer, et al. 1995 #630} and the PDO. There also is a reported coincidence of size-at-age data for Pacific herring with this same cycle {Ware 1991 #940}. 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 of recruitment for 15 crab stocks in the Bering Sea, Aleutian Islands and Gulf of Alaska, time trends in 7 of 15 crab stocks are significantly correlated with time series of the strength of Aleutian Low climate regimes {Zheng & Kruse In press #1000}. 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 7 of the 15 carb stocks. The seven significantly negative correlations between ocean productivity and crab recruitment were from Bristol Bay, Cook Inlet and the Gulf of Alaska. 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 & Kruse 1996 #910}.

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 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 favors 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 dominates 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.

Related modeling studies recently completed {Rosenkrantz 1999 #1050} 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 ware expected to augment the effect of NE wind by increasing survival of newly hatched larvae {Rosenkrantz 1999 #1050}.

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 & Anderson 1996 #670}. 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 very significantly correlated with fisheries for Pacific salmon in the GOA is very strong {Hare, Mantua, et al. 1999 #350}, 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 (i.e., Atka mackrel, Pacific cod, Pacific hake and walleye pollock) {Francis, Hare, et al. 1998 #280} With fisheries accounting for up to 25% of the energy produced by coastal shelf and upwelling systems on a worldwide basis {Pauly & Christensen 1995 #640}, 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 contribute to an estimated total of 8 million birds in 1987 in the GOA {DeGange & Sanger 1987 #160}. In addition, the large estuarine habitats in Cook Inlet and the Copper River Delta are critically important for migrating shorebirds {Senner 1999 #840} in the spring. During the summer breeding season, colonial seabirds aggregate at about 800 different colonies around the periphery of the GOA {DeGange & Sanger 1987 #160} 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 sea birds that nest and reproduce nearby {Furness & Camphuysen 1997 #310}{Phillips, Caldow, et al. 1996 #660}.

Seabirds also provide a relatively 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. Since 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.

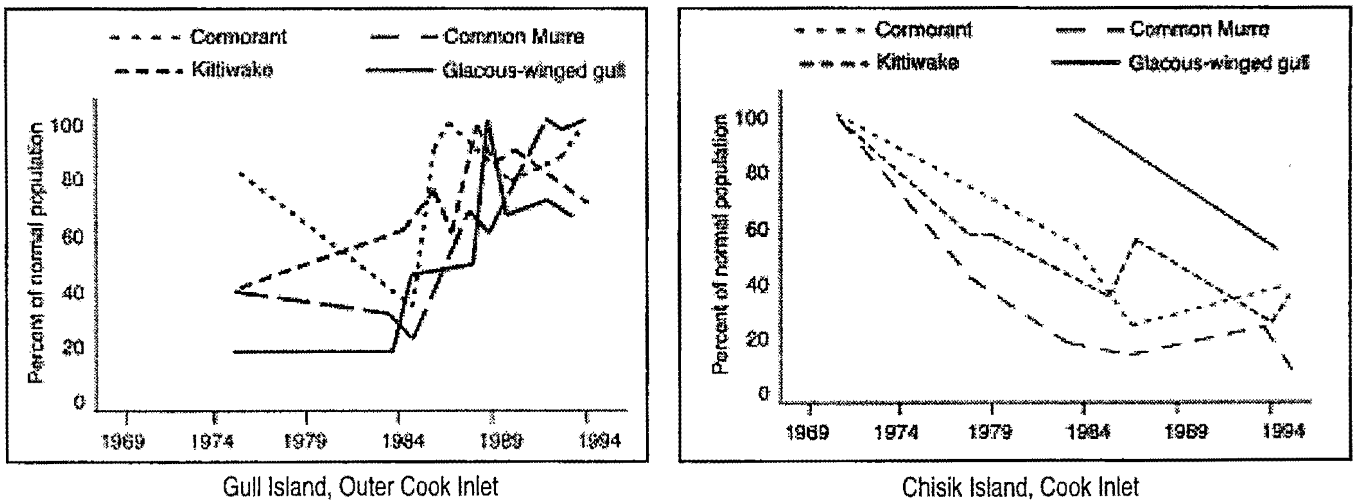

Figure 2. Long-term decline of seabirds at Chisik Island, Cook Inlet (bottom) and increase at Gull Island, Outer Cook Inlet (top). (Piatt and Anderson, 1996).

