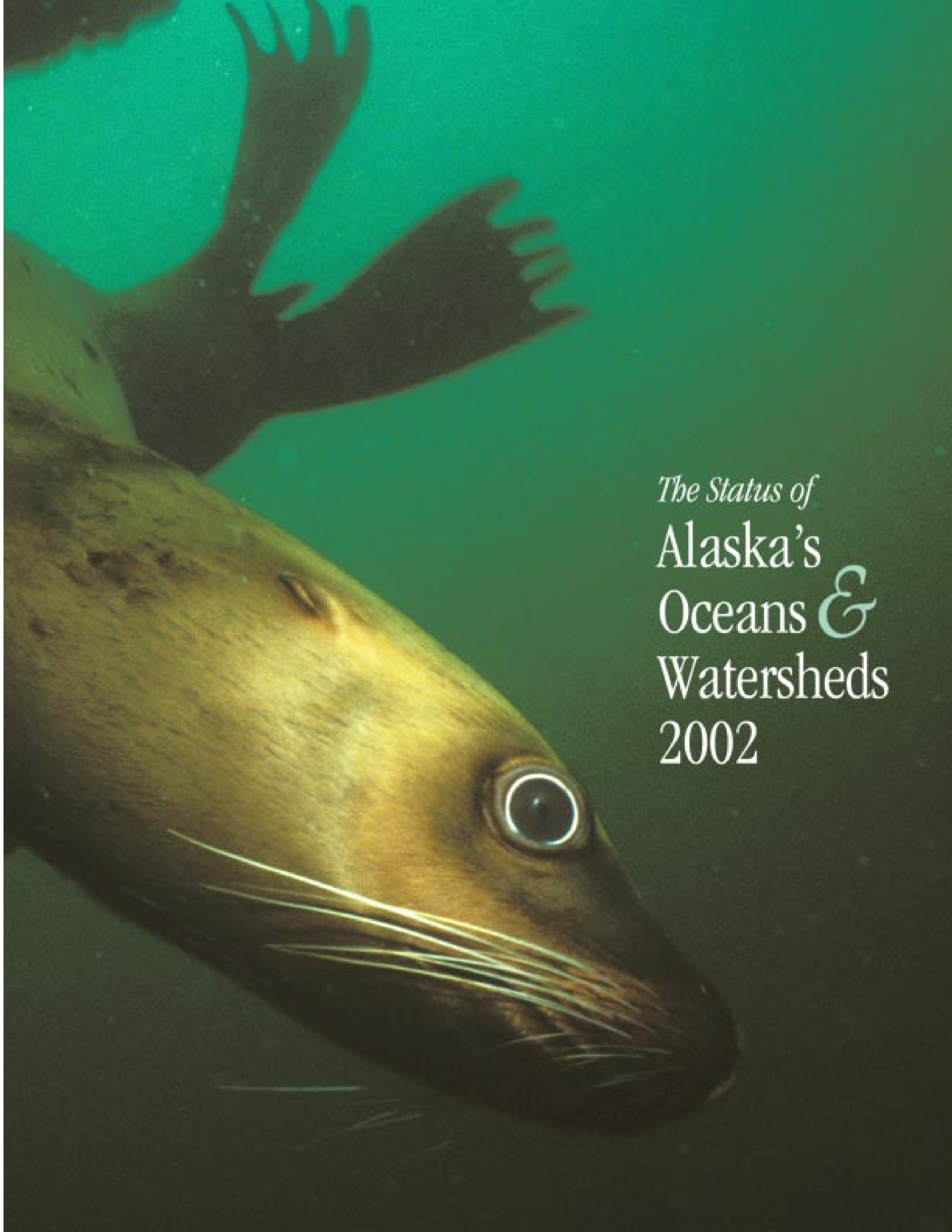


The Status of

Alaska's Oceans & Watersheds 2002

The information provided in this report is largely the result of a two-day symposium on Alaska's Oceans and Watersheds, held in Anchorage, Alaska on June 18 and 19, 2002. The symposium consisted of five invited talks and seven panel presentations covering issues such as the effect of climate on ocean carrying capacity; status and trends in Alaska's marine fish, shellfish, birds, and mammals; persistent pollutants in Alaska's environment; and how changes in technology and management can help ensure sustainable resource use.

The symposium was sponsored by the following organizations:

State of Alaska

University of Alaska

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

North Pacific Research Board

North Pacific Fisheries Management Council

Alaska Coastal Policy Council

Alaska Board of Fisheries

U.S. Geological Survey

U.S. Fish and Wildlife Service

U.S. Environmental Protection Agency

National Oceanic and Atmospheric Administration

The views in this publication are those of the authors and presenters and do not necessarily represent the views of the sponsoring organizations.

Cover/title page photo: sea lion. Inside cover: jellyfish. Back cover: starfsh.

Table of Contents

Introduction *6*

Alaska's Oceans and Watersheds Report Card *8*

The State of Alaska's Approach to Oceans and Watersheds Management *10*

Section I • Panel Presentations

1. Variability in Alaska's Salmon Stocks *15*
2. Variability in Pollock, Crab and Herring Populations *23*
3. Changing Bird and Mammal Populations in Alaska *31*
4. Impacts of Contaminants on Alaska's Wild and Traditional Foods *37*
5. Furthering our Ecological Knowledge with Changing Technology *43*
6. Perspectives on Ecosystem-based Management *49*
7. Ocean and Watershed Policies and Governance *55*

Section II • Invited Papers

8. Large Scale Climate Variability and the Carrying Capacity of Alaska's Oceans and Watersheds *64*
   Nathan J. Mantua, University of Washington, Joint Institute for the Study of the Atmosphere and Ocean
   Steven R. Hare, International Pacific Halibut Commission
9. Status and Trends of Alaska's Marine Resources: Fish, Birds and Mammals *76*
   Douglas P. DeMaster, Alaska Fisheries Science Center
   Alan M. Springer, University of Alaska Fairbanks
10. Persistent Organic Pollutants in the Alaskan Environment *86*
   Michael Smolen, World Wildlife Fund
11. Contaminants in Alaska: Is America's Arctic at Risk? *97*
   Carl Hild, Institute of Circumpolar Health Studies, University of Alaska Fairbanks
12. Oceans, Watersheds and Humans: Facts, Myths and Realities *111*
   Steve Colt, Institute of Social and Economic Research, University of Alaska Anchorage
   Henry P. Huntington, Huntington Consulting, Inc.

Affiliates *120*

Eshamy Lake drawing into Eshamy Lagoon, Prince William Sound, AK.
EVOS photo library.

Introduction

"To the lover of pure wildness Alaska is one of the most wonderful countries in the world . . . .Never before this had I been embosomed in scenery so hopelessly beyond description . . . .In these coast landscapes there is such indefinite, on-leading expansiveness, such a multitude of features without apparent redundance, their lines graduating delicately into one another in endless succession, while the whole is so fine, so tender, so ethereal, that all pen-work seems hopelessly unavailing. Tracing shining ways through fiord and sound, past forests and waterfalls, islands and mountains and far azure headlands, it seems as if surely we must at length reach the very paradise of the poets, the abode of the blessed."

~ JOHN MUIR, *Travels in Alaska, 1915* ~

Although Alaska has gone through many changes since John Muir first visited in 1879, it remains a land of vast and varied landscapes: from temperate rainforests and alpine mountaintops in the southeast, to interior boreal forests and taiga, and north to the North Slope coastal plain. Stretching 2,700 miles from east to west and 1,700 miles from north to south, Alaska has a land area of 586,412 square miles, making it the largest state in the nation and the only arctic ecosystem within the borders of the United States. It has about 55 million acres of inland waters and its boundaries are defined in large part by 47,000 miles of coastline. These oceans and watersheds are home to rich terrestrial and aquatic life, providing commercial, recreational and subsistence resources to many of Alaska's people.

The marine ecosystems surrounding Alaska are incredibly vast, complex and dynamic. Winds, waves and tides shape Alaska's coast and weather patterns and play a strong role in determining the distribution and abundance of marine resources. Tiny plants and animals called plankton form the base of a vast food web supporting most seabirds, marine mammals and fishes and making the cold and turbulent waters of the Gulf of Alaska and the Bering Sea among the world's most productive ocean regions.

The intertidal and shallow subtidal habitats in Alaska represent a variety of near-shore estuarine, fjord and exposed coastal settings. These habitats range from precipitous and rocky to gently sloping with muddy or sandy bottoms. Here microalgae, seaweeds and seagrasses support many invertebrates that, in turn, are food for fish, marine birds and mammals. These inhabitants include 100 million seabirds representing 66 species, 32 species of marine animals and huge marine fish stocks.