While the very favorable production regime for salmon in the central gulf was occurring, many, but not all, nearshore seabird colonies were in decline {Piatt & Anderson 1996 #670}{Hatch, Byrd, et al. 1993 #360} (Figure 2). This was apparent in PWS, especially in data on black-legged kittiwakes from southern PWS {Irons 1996 #440}. 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 (John F. Piatt, unpublished). The 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.

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 (John F. Piatt, unpublished).

IV. C. 2. c. Marine Mammals

Three groups of marine mammals occur in the northern Gulf of Alaska, 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 & Zimmerman 1986 #420}. 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 Gulf of Alaska as a result of human harvest of marine mammals {Scheffer 1972 #1060}. 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 area and laid claim to it for Russia.

Continuing concern about past alteration of trophic structure in the Gulf of Alaska and its consequences for contemporary trophic structure is well warranted. Six species of large baleen whale inhabit the Gulf: blue, fin, sei, humpback, gray, and Pacific right (Calkins 1986). 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 1986). 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 Gulf of Alaska. 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 whale species leads to concern about future alteration of the trophic structure of the Gulf in ways that would 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 Gulf of Alaska, 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 1986). Recent growth in numbers of humpback whales, which were radically reduced in population size prior to 1966 {Scheffer 1972 #1060}, 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 final third of twentieth 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 Gulf of Alaska and North Pacific.

Some species of pinniped such as the northern elephant seals have increased dramatically during recent decades. But even with cessation of most harvest, other pinniped species such 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 twenty years. Harbor seals should be considered candidates for long-term monitoring since they have relatively small geographic ranges, and since they 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.

Sea otters, very nearly extirpated from the North Pacific by 1900, have also 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 100m 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).

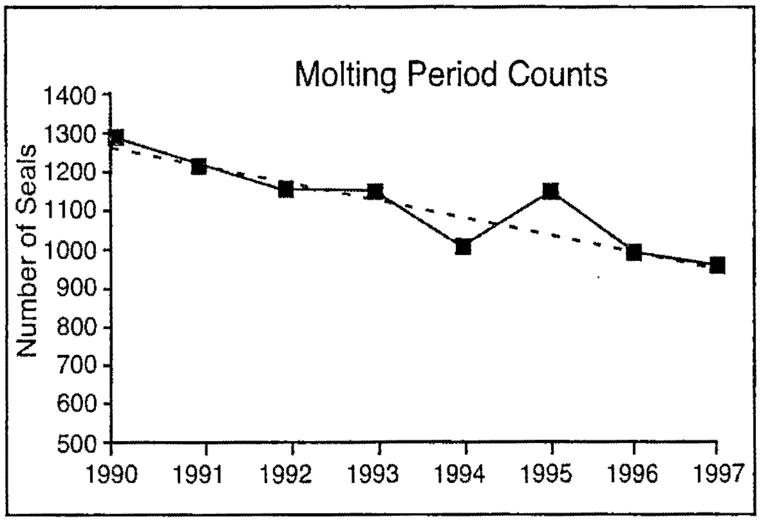

Figure 3. Population trend of molting seals in Prince William Sound. (Frost, 1998)

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 #900}. Although food limitations in the Bering Sea may not be limiting population growth, food limitations in the Aleutians and in the Gulf of Alaska may be creating a population growth bottleneck by causing high mortalities on juveniles during migrations. The bottleneck hypothesis of fur seal abundance control {Trites 1992 #900} illustrates but one of many ecological connections between the Bering Sea and the Gulf of Alaska. Steep declines in harbor seals in the Gulf of Alaska have been documented in and around Kodiak Island 1956 – 1976 {Pitcher 1990 #680} and in Prince William Sound throughout the 1990's {Frost, Lowry, et al. 1998 #290}.