Extensive coastal watersheds provide spawning and rearing habitat for anadromous species such as Pacific salmon and eulachon, and nesting habitat for some seabirds like marbled murrelets. These areas also provide food for terrestrial species including bear, deer, moose, otter, and beaver. The carcasses of spawned-out salmon supply substantial amounts of marine-derived nutrients to the poorly nourished streams, lakes, and rivers used for their reproduction. In addition, dying salmon provide a food supply for many birds and mammals throughout the coastal range.

Bears, eagles and gulls are among those that benefit locally from this extensive forage resource. Alaska's diverse and abundant wetlands provide nesting habitat for 37 species of ducks, geese and swans with populations totaling more than 10 million.

The people of Alaska rely heavily on their oceans and watersheds. Anthropologists believe that Alaska's Native people originated in Asia, either crossing to Alaska over the Bering land bridge from Siberia or traveling by watercraft along the shorelines. While it is clear from archeological and Native history that people have lived in parts of Alaska for at least 10,000 years, there also is some evidence that colonization may have taken place thousands of years earlier. Many of Alaska's Native people today continue to follow the traditions of their ancestry by obtaining their livelihoods from the sea, and many Native communities still rely heavily on both terrestrial and aquatic resources for subsistence foods. The central role of marine fish and wildlife resources in the Native subsistence economies profoundly influenced the social organization of pre-contact societies and shaped their spiritual and cultural values. These resources play equally important economic and spiritual roles today.

Since the "discovery" of Alaska and through the period of colonization and then statehood, exploitation of natural resources has been the mainstay of the economy. Fishing, whaling, logging, mining, and other natural resource-based industries supported the early settlers and helped Alaska grow. The development of oil and gas greatly accelerated that growth. Even so, although oil revenues make up approximately 85 percent of the state government's budget, tourism, commercial fishing, logging, and mining are still vital components of Alaska's economy.

Alaska's environment is among the most pristine in the world, yet it is not immune to changes taking place both nationally and globally. The actual and potential impacts of natural or human-caused change, whether it is climate change, habitat loss or degradation, pollution, or unsustainable extraction of resource, are real. They signal a warning that Alaskans need to be proactive about understanding the causes of these changes and prepare to respond as needed to maintain a healthy ocean and coastal ecosystem.

Some of these changes are subtle and long term; others are startling and demand immediate attention. Steller sea lions have experienced a population decline of more than 80 percent in the eastern Bering Sea and western Gulf of Alaska. The fur seal population in the Bering Sea has declined by half since 1950, and in some regions, populations of seabirds such as thick-billed murres and red-legged and black-legged kittiwakes have also declined by 50 percent. The sea otter population in the Aleutian Islands has dropped by more than half in just the past five years. Some western Alaska salmon runs have experienced dramatic declines, even though most parts of Alaska have been blessed with healthy runs.

This report presents information gathered during the first *Alaska Oceans and Watersheds Symposium*, which brought together a variety of researchers, policy makers and community members to discuss the state of Alaska's oceans and watersheds. This two-day symposium, held on June 18-19, 2002 in Anchorage, Alaska, was the first attempt to feature in one place a discussion of the myriad ocean and watershed issues facing the state. The symposium included talks on topics ranging from the causes of variability in fish, bird and mammal populations, to recent concerns over the detection of contaminants in the Alaska arctic. Panel presentations addressed these and other issues from a variety of perspectives including academia, government, Alaska Natives, and industry.

Included in this report are papers based on the invited talks and summaries of the panel presentations. Both papers and panel summaries have been peer-reviewed, but it should be noted that the views expressed by the authors are not necessarily those of the symposium sponsors.

The very size of the topic area, and of Alaska itself, precludes comprehensive coverage of all ocean and watershed issues in the state in this single report. It is hoped, however, that this symposium made a start at identifying issues of concern where action is needed. Immediately following this introduction, we provide a *Status of Alaska's Oceans and Watersheds* summary based on the information in the report, as the beginning of what we hope will prove to be a helpful tool for resource managers, stakeholders and residents to use in managing, conserving and protecting Alaska's spectacular marine resources.

Watersheds

Alaska's size, sparse population, and general remoteness help ensure that most watersheds are relatively pristine. Localized water pollution is a concern in urban areas and near mining operations, seafood processing facilities, and forest products facilities.

Fisheries

of concern — **Salmon:** Total commercial harvest of Alaska salmon appears to be in decline since 1995. Competition with farmed salmon has significantly decreased the value of commercial salmon harvests.

good — **Groundfish:** Harvests have remained relatively high; however, localized declines have been detected.

of concern — **Crab:** Commercial landings of king crab have decreased significantly, especially in the Gulf of Alaska. Tanner and snow crab landings have been mixed, but are currently at low levels.

of concern — **Shrimp:** Commercial harvest of shrimp in the Gulf of Alaska and Bering Sea declined precipitously after 1988. Small amounts are still harvested in Southeast Alaska.

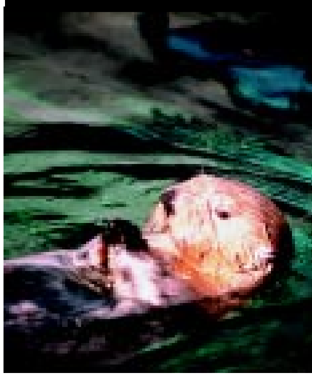
Traditional Foods

Alaska's traditional foods are healthful and beneficial. There is some concern about potential contaminants in traditional foods, but this concern is not sufficient to discourage use of these foods.

Fish & Shellfish

mixed	**Salmon:** Several salmon populations in the Gulf of Alaska appear to be declining, while populations in Southeast Alaska are stable or increasing.
good	**Pollock:** Most pollock populations are stable, with some declines being noted in the Gulf of Alaska.
of concern	**Herring:** Recently herring roe fisheries have been closed in some parts of SE Alaska, Prince William Sound and Cook Inlet as a result of low spawning populations. In Prince William Sound, the herring population continues to be at very low levels despite closures of the herring fisheries.
good	**Halibut:** Halibut stocks are believed to be in generally good condition.
good	**Groundfish:** Bering Sea and Aleutian groundfish stocks are believed to be in good condition, while those in the Gulf of Alaska are considered stable.
mixed	**Crab:** King crab populations in the Gulf of Alaska and Bering Sea have declined, while snow and tanner crab populations are fluctuating between high and low levels.
of concern	**Shrimp:** Shrimp populations have declined throughout the state.

Marine Mammals



of concern	**Sea lions:** The western Pacific population of Steller sea lions is in serious decline, while the eastern population appears to be stable.
of concern	**Seals:** Northern fur seal populations are considered depleted under the Marine Mammal Protection Act.
mixed	**Killer whales:** The population of one resident pod of killer whales in Prince William Sound decreased after the 1989 *Exxon Valdez* oil spill and has still not reach pre-spill numbers. Data on other pods, especially non-resident pods, are too sparse to identify specific population trends.
of concern	**Beluga whales:** Cook Inlet beluga whales decreased between 1994 and 1998, when new subsistence hunting regulations were implemented. Since 1999 subsistence harvest has been reduced; however, it is too early to tell whether population declines have been halted.
mixed	**Sea otters:** Sea otter populations in the Aleutian Islands have decreased significantly, while elsewhere in the state, populations are stable or increasing.

Seabirds, Sea Ducks and Sea Geese

of concern	**Red-legged kittiwakes:** Breeding colony counts have decreased by 50 to 70%; however, the rate of decline on St. George Island has decreased in recent years.
of concern	**Kittlitz's murrelets:** The Glacier Bay population, one of the largest, has declined by 80% in the past decade.
of concern	**Spectacled and Steller's eiders:** Spectacled eider populations have been steadily declining since the 1960s. Steller's eiders, once abundant on the Yukon-Kuskokwim Delta, have essentially disappeared.
of concern	**Emperor geese:** Abundance fell significantly in the 1960s, but appears to be increasing.

The State of Alaska's Approach to Oceans and Watersheds Management

The first photographs from space showed the earth as a planet of great oceans. Now, earth is known as the blue planet because three-quarters of its surface is covered by oceans. Yet, some of the blue may be turning brown as life is choked out of the world's waters. We must turn the tide. In Alaska, our environment, culture and economy are inextricably linked to the health of our oceans and watersheds.

No state is more blessed by, no state is more dependent upon, no state has more responsibility for and no state has more opportunity to benefit from the abundance of healthy oceans than Alaska. Our state's oceans are significant internationally; our rivers and watersheds are among the mightiest and most productive anywhere.

We are not immune from changes taking place nearby our home or on distant shores and our oceans are dependent on a change of attitude. Ecosystem-based management is the only rational way to bring science to bear on all of the interrelated issues. As our understanding of new science and management increases, we have changed our approach in recent years:

- The *North Pacific Anadromous Fish Commission* has worked on strategies for high seas fish research and policy.
- The *Sitka Salmon Summit* and recently negotiated Yukon River and Pacific salmon treaties recognize habitat, sustainable harvesting and the need for research.
- The state's *Salmon Management Program* was certified by the Marine Stewardship Council as sustainable, making it the first major fishery in the world to attain that status.
- *Operation Renew Hope* responded to disastrously low salmon returns by addressing the immediate needs of western Alaska families, fishermen and communities.
- With the *Bering Sea Task Force*, we saw how Alaska must act to provide a better understanding of marine ecosystems and a greater capacity to sustain healthy fish and wildlife populations through comprehensive and coordinated research.
- *Alaska Clean Water Actions*, in an inter-agency team effort, has made progress in keeping Alaska's waters clean.

(opposite page)
Visualization of planet earth
centered on the North Pole.
Photo courtesy NASA.

(right)
Orca.
EVOS photo library, Craig Matkin.

- *Fish habitat measures* have been established by the North Pacific Fisheries Management Council, Alaska Department of Fish and Game and the Board of Fish.
- *Ecosystem-based recovery measures* regarding declines in marine mammal species such as sea lions and Aleutian sea otters are progressing.
- Alaskans helped negotiate an *International Persistent Organic Pollutants Treaty* last year and legislation implementing the *National Persistent Organic Pollutants Treaty* is pending. Alaskans need to know our wild food will always be safe to eat, which means that the production and the distribution of persistent organic pollutants must be curtailed.
- The *Wild and Traditional Foods Safety Initiative* brought Native tribal leaders together with scientists and health experts, calling for a long term commitment to monitoring our wild foods.
- The Department of Environmental Conservation's *Fish Testing Program* will help ensure that Alaska's wild, naturally organic seafood remains so.
- Alaska pushed for *Cruise ship standards* to strengthen federal laws and standards for cruise ship gray water and sewage discharges, keeping Alaska's waters pristine.

Much has already been accomplished to protect the health of our oceans, which serves as an inspiration to accomplish what's next in line. With regard to sustaining Alaska's wild salmon heritage, we're working hard on the next steps of ensuring adequate in-stream flow, stronger habitat protection along interior streams, and providing safe passage or—as stated eloquently by Northwest tribal fishermen—gravel-to-gravel protection, for salmon throughout their life history.

Our goal is to sustain the productivity and richness of our oceans and watersheds, a goal shared by the Pew Oceans Commission, on which I'm honored to serve as chair of the governance committee. An independent group of scientists, business leaders, fishermen and elected officials, the Oceans Commission is tackling some of the thorniest issues facing America's oceans: pollution, coastal development, impacts of fishing and governance of ocean resources.

We must have a unified regional and national response that recognizes the critical importance of the next frontier of our oceans and watersheds. The time has come for a national ocean policies act—a sound policy to protect, sustain and restore the ocean's living resources, backed by a sustained and coordinated commitment to research.

We need grassroots support that brings a sense of urgency for action on these issues. So please join me in recommitting ourselves and our resources to better protect our oceans. Let's do everything we can to make sure the blue planet stays blue and that the next frontier remains a place of great beauty and great abundance.

These remarks were given as a keynote address by Tony Knowles, Governor of the State of Alaska from 1994-2002, at the Oceans and Watersheds Symposium in Anchorage, Alaska, June 18, 2002.

Section I:

Panel Presentations

13

2. Variability in Pollock, Crab and Herring Populations 21

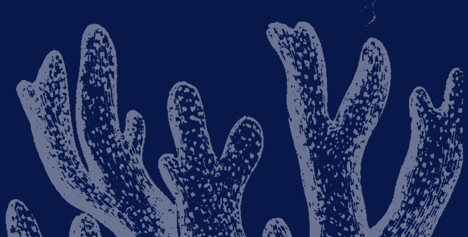
3. Changing Bird and Mammal Populations in Alaska 29

4. Impacts of Contaminants on Alaska's Wild and Traditional Foods 35

5. Furthering our Ecological Knowledge with Changing Technology 41

6. Perspectives on Ecosystem-based Management 47

7. Ocean and Watershed Policies and Governance 53



1. Variability in Alaska's Salmon Stocks

Panel Moderator:
Phillip R. Mundy, Science Director, GEM/Exxon Valdez Oil Spill Trustee Council

Population Levels are Fixed by Events During a Critical Period: Critical Size Hypothesis.
Richard Beamish, Fisheries and Oceans Canada

Is the North Pacific Ocean's Carrying Capacity for Pacific Salmon Limited?
Douglas M. Eggers, Alaska Department of Fish and Game

Ocean Carrying Capacity Program.
John H. Helle, Auke Bay Laboratory, National Marine Fisheries Service

Natural and Human-induced Limitations to Salmon Sustainability: Adjusting Expectations.
Eric Knudsen, Alaska Science Center, U.S. Geological Survey

The following is a synopsis of the above presentations and does not necessarily represent the views of individual panelists.

Sockeye salmon spawning.
Photo courtesy Alaska Division of Tourism.

1. Variability in Alaska's Salmon Stocks

Salmon have long been an important resource in Alaska, providing economic, recreational and cultural sustenance. All five species of Pacific salmon (pink, sockeye, chum, coho, and Chinook) are present in Alaska. Overall state-wide commercial salmon harvests have been at or near historic highs over the last two decades, although sockeye, Chinook and coho harvests have fluctuated downward since 1995. Geographic variation in harvest within species can be substantial, with western Alaska chum harvests approaching historic lows during the same two decades as the state as a whole experienced historic high chum salmon catches. In addition, the overall economic value of the harvests in recent years has declined significantly due to a number of complex worldwide factors, including increases in the production of farmed salmon. To manage salmon for continued, sustainable human use, managers must understand how natural cycles and human activities affect fluctuations in salmon abundance.

To manage salmon for continued, sustainable human use, managers must understand how natural cycles and human activities affect fluctuations in salmon abundance.

Natural Regulation of Salmon

As anadromous fish, salmon spend a portion of their life at sea and return to freshwater streams, rivers and lakes to spawn and die. As a result, variables in both freshwater and marine systems naturally regulate salmon abundance over the short and long term. It has been established within the last two decades that large scale, long term swings in salmon abundance and catches have occurred throughout Alaska's history. These long term swings have been associated with large scale environmental changes, such as increased or decreased ocean temperatures and major shifts in species biomass, that result from natural, and possibly human-induced (e.g., past high seas fishing), events. One way salmon cope with this extreme environmental variability is to evolve a large number of different stocks for each species. Large numbers of stocks maximize the opportunities for a species to survive and reproduce because stocks differ in how they respond to environmental fluctuations, and straying from abundant stocks helps to revitalize diminished populations. Stocks show heritable differences in traits such as time of spawning and ocean migration. These stock-specific traits determine how stocks interact with both short and long term environmental fluctuations. Recent research demonstrates that the geographic extent of individual salmon stocks can be very limited, with stocks demonstrating identifiably unique traits at the level of small streams.

The salmon life cycle begins when salmon eggs are deposited in the bed of a river, lake or stream. Young of all pink and chum salmon stocks move to saltwater soon after they are hatched. The young of all coho, most Chinook and nearly all sockeye salmon stocks on the other hand, remain in freshwater for one to three years before heading out to sea.

The amount of nutrients in freshwater systems may naturally regulate salmon abundance. Recent research suggests that knowing the number of salmon that are allowed to escape, spawn and then die in freshwater may be essential in determining the number of salmon that a given water body can produce. Nutrients from decomposing salmon may play a critical role in determining the carrying capacity of freshwater systems for salmon production. One study on the Karluk Lake system *(figure 1.1)* on Kodiak Island has used stable isotopes of nitrogen in sediment core samples from the lake as a surrogate for sockeye salmon escapement. The results of this study suggest that the total return of sockeye salmon biomass to the Karluk Lake system fluctuated widely for hundreds of years, but declined dramatically with the advent of commercial fishing, which decreased the number of salmon that were allowed to spawn and die in the lake. This decrease may have reduced the amount of nutrients available to support food production for juvenile salmon in the early stages of their life, which thereby reduced the ability of the Karluk Lake system to produce sockeye salmon.