Concepts on control of marine mammal populations focus on food limitation and hunting or other human removals. Steller sea lions, now listed under the Endangered Species Act, have declined steeply starting in the early 1970's, particularly in the Aleutian Islands {Trites 1992 #900}. Current hypotheses on limitation of Steller sea lion abundance center on food limitation, possibly due to competition with humans for prey species {Bowen et al. 1999 #80}. Current information is not conclusive with respect to the role of fisheries in causing food limitation for Steller sea lions {Bowen et al. 1999 #80}. 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 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 funded to implement 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 further 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.

added

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 are expected to change in ways that are not anticipated based on past experience, as happened during 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 ecosytem, as discussed and illustrated in Section III.

Developing testable hypotheses based on the conceptual foundation is important to serve the purposes of GEM. 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 to detect trends in anthropogenic influences.

IV. D. 2. The conceptual foundation

The direct effects and interactions among related natural and human factors control productivities of all species of birds, fish, shellfish and mammals in the watersheds and waters of the Gulf of Alaska (GOA). The key factors controlling animal populations are summarized as food, habitat, and removals. Production of some species of birds, fish, shellfish and mammals in GOA watersheds and waters is linked, or coupled to the amount of food produced at the front (see Figures 11 and 12) associated with the continental shelf break. A front is an area on a lake or the ocean where two different bodies of water come into contact. On the surface some fronts may be identified by long lines, or "rips," of debris or foam with water of differing colors on either side. Production of break-

revised

coupled species depends mostly on mechanisms that distribute shelf-break carbon and nutrients among the watersheds and waters. Production of non-break or weakly coupled species depends mostly on primary production in waters inshore of the shelf break, and on non-coupled primary terrestrial production.

Primary productivity at the front and elsewhere is 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. There are four candidates for geophysical factors that may act alone or in combination to drive primary productivity. The four factors are the ENSO (El Nino-La Nina) phenomena with 3-7 year oscillations, the PDO with a 20-30 year oscillation, the lunar tidal node with an 18.6-year period, and the linear trend in long-term global warming. The factors may combine to produce an effect, and they may influence one another (see Minobe).

revised

Since the mechanisms through which the tidal node may be expressed in system oceanography are not as apparent or extensively elaborated {Parker, Royer, et al. 1995 #630}{Royer 1993 #810}, much of our current understanding of atmospheric phenomena is based on the PDO and ENSO (Figures 11 and 12). For purposes of this conceptual foundation, there may be enough confluence in the PDO and lunar cycle so that it is not important to specify which of these explanations (or both) are significantly affecting the ecosystem.

In decades of positive PDOs the GOA is warm and windy with lots of precipitation. Under those conditions, coupled offshore grazers, such as salmon and some seabirds, do well. As influenced by human removals, increases in adult salmon during a positive PDO return larger amounts of nitrogen to natal streams. Increased returns of nitrogen to natal streams increase production of coupled species of plants and animals in the watersheds. In decades of negative PDO the GOA is cooler and less windy with less precipitation. Non-coupled inshore grazers, such as some seabirds, herring and seals, do not thrive in a negative PDO.

Available habitat for both coupled and non-coupled species is determined by geophysical processes, such as climate, and by degradation of habitat through human activities such as pollution and harvest removals. In addition to harvests, removals of both coupled and non-coupled species are determined by a wide variety of human activities that affect habitat, including logging, road building and other aspects of urbanization, and by natural causes such as starvation and non-human predators. Note that key factors (food, habitat, and removals) 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.