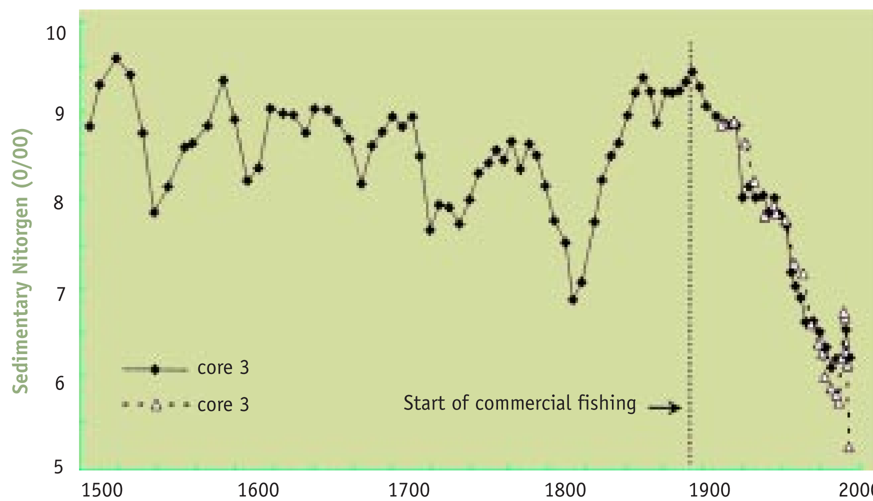


figure 1.1
Nitrogen Content of Karluk Lake

Sedimentary marine-derived nutrients as a surrogate for historic, pre-harvest escapement in Karluk Lake. While populations appear to have fluctuated naturally, the total delivery of biological inputs to the freshwater system appears to have been reduced once fishing began.

Credit: Schmidt et al. 1998.

Of those salmon that eventually enter the ocean, about 90 to 98 percent may die before they can return to their natural streams to spawn. Thus, even a small change in ocean survivability can make a large difference in the number of salmon that return to spawn. The first marine year is one of the most critical periods for determining ocean survivability. During this year, salmon entering the ocean encounter a period of predation-based mortality that is most severe for the smaller sizes of young salmon. To avoid predation and survive, salmon must grow to reach a critical size beyond which the mortality due to predation is thought to be diminished. Growth-based mortality occurs when juvenile salmon are unable to obtain sufficient food and grow to a large enough size to be able to survive the winter. Growth-based mortality is present in all ecosystems, but in some systems, it may play a more important role in determining the number of salmon that will survive to reach adulthood.

Research conducted in Canada's Gulf of Georgia suggests that this ecosystem may be food-limited, such that the overwinter mortality is as high as 80 to 95 percent of the total volume of coho salmon entering the strait. Additional data from scale analysis shows that fish that grew faster during the first summer in the marine environment were also the fish that had the best chance of surviving the first winter. In a system such as this, where salmon abundance is naturally regulated by the abundance of food and the ability of juvenile salmon to reach a critical size, salmon survivability is highly density-dependent.

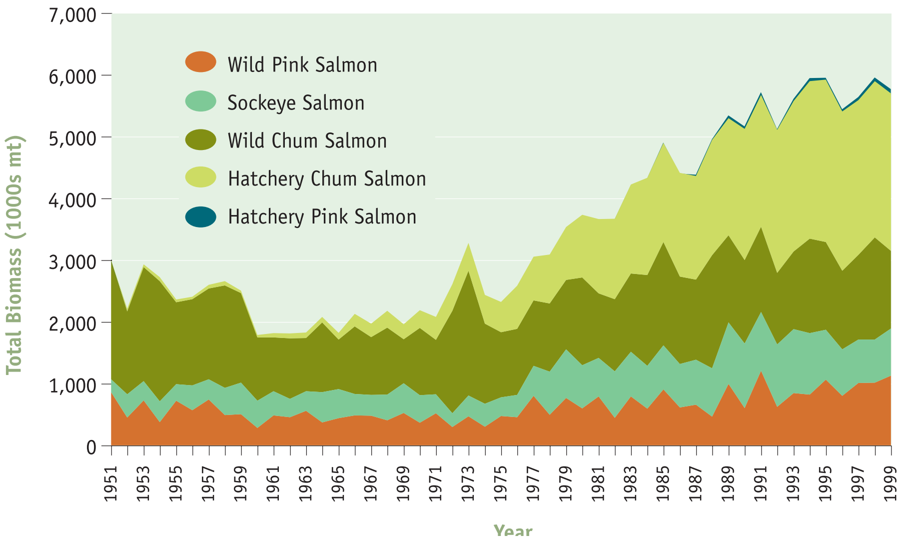


figure 1.2

Biomass of Pink, Chum and Sockeye Salmon in North Pacific Ocean

Hatchery production has doubled the biomass of salmon in the North Pacific Ocean since the 1970s.

Credit: Eggers. 2002. Oceans and Watersheds Symposium Presentation. Anchorage, AK.

The addition of hatchery fish may be able to overcome, to some extent, the loss of juveniles from predation and thereby increase the number of adults. However, in food-limited environments the addition of hatchery fish increases competition among juvenile salmon, reducing the number of fish that are able to reach critical overwintering size, and thereby reducing survivability of both hatchery and wild stocks in the area. Before management decisions can be made, it is important to assess whether predation-based mortality or growth-based mortality is the primary factor in determining the number of salmon that will survive to adulthood.

Hatchery Impacts

Since 1951, hatchery production has doubled the biomass of salmon in the North Pacific Ocean, with most of this growth occurring since the early 1970s *(figure 1.2)*. Several studies have demonstrated that, as the biomass has increased, both the size and age of salmon at maturity have decreased.

The results of a study which analyzed data on the size of wild chum salmon returning to Fish Creek in Southeast Alaska and the Quilcene River in Washington State compared to Japanese and world hatchery production of chum salmon show a negative correlation between hatchery production of chum salmon and the size of male, wild chum salmon returning to both Fish Creek and the Quilcene River. These results suggest that while the limitations of "ocean carrying capacity" may not be apparent in the overall annual numbers of salmon, it may be apparent in the total weight, or biomass, of salmon produced annually.

The cap on total annual salmon biomass, or carrying capacity of the ocean for salmon, means that artificial increases in abundance from sources such as hatcheries or fish farms, could have negative impacts on some wild stocks of salmon in the form of reductions in production due to lowered growth potential and changes in age at maturity.

Support for the concept that reduced production of some wild chum stocks could occur as a consequence of lowered growth potential and changes in age composition of spawners comes from a long time series available for Prince William Sound, Alaska. The 20-year time series showed that, when the mean length of returning chum salmon was lower than average, survivability of offspring was indeed reduced.

Sustainable Salmon Management

Most of the freshwater habitat essential to salmon production in Alaska remains in pristine condition, allowing salmon populations to flourish when ocean conditions favor high productivity. Relatively pristine habitats, sound management of salmon stocks and proactive protection of habitats during development of other natural resources have all contributed to maintaining quality salmon fisheries. The Alaska Department of Fish and Game was among the first management agencies in the nation to formally adopt protection of habitats and genetic diversity of stocks as salmon management principles (Sustainable Salmon Fishery Policy 2000).

Although a large proportion of Alaska's many salmon runs still exhibit high productivity, the status of salmon stocks varies geographically. Some salmon stocks have been significantly diminished; others are currently experiencing extreme variability in abundance; and still others appear to have been extirpated entirely. While overall chum salmon harvests in Alaska are at, or near historic highs, much of this increase can be attributed to chum harvests in Southeast Alaska, which are largely due to hatchery production. *Figures 1.3a,b,c* provide a graphic illustration of this situation. *Figure 1.3a* presents catch data for chum salmon throughout Alaska, while *figures 1.3b and 1.3c* show similar data for northern and southcentral Alaska combined and for the Yukon River drainage area alone. Formerly abundant chum salmon stocks in western Alaska have been in significant decline since the 1980s.

The reasons why some stocks appear to be increasing while others are decreasing are complex, having to do both with natural variation in stocks and with management decisions that affect salmon abundance. Alaska salmon management is moving into a new realm as the state continues to search for more effective salmon research and management programs to fully implement the provisions of the Sustainable Salmon Fishery Policy adopted in 2000. As Alaska's fisheries scientists watch and learn from threatened runs in Pacific Northwest fisheries and the demise of Atlantic salmon, some important shifts in salmon science are occurring that can lead to improved management.