The location and intensity of the winter-time Aleutian Low pressure system results in a set of atmospheric circumstances collectively known as the Pacific Decadal Oscillation (PDO). The PDO changes, or oscillates, between positive and negative states described diagrammatically in Figures 11 and 12. Northerly movement and intensification of the winter-time Aleutian low pressure system results generally in the following interrelated changes, known as positive Pacific Decadal Oscillation (PDO) (Figure 11):

1. Acceleration of cyclonic motion in the Alaskan 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;

10. Deepening of the Alaska Coastal current nearshore; and

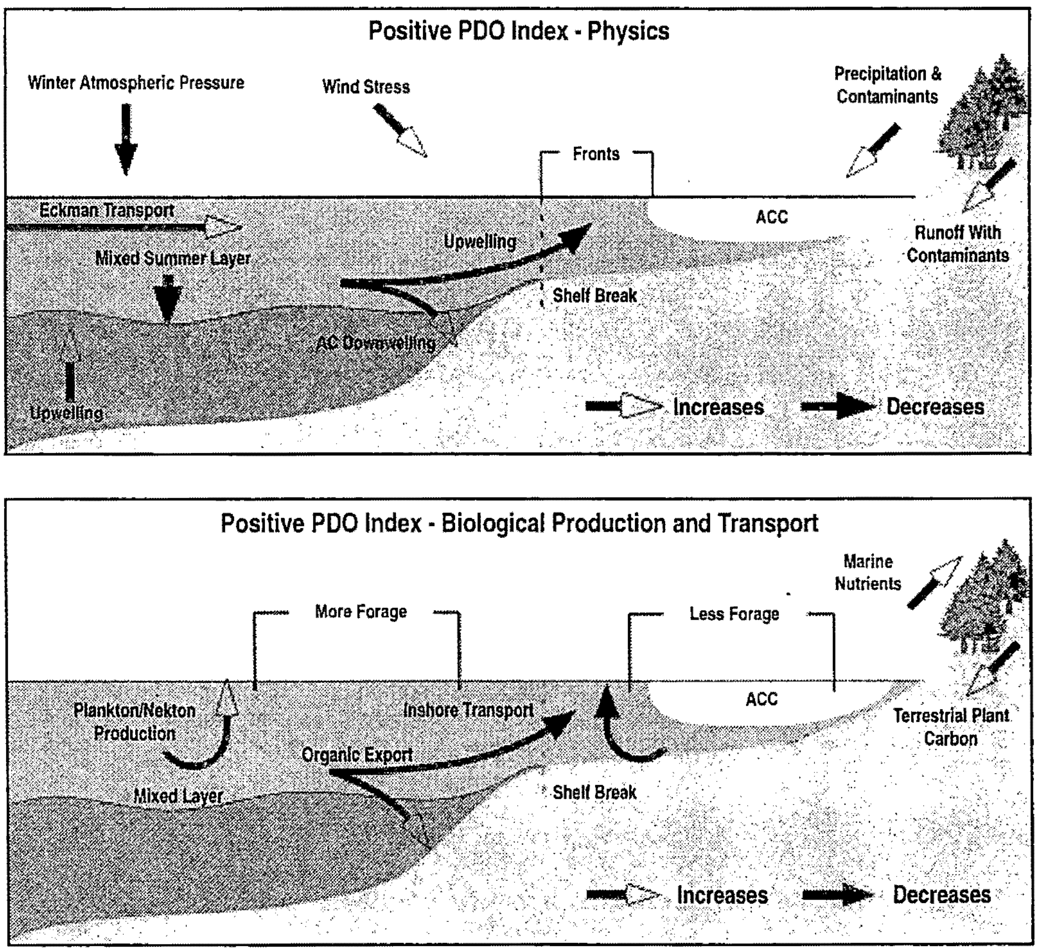

Figure 11. Schematic of physical processes during the winter in a positive PDO climatic regime in the Gulf of Alaska from offshore to nearshore areas showing the Alaska Current (AC) and the Alaska Coastal Current (ACC).

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

During the spring and summer the following differences also characterize a positive PDO (Figure 11):

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 is 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 central 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;

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.

IV. D. 3. Discussion

The conceptual foundation is a mechanistic explanation of how the largest climate signal, PDO, could cause positive and negative biological changes in the abundances and

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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 levels 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 thoughts in the current conceptual foundation will be expanded, modified or totally discarded.

Much of the conceptual foundation already appears in the literature, as described in the background section. However, the conceptual foundation also has 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 previously been described. 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 indices being associated with greater offshore production and weaker nearshore production (1978-1990), and negative PDO indices (1948-1977) being associated with greater onshore production and weaker offshore production.

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The fate of offshore production during the two regimes is key, with shoreward-transported organic production being downwelled more strongly onto the slope 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 foundation proposes that the separation between onshore and offshore production regimes occurs between the fronts associated with the shelf break and the Alaska Coastal Current (Figures 11 and 12). The "ring of plankton" often seen in sections 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 #150}. The fate of this organic matter during different climate regimes is key to the oscillations in the model 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 nearshore production or organic matter. Cooney (1984, 1987) calculated that shoreward-advected zooplankton in the upper 50 m during the convergence season (October through April) was approximately 10×10^6 metric tons. This compares to 2×10^6 metric tons produced in the Alaska Coastal Current, a five-fold difference. The fate of this material may have potent implications for seabirds and juvenile fish that can access it.