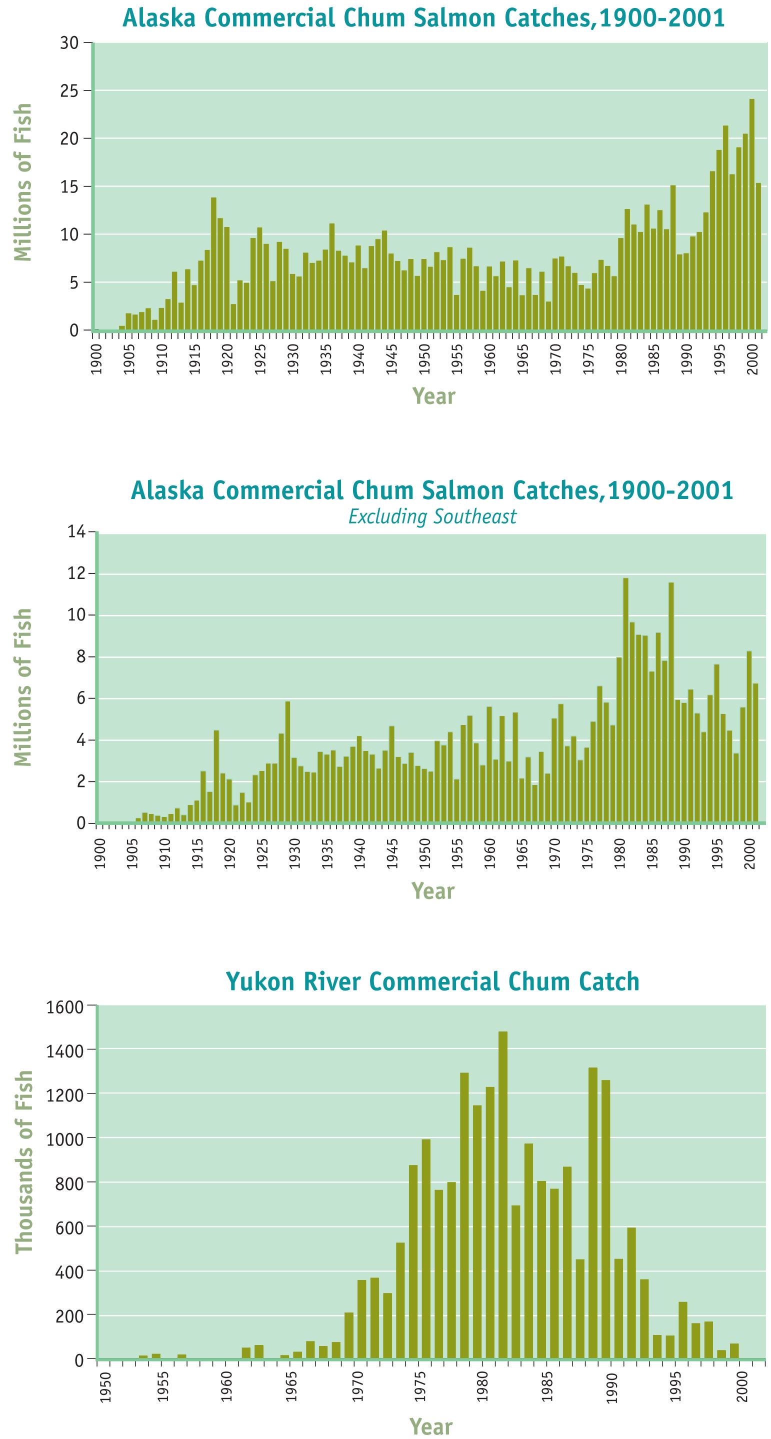


figure 1.3a,b,c

Commercial Chum Catches from 1900-2000

Regional differences can be present even in seemingly healthy salmon populations.

Credit: Eric Knudsen. 2002. Oceans and Watersheds Symposium. Anchorage, AK.

Until recently, fisheries management operated on the assumption that salmon stocks should provide harvest at predictable levels that correspond to past escapement levels through time.

To manage salmon stocks sustainably, it is necessary to recognize the scales of variability, both geographic and temporal, that influence salmon productivity throughout the salmon's life cycle. Under the previous management paradigm, salmon stocks within a watershed were treated as a single population. Current research in genetics suggests that individual salmon stocks may actually be composed of multiple unique spawning populations. It is theorized that specialized spawning populations evolve within a stock to maximize use of available habitat. Such evolutionary processes operate to create multiple populations within individual stocks and bring about differences among stocks. Observed and apparent differences among stocks in traits determining survival and growth such as ocean migration patterns, need to be taken into account when deciding whether to treat a salmon stock as a single unit, or as a collection of unique populations for management purposes. Approaches to fishery regulation such as setting levels of allowable harvest and spawning escapement goals need to be based on an understanding of differences in survival traits both within and among stocks.

Until recently, fisheries management operated on the assumption that salmon stocks should provide harvest at predictable levels that correspond to past escapement levels through time. That premise is now under challenge, with managers questioning how escapement goals are set and whether current approaches are really maximizing production of all the stocks and species of concern. Standard management practice has been to set goals based on historical productivity and observed sizes of salmon escapements. Using standard methods, in periods of changing productivity, such as occurred from the late 1970s to the early 1980s, escapement goals were not sufficient to take advantage of the conditions at the time. New modeling approaches consider various life history features, climatic and oceanographic conditions, natural variability and abundance within populations, and the effect of marine nutrients on freshwater carrying capacity. In addition, the potential impact of hatchery enhancement on salmon abundance and the natural limitations of the ecosystems into which the hatchery fish will be released now need to be considered in management decisions.

Panel Moderator:
Chris Oliver, Executive Director,
North Pacific Fisheries Management Council

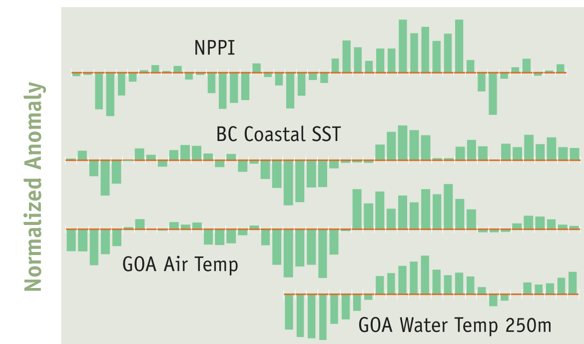
Predation as a Controlling Factor in the Groundfish Populations of the Eastern Bering Sea.
Jesus Jurado-Molina, University of Washington

Recruitment-Mediated Control of Herring in Prince William Sound.
Brenda L. Norcross
University of Alaska Fairbanks

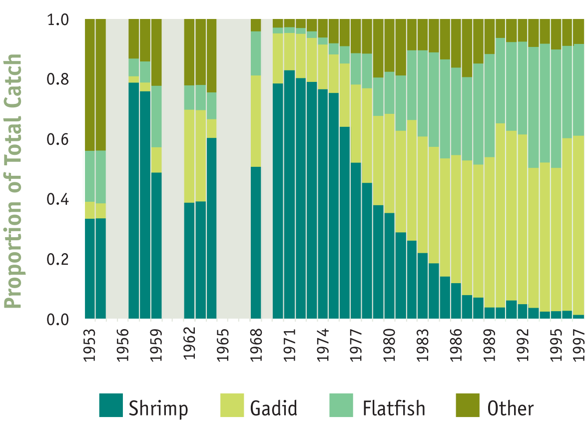
Mechanisms of Climate Impacts on the Ecosystem.
Carol Ladd, Pacific Marine Environmental Laboratory,
National Oceanic and Atmospheric Administration

How Crab Populations are Controlled by Climate-mediated Variability.
Gordon H. Kruse, University of Alaska Fairbanks

2. Variability in Pollock, Crab and Herring Populations



Changes in Air and Water Temperatures in the Gulf of Alaska



Variation in Small Mesh Trawl Catches in the Gulf of Alaska between 1953 and 1997

figures 2.1a, b

Note the complete transition in catches following the climate regime shift in the late 1970s when water temperatures (BC Coast SST and GOA water temperature) went from being colder than average to warmer than average.

Credit: Anderson and Piatt. 1999.

The complex of groundfish species is the most abundant of all fisheries resources off Alaska, totaling more than 21 million metric tons of biomass. Prior to the passage of the Magnuson-Stevens Fishery Conservation and Management Act in 1976, foreign fisheries accounted for most groundfish landings off Alaska. Since the mid-1980s however, the domestic groundfish fishery in Alaska has grown dramatically by replacing foreign and joint venture fisheries. In contrast, the fate of Alaska's shellfish fisheries has been much more variable. Some of the shrimp species have been severely depressed since the late 1970s, while crab populations have fluctuated through a series of highs and lows. Recent theory suggests that a shift in North Pacific ocean temperatures during the 1970s caused a change in overall biomass composition, with the amount of pollock and other groundfish increasing and the amount of shrimp and other forage fish decreasing (*figures 2.1a,b*).