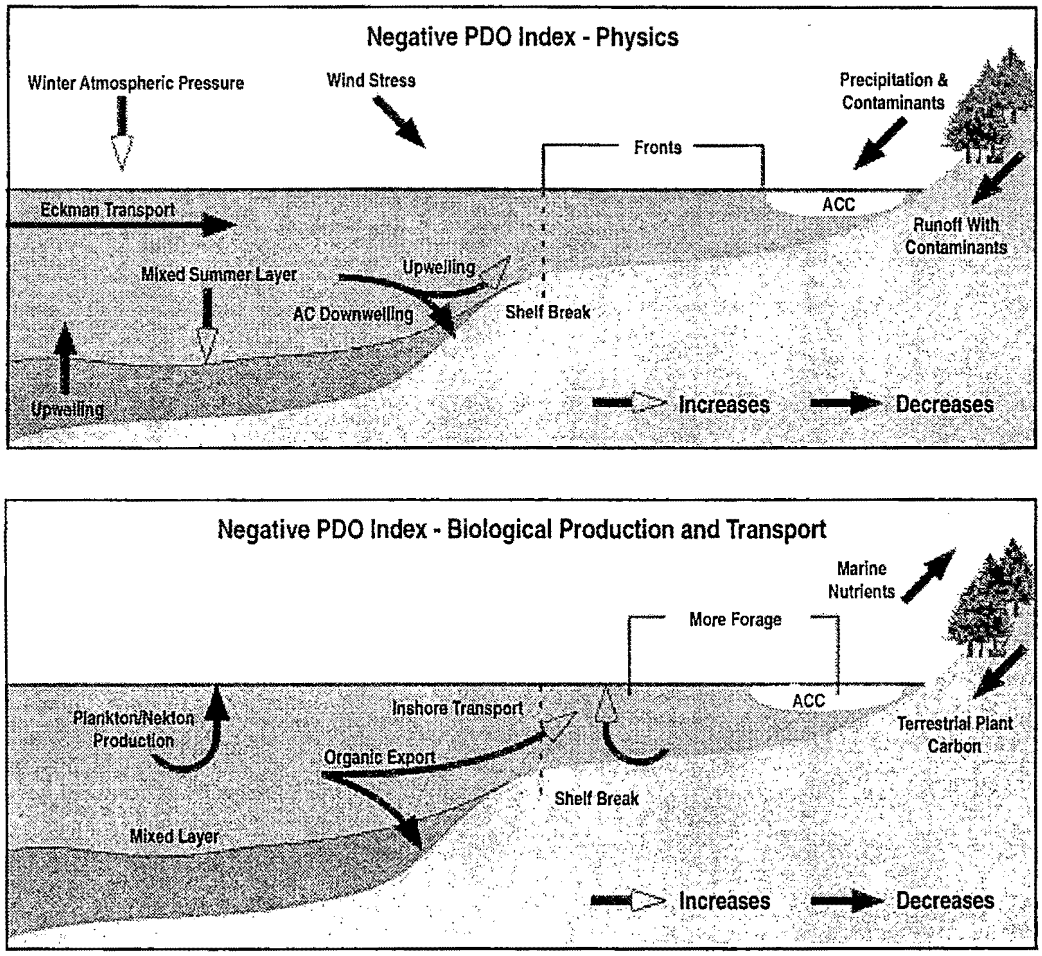

Figure 12. Schematic of physical processes during the winter in a negative PDO climatic regime in the Gulf of Alaska from offshore to nearshore areas showing the Alaska Current (AC) and the Alaska Coastal Current (ACC).

Recently a mechanistic hypothesis has been advanced to explain the decadal scale variation in eastern North Pacific salmon stocks {Gargett 1997 #330}. Gargett proposes that increased precipitation in coastal areas during positive PDO's makes the water column more stable and that this increased stability promotes greater primary production. Polovina (19) has 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 Alaska Coastal Current to become nutrient limited, the foundation holds that increased water column stability during positive PDO's will result in net production decreases, 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, the foundation would explain abundant food on the outer shelf as a result of onshore transport of offshore production, i.e. Cooney's ring of zooplankton production. If increased salmon production results from favorable productivity in coastal waters, where many salmon spend their first year at sea, our hypothesis would explain abundant food on the outer shelf as a result of onshore transport of offshore production, i. e. Cooney's "ring of zooplankton." Is the carbon in the Alaska Coastal Current during a positive PDO due to *in situ* production or onshore transport? Resolving which, if either, of these two hypotheses 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 #460}.

If the source of increased carbon during a positive PDO is due to onshore transport, 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 there are data available to distinguish which hypothesis is correct.

In addition to conceptual foundations 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.

added

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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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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 October 1999, the database has information on 240 projects. Most of these projects were funded or conducted by government agencies. Major projects in this database are summarized in Appendix Table 1. The summary of projects is not exhaustive. There are two additional sources that may be consulted for a more extensive listing of projects, PICES web site, (http://pices.ios.bc.ca/data/weblist/weblist.htm), 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).

Each project in the database falls into one or more of the following categories: oceanography, fish and shellfish, marine mammals, seabirds, and contaminants. 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 end 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 Gulf Ecosystem Monitoring program. Still other projects compile data into catalogues or databases. Examples of such compilations are the [Pacific salmon and steelhead] 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.

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 56N148W North PWS 60N146W South PWS 60N146W
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
Fish and Shellfish		
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.
ADFG / Salmon Escapement Counts	Enumeration of returning adult salmon. Data since early 1900's.	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.

ɟency/Program	Data	Coverage in Gulf of Alaska
ADFG / Fish Pathology Disease History	Disease histories of salmon, trout, herring, clams,	Full coverage.
ADFG / Coded Wire Tagging	Identification of a particular stock from a particular	Primarily salmon hatcheries; a
Marine Mammals and Seabirds		
NOAA / Marine Mammal Stock	Stock assessments for sea lions, harbor seals, various	Full coverage.
DOI / Beringian Seabird Colony	Breeding population size, species composition and	Seabird colonies throughout Alaska
DOI / Alaska Seabird Inventory and	Population, nesting productivity and timing, prey	10 different sites annually on the Alaska Maritime NWR
Contaminants		
AA / National Status and Trends	Contaminants in sediments and bivalve mollusks	Cook Inlet, Kodiak Island, PWS
NOAA / National Status and Trends Program / National Benthic Surveil-	Chemical concentrations in the livers of bottom-	Prince William Sound
DOI / Alaska Marine Mammals Tissue	Heavy metals, PAH's, organic pollutants and other	Full coverage.

Appendix C. Elements of research and monitoring

The following areas of interest for long-term monitoring and supporting research represent an initial effort on which to build. The monitoring areas and questions are by no means exhaustive or exclusive, as they are intended to be serve as a start to the GEM research and monitoring plan.

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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. A. Long-term Monitoring

A central focus of the GEM program is the existence of 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 changes in monitoring programs may be made to reflect the utility of the monitoring programs to research and management. Subject to periodic review, GEM recognizes the need to maintain a core of measurements taken with enough consistency in time and space to be able to make conclusions about changes that occur several times a century. Results from the research program, however, should also inform the monitoring program, so that it may be changed or augmented to reflect the most accurate, up-to-date understanding of the functional processes that should be monitored and the technologies available to monitor those processes. There will always be a dynamic balance between the need for continuity and making the monitoring program most reflective of our latest understanding of how the system functions and where, when and how it is best measured.

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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 or "top" 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, and 4) craft a program of monitoring and related research that is appropriate to the cash flow expected from the endowment.

The following are suggested as areas of interest in no particular order. 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.

Appendix C. A. 1. 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 PWS, Kodiak and lower CI. Relate retention and transport phenomena to larval supply and recruitment. Possible cooperating agencies/programs: MMS, PWS and CI RCACs.

Appendix C. A. 2. Apex predators

To monitor: seabird colony attendance at intervals of perhaps every 4 years and chick productivity as often as every year at established USFWS GOA index colony sites (e.g., Barren Islands) within the spill area for at least common murres and black-legged kittiwakes. Also total seabird guild composition and abundance at major index sites. Occasional at-sea counts of seabirds. Possible cooperating agencies/programs: USGS/BRD, USFWS/Alaska Maritime National Wildlife Refuge Seabird Monitoring Program, US GLOBEC (?), MMS.

To conduct regular periodic surveys of harbor seal molting at select sites across the northern GOA coast (e.g., PWS, outer Kenai coast, CI, Kodiak) accompanied by biological studies to assess body condition and other factors likely to be indicative of population status. Possible cooperating agencies/programs: NMFS, ADF&G, Nation Park Service, 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. A. 3. 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 cooperators: the NOAA (buoy system, National Weather Service), NCAR, USGS coastal stream gauge data; use of existing local precipitation and air temperature records.

Appendix C. A. 4. Physical oceanography

To measure: strength, location and variation of Alaska Current/Stream and Alaska Coastal Current at key sites; variation in the circulation of PWS and lower CI (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 cooperators: NOAA (COP, OCC, FOCI, GLOBEC, buoy data, Coastwatch Remote Sensing Program), NSF (Snow and Ice Data Center), Canadian GLOBEC, US GLOBEC, UAF (GAK line), MMS.

Appendix C. A. 5. Chemical oceanography

To measure: NO_3, PO_4 and iron concentrations and selected tracers (e.g., isotope tracers) at key locations and times in GOA, on the shelf and in CI and PWS. 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. A. 6. Biological oceanography

To characterize: chlorophyll *a* (continuous) and primary productivity at key sites in the Gulf, on shelf, in PWS and CI; to obtain synoptic views of sea surface chlorophyll *a*. Possible cooperating agencies: NOAA/NMFS (FOCI, Coast Watch), Department of Fisheries and Oceans Canada, NASA, UAF, PWS Aquaculture Corporation.

To measure: zooplankton settled volume at inshore sites within PWS, CI 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: PWS Aquaculture Corporation, US GLOBEC, GLOBEC Canada.