Data indicate that as the populations of some species go up, others go down. A basic shift started with Alaska's groundfish and other marine fish in the early 1980s. Most of the groundfish species in the North Pacific increased at a significant rate during the 1980s, leveled off in the mid-1990s, and have remained at a fairly high level since then. Within that general aggregate pattern, some individual species are declining while others are increasing.

Biomass of pollock in the eastern Bering Sea and Pacific halibut throughout Alaska appear to be at near record levels, although biomass of pollock in the Gulf of Alaska has declined to pre-1977 levels. In both the Bering Sea and Gulf of Alaska, Pacific cod biomass has been declining steadily after achieving peak levels in the late 1980s. The biomass of many flatfish species showed a strong increasing trend in the 1980s and a moderate decreasing trend in the 1990s. Exceptions include Greenland turbot in the Bering Sea, which has declined steadily since the early 1970s, and arrowtooth flounder in the Gulf of Alaska, which remains near record levels of abundance after a dip in the late 1990s.

In common with other temperate and subarctic marine ecosystems, variability is largely attributed to fluctuations in recruitment, a dominant and natural feature of these marine populations. Recruitment is the amount of fish added to the stock each year due to growth and/or migration. Patterns in variability do exist, but determining the causes of population fluctuations is not simple, and subtle long term trends and patterns are often difficult to discern.

Pollock

Approximately 40 percent of the total U.S. commercial fishery landings by weight come from the Bering Sea. Walleye pollock is the dominant groundfish species in the Bering Sea in terms of biomass and catch. It plays important roles in the ecosystem as prey and predator in relation to other Bering Sea species. One of the important characteristics of Walleye pollock is its high rate of cannibalism, which is a mechanism by which the species controls its own population. Recent multi-species modeling efforts have demonstrated that cannibalism is the main component of predation on pollock less than one year old, but less so for age one pollock, where several predators are involved. Pollock populations exhibit a classic predator-prey relationship: as the adult pollock population increases, the juvenile population decreases, and vice versa. This pattern has implications for fisheries management, since fishing at some levels and under certain climate scenarios may have a positive effect on recruitment by removing adult pollock that are the primary predators of age zero pollock recruits.

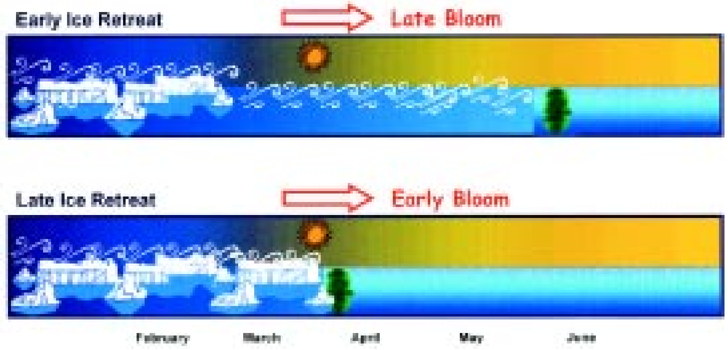


figure 2.2

Role of Ice and Wind in Determining the Timing of Spring Phytoplankton Bloom in the Bering Sea

Studies have shown that the timing of the retreat of sea ice determines the timing of the spring phytoplankton bloom.

Credit: Hunt, G. L., Jr., P. Stabeno, G. Walters, E. Sinclair, R. D. Brodeur, J. M. Napp, and N. A. Bond. 2002. Climate change and control of the southeastern Bering Sea pelagic ecosystem. Deep-Sea Res. II., in press.

Climate also plays an important role in determining the abundance of pollock. Studies conducted in the Bering Sea have shown that the timing of the retreat of sea ice determines the timing of the spring phytoplankton bloom (*figure 2.2*). During cold periods, the phytoplankton bloom occurs early in the year and the timing of the bloom is disconnected from zooplankton predators. Because zooplankton are the primary food of juvenile pollock, this results in less food for juvenile pollock, lower juvenile survivability, and thus, fewer adults. This process, which is driven by the availability of food at the lower trophic levels, is referred to as a "bottom-up" process. During warm periods, the opposite is true. Larger amounts of phytoplankton and zooplankton result in larger populations of juvenile pollock and, eventually, a larger number of adults. Through cannibalism, the larger number of adults exerts a "top-down" control on young pollock.

It appears that the system is thrown out of balance when there are extended warm or cold periods. During extended warm periods, the large pool of juvenile pollock results in a large number of cannibalistic adults feeding on them. This cannibalism exerts downward pressure on the juvenile pollock population. When the climate switches back to a cold regime, the combination of reduced food availability (decreases in phytoplankton and zooplankton) with this downward cannibalistic pressure creates extreme pressure on the juvenile population. This causes a significant decrease in juvenile survivability, with corresponding impacts on future adult populations (*figure 2.3*).

figure 2.3

Oscillating Control Hypothesis

Changes in ocean temperatures result in changes in juvenile and adult pollock abundance.

Credit: Hunt, G. L., and P. J. Stabeno. 2002. Climate change and the control of energy flow in the southeastern Bering Sea. Prog. Oceanogr., in press.

Model runs that simulate the timing and water temperature during the spring bloom over the past 50 years suggest that six of the eight coldest bloom temperatures occurred since 1989, which may indicate that the Bering Sea is currently in a cold regime where pollock productivity is controlled by bottom-up forces. These data also suggest that there is significant inter-annual variability in the Bering Sea that may play a stronger role than the regime shift variations that are hypothesized to be influencing productivity in the Gulf of Alaska.

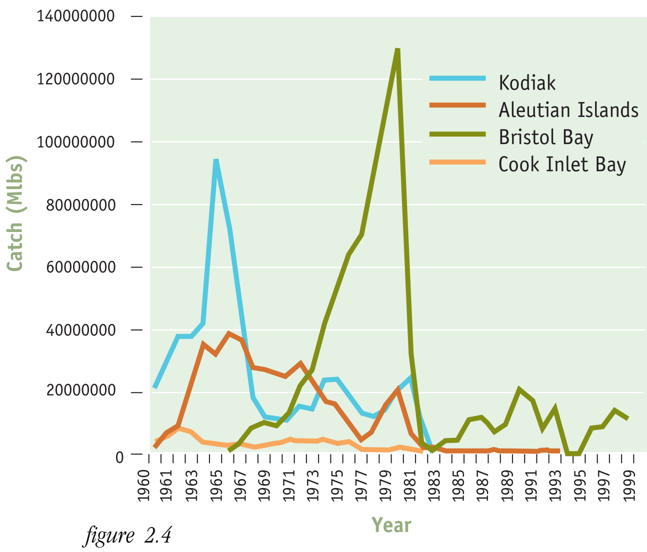


figure 2.4

Red King Crab Population Fluctuations, 1960-1999

Crab populations have peaked in different areas at different times.

Credit: Kruse. 2002. Oceans and Watersheds Symposium. Anchorage, AK.

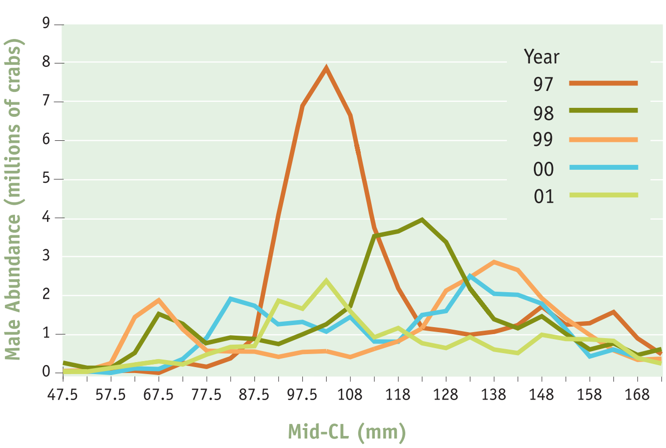


figure 2.5

Red King Crab Male Abundance, Bristol Bay, 1997-2001

Natural mortality appears to have resulted in significant decline of crab stocks.

Credit: Kruse. 2002. Oceans and Watersheds Symposium. Anchorage, AK.

Crab

A suite of crab species is commercially fished in Alaska. Some of the more important species are red king crab, blue king crab, Dungeness crab, Tanner crab, and snow crab. Like other commercially important species, crab populations are also subject to significant variability. *Figure 2.4* shows the variability in commercial landings of red king crab at several locations from 1960 through 2000. Crab populations have peaked in different areas at different times. However, in most areas of the state, king crab fisheries have been closed since 1983 due to low abundance.

Several factors determine whether crab populations increase or decrease. One obvious factor is recruitment. Recruitment is defined as the number of young crab that enters the adult population. Crab populations will increase when the number of young crab added to the adult population exceeds the number of crab that is lost due to natural mortality or fishing. Likewise, the population will decrease if natural mortality or fishing pressure removes more adult crabs than are replaced by juvenile recruits.

Natural mortality in some instances, such as in the Bristol Bay king crab fishery in 1980 (*figure 2.5*), seems to have been catastrophic and resulted in the significant decline of crab stocks. The reasons for this are not clear. Data indicate that mortality occurred in crabs of all sizes and both sexes. Thus, this mortality cannot be explained by excessive fishing pressure, because fisheries are limited to the harvest of larger-sized males. The length of time it takes juvenile crabs to reach the legal size limit for commercial fishing depends on the crab species, rearing location, and other factors. Red king crab in Bristol Bay can take between six to nine years to mature to legal size from the time juveniles first settle on the sea bottom. Thus, strong year classes (high abundance) for crab species are formed long before fisheries for those crabs occur. This provides an additional argument for the assertion that the severe reduction in commercial catch of red king crab in Bristol Bay in 1980-81 was not the result of overfishing of crab stocks in the late 1970s, but rather, a result of a recruitment failure that occurred several years earlier. However, there were specific years in which harvest rates were excessive, and there are several ways in which fishing can adversely affect crab populations, such as bycatch mortality or changes in size and sex structure.

Fisheries can also impact crab stocks through the stock recruitment relationship. Fairly strong evidence exists for density dependence in crab recruitment, especially for Bristol Bay red king crabs. When adult abundance is low, recruitment is also low; when adult abundance is high, recruitment remains low. The highest level of recruitment occurs in years when stock levels are intermediate. Research shows that the late 1960s and early 1970s were generally favorable for red king crab recruitment. However, recruitment declined during the 1970s and 1980s and remained low through the 1990s, with the exception of a single moderately strong year class in 1989-1990. Until 1967, Japanese and Russian fisheries dominated the king crab fisheries in the Bering Sea, but those fisheries were phased out in 1974.

While fishing may alter adult stocks sufficiently to adversely affect recruitment, environmental conditions appear to play a more important role in determining recruitment patterns of most crab populations. However, fishing may have larger impacts when crab populations are at low abundance after extended periods of recruitment failures. Accordingly, management plans now include lower harvest rates and fishery thresholds (stock levels below which fishing is not permitted) to mitigate adverse synergistic effects of fishing and unfavorable environmental conditions on declining crab stocks.

Photo courtesy Susie Byersdorfer, Alaska Department of Fish and Game. 2002.

Recent research has examined the relationship between crab recruitment and changes in the physical environment, such as weather and ocean temperatures. For king crab, this analysis has focused on the relationship between recruitment and large scale weather events, such as the Pacific Decadal Oscillation (PDO). The PDO is associated with variability in sea surface temperatures in the North Pacific and is strongly coupled to the sea level pressure patterns and thus, to changes in near-surface winds. Under the warm phase of the PDO, the Aleutian Low Pressure system is intensified, resulting in stronger winds and enhanced vertical mixing of the upper ocean in the North Pacific. It is theorized that these stronger winds reduce the abundance of diatoms *(Thalassiosira)*, which are the preferred prey of king crab larvae, and thus, result in lower king crab recruitment.

While fishing may alter adult stocks sufficiently to adversely affect recruitment, environmental conditions appear to play a more important role in determining recruitment patterns of most crab populations.

For other species, such as Tanner crab in Bristol Bay, there is a weaker relationship between adult stock size and recruitment, and it is hypothesized that three physical features combine to influence recruitment: warm bottom temperatures may enhance gonadogenesis and embryo development; warm surface temperatures enhance production of the copepod *nauplii*, the preferred prey of Tanner crab larvae; and winds blowing from the northeast may favor settlement in offshore habitats with fine sediments where young crabs can bury to reduce exposure to benthic predators, such as Pacific cod.

Crab reproduction is extremely complex and investigations of crab recruitment remain in their infancy. In the next several years, dynamic simulation models coupled with both laboratory and field trials are expected to yield some more useful information on the relationships between recruitment and environmental factors. They may reveal more subtle ways in which fishing may alter crab reproduction.

Herring

For herring, good survival depends on survival variability at each growth stage. The challenges that individual fish encounter throughout their life cycle are immense. Survival is dependent on multiple factors: number of adults, water movement, currents, predation, waves, food, temperature, disease, and more.

The juvenile stage for herring, especially the first year, is very important for determining survivability to adults. Juvenile herring survival is higher when there are more adult (age 4) herring to spawn. Spawning time is mid- to late April in Prince William Sound. One female herring will lay 20,000 to 50,000 eggs. Eggs are deposited in intertidal and shallow subtidal areas, with egg mortality caused by waves, currents, bird predation, and dehydration. Approximately 24 to 45 percent of the eggs laid survive to hatch. Additional mortality occurs within the first five days of hatching as larvae that are physically or genetically defective die off. Natural factors are often responsible for these defects, but they can also be caused by human activities, such as oil spills.

During the late spring and early summer, currents carry the juvenile herring from the hatching areas to the nursery grounds, usually in semi-enclosed bays. Research has estimated that only one to seven percent of the larvae survive to reach the nursery areas. The herring remain in the nursery areas through October to feed, where they are also preyed upon by many species of birds, fish and mammals. This predation can reduce the population by an additional 79 to 99 percent. Survival through the winter depends on how much food the larvae are able to consume before November, how large they are going into the winter, and the conditions of the particular bay. Winter survival is highly variable, ranging between five and 99 percent (*figure 2.6*).

The foregoing discussion provides some indication of the natural mortality in herring populations through the first year. It is estimated that for each million herring eggs laid, between one and 6,500 will survive the first year. Thus, the large number of natural factors impacting herring survival complicates management of herring stocks. In addition, human factors, such as fishing pressure and pollution, add additional complexity and variability to management decisions. Because the natural factors are beyond their control, fisheries managers have focused on protecting the adult spawning biomass as the best way to protect the herring population.

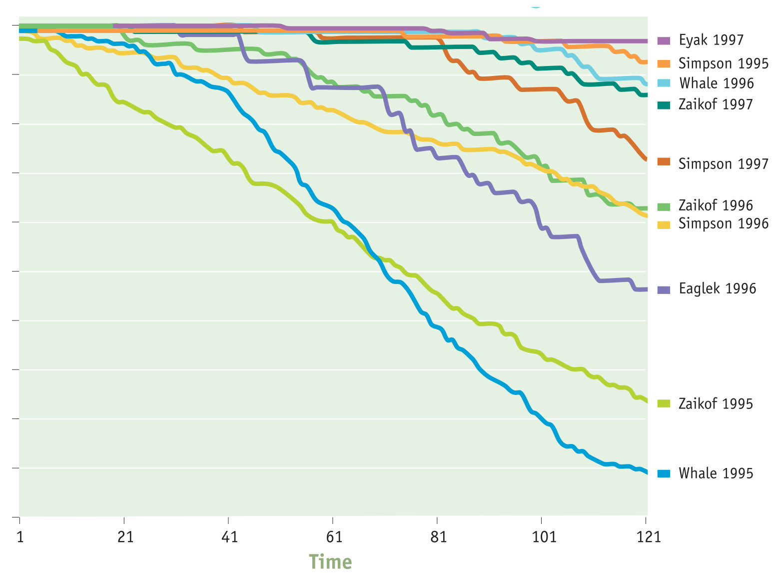


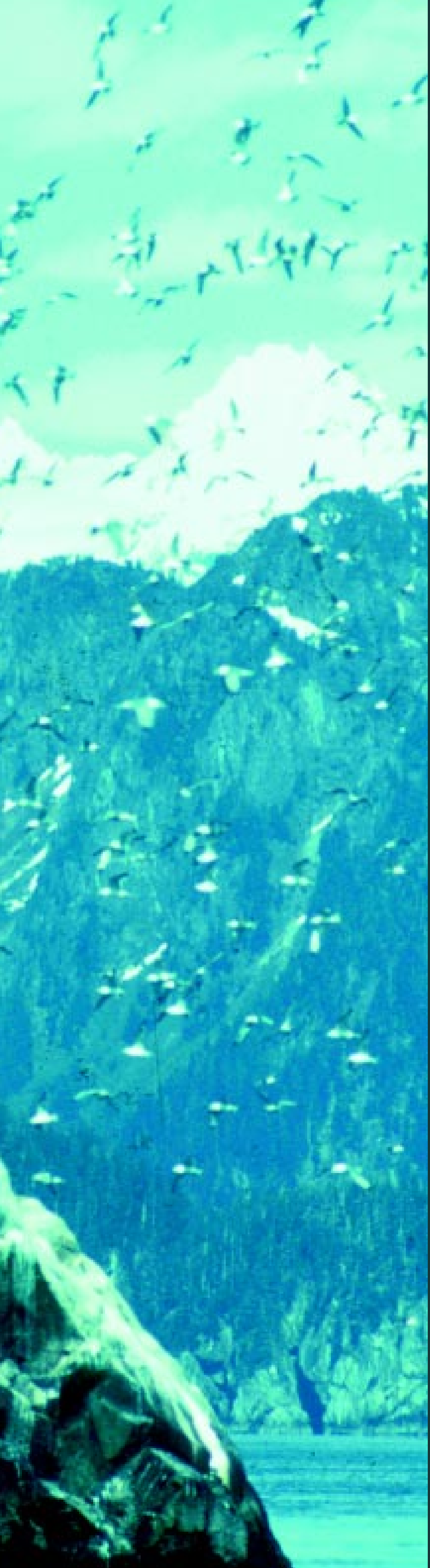
figure 2.6

Over-Winter Survival of Pacific Herring

Overwintering energetics model predicts proportional total over-winter survival of Pacific herring for various locations in Prince William Sound.