Appendix C. A. 7. Nekton including forage fish

To make estimates of biomass and species composition by hydroacoustic and net sampling on the shelf and within PWS and CI at key sites and times. Possible cooperating agencies/programs: US GLOBEC, UAF, FOCI, NOAA/NMFS.

To monitor: halibut and Pacific cod stomach contents in CI and other possible regions; seabird diets in PWS and CI (summer); juvenile herring surveys in PWS. To do hydroacoustic and net sampling at key shelf sites. Goal: An index of species composition and relative species composition and relative abundance of forage fishes. To measure carbon and nitrogen stable isotopes and fatty acids of herring and other forage fish on shelf and in PWS and CI. To do 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 PWS, Kodiak, and CI. When available, supplement with additional data from sport and subsistence harvests. Possible cooperating agencies/programs ADF&G, NOAA/NMFS.

Appendix C. A. 8. 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, ADNR, Alaska Department of Transportation (ADOT), EPA, NMFS.

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Appendix C. A. 9. 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

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miles of roads, and human popluation density. Provide information supportive of resource management agencies' actions. Possible cooperating agencies/ programs: ADEC, ADF&G, ADNR, ADOT, EPA, NOAA, USGS, USFWS, USFS.

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Appendix C. A. 10. Pollution

To monitor: Indicators of human use including water quality (salinity, dissolved oxygen, pH, bacteria levels, harmful algal blooms; PSP, Amnesiac Shellfish Poisoning) point source (i.e. organochlorines, heavy metals) and non-point source (i.e. 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. B. 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 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.

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Appendix C. B. 1. Climate, sea-surface interactions and physical oceanography

a. What are the periodic and aperiodic changes in the atmosphere that influence the northern GOA? Are they predictable ? How will the trend in global warming affect cycles in the future?

b. What is the annual, interannual, and interdecadal variability in the position and strength of the Alaska Coastal Current? What is the annual, interannual, and interdecadal variability in the Alaska Current and Alaska Stream?

c. How is downwelling of onshore-driven water and upwelling of deep water affected by changes in wind and coastal precipitation during different climatic regimes? Does freshwater-induced stratification and wind-induced mixing on the continental shelf change significantly under various climatic regimes?

d. How do fronts and eddies affect biological production and 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. B. 2. Ocean fertility and plankton

a. How are nutrient transport and recycling in the central GOA and on the shelf different in different climate regimes?

b. What are the relative roles of local nutrient recycling versus deep-water supply and cross-shelf transport in PWS, Cook Inlet and Kodiak Island?

c. Does the intense upwelling in outer Cook Inlet vary significantly interannually or interdecadally ? Do long-term changes in some tidal nodes (e.g., an 18.6-year nodal cycle) affect nutrient supply in this region?

d. Are PWS, Cook Inlet and the Kodiak shelf net importers or net exporters of nutrients, carbon and energy?

e. How does 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 climate 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 PDO bring significantly greater inputs of terrestrial produced carbon?

Appendix C. B. 3. Fish and fisheries

a. What are 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. B. 4. 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 (cod, halibut, sable fish ...) and benthic productivity?

Appendix C. B. 5. Bird and mammal populations

a. How do populations and productivity of seabirds fluctuate interannually and interdecadally? Is the availability of fatty forage fishes (e.g., herring, capelin and eulachon) in the shelf environment the main determinant of population success?

b. How do populations and productivity of harbor seals fluctuate interannually and interdecadally?

c. Do populations of harbor seals fluctuate with the availability of fatty forage fishes (e.g., herring, capelin and eulachon) in the shelf environment?

d. How do populations and productivity of sea otters fluctuate interannually and interdecadally? Does food supply play the main role, or do disease and predation?

e. To what extent does transport of marine nitrogen from the GOA determine or limit the production of terrestrial bird and mammal populations?

Appendix C. B. 6. 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 EVOS 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?