Credit: Norcross, 2001. Fisheries Oceanographer, Vol. 10, Supplement 1.

Herring research.
EVOS photo library.



3. Changing Bird and Mammal Populations in Alaska

Panel Moderator:
David Irons, Alaska Seabird Coordinator, U.S. Fish and Wildlife Service

Factors That Can Cause Changes in Marine Bird Populations.
Vernon Byrd, Alaska Maritime Refuge

Why is Anyone Surprised that Steller Sea Lions Have Declined in Western Alaska?
Lloyd Lowry, Alaskan Biologist and Fisherman

Seabirds, Forage Fish and Marine Ecosystems.
John F. Piatt, Alaska Science Center, U.S. Geological Survey

That is My Garden.
Caleb Pungowiyi, Robert Aqqaluk Newlin Sr. Memorial Trust

The following is a synopsis of the above presentations and does not necessarily represent the views of individual panelists.

3. Changing Bird and Mammal Populations in Alaska

A shift in ocean climate, reflected by temperature changes during the late 1970s, is believed to have played a significant role in changing the composition of the fish and invertebrate communities in the Northern Gulf of Alaska from a system dominated by shrimp and forage fish to one dominated by pollock, cod and other groundfish. During the transition, trawl catch biomass declined by half, but recovered to pre-transition levels by the late 1980s. These changes may be partly responsible for some of the changes that have occurred and are continuing to occur in marine predators such as seabirds, sea lions and other marine mammals.

Many factors influence populations of marine predators, and they operate over a wide range of temporal and spatial scales. Since it is difficult to study marine mammals and seabirds at very large spatial scales, most research is conducted when species come together in feeding and reproductive aggregations and are easily counted and observed. As a result, much of the life history data on these animals has been collected from only a few areas and during relatively short time periods.

Even at small spatial scales, it is difficult to measure how changes in the type and availability of prey affect aggregation behavior and foraging success of marine predators. Foraging takes place under water and is difficult to observe. In addition, for many marine predators (particularly large mammals) it is generally not feasible to collect individuals and determine what they have been eating. As a result, it is not easy to answer questions about the extent to which fishery reductions influence the density of prey species and whether or how they adversely impact marine predators.

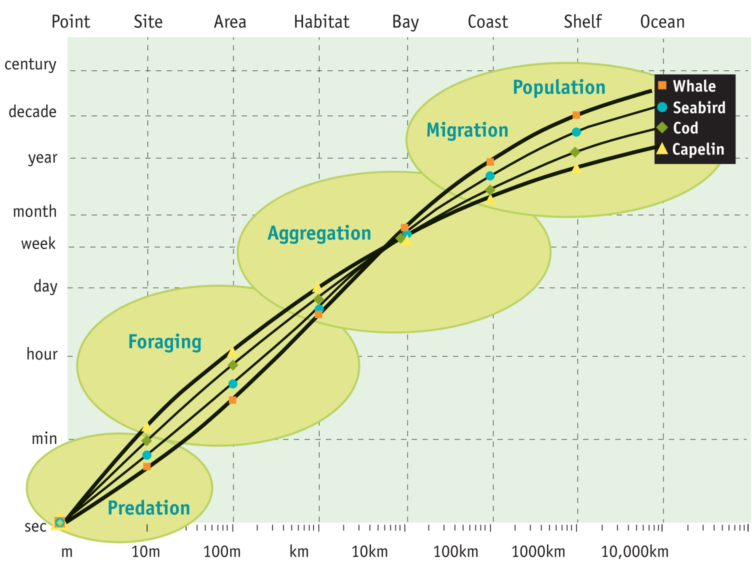


figure 3.1

Spatial and Temporal Scales for Studying Marine Predators

Populations of higher vertebrates such as seabirds, whales and other marine mammals take years or decades to increase or decline in response to environmental changes, and the factors that cause these changes may function over scales of meters to thousands of square kilometers.

Credit: Piatt. 2002. Oceans and Watersheds Symposium. Anchorage, AK.

Birds

Indicators of change

Seabirds are often used as indicators of marine ecosystems because they are relatively easy to study, are widespread, and gather in large multi-species colonies, so that inferences can be based on more than one species. Research conducted following the *Exxon Valdez* oil spill has contributed to understanding the way in which seabird populations are regulated by food supply. Water temperatures and local oceanography can markedly influence the geographic distribution and abundance of different forage species. Similarly, water temperatures may influence the depth distribution of prey, which in turn may affect where and how deep seabirds and marine mammals need to dive in order to obtain food.

Different bird species react differently to changes in the density of their prey. Kittiwakes for example, exhibit a strong functional relationship between fledgling success and prey density: when food is scarce, kittiwakes fail to produce fledglings; when food is abundant and above a certain critical threshold, kittiwake fledgling success is high and independent of further fluctuations in prey abundance. With common murres, on the other hand, the relationship between food abundance and fledgling success is not strong. Murres are able to adjust their foraging behavior in response to changes in food supply, so their time budgets provide a better measure of variability in food.

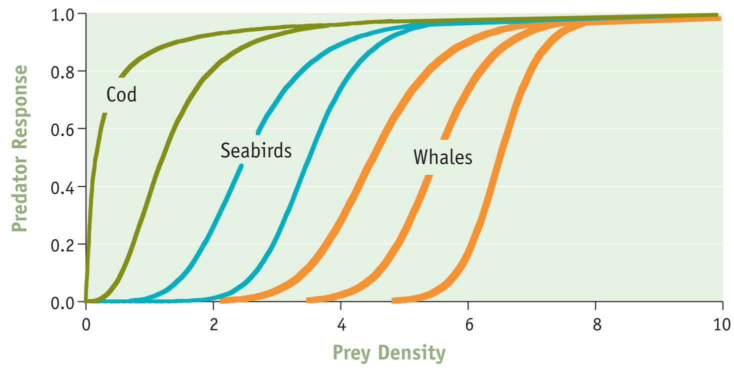


figure 3.2
Theorized Relationship between Prey and Density and Predator Populations

When prey densities fall below threshold levels, populations decline abruptly; when prey densities increase above threshold values, predator populations also increase.

Credit: Piatt. 2002. Oceans and Watersheds Symposium. Anchorage, AK.

Because there is a strong relationship between food abundance and fledging success in kittiwakes, historical records of breeding success can be used to evaluate past decadal changes in the overall marine ecosystem. Research has shown that before the 1970s, kittiwakes were rarely deprived of food or limited by food. In the 1980s, the number of kittiwake colonies exhibiting breeding failure increased dramatically. Some improvements in fledgling success in the Gulf of Alaska and the Bering Sea were observed in the 1990s, but foraging conditions are apparently far inferior to those of the 1970s. The relationships between prey density and marine predator success are probably mostly nonlinear, and different animals have different thresholds (*figure 3.2*).

In addition to large scale changes in the ecosystem, changes in marine bird populations also can be caused by other factors that can affect birds both at nesting sites on land and on their marine feeding grounds. In Alaska, these are primarily introduced species on islands, contaminants, and fisheries, particularly bycatch of seabirds themselves.

Introduced species

The two most serious predators of seabirds and other marine birds on Alaska islands are foxes, particularly Arctic foxes, and Norway rats. Arctic foxes were introduced for commercial fur harvesting on as many as 450 islands throughout Alaska in the 1930s and earlier. The growing fox populations had a devastating effect on local bird populations, in some cases leading to local extirpation of individual species. In the 1950s an active program was initiated to remove foxes from the islands of the Alaska Maritime National Wildlife Refuge. The removal of foxes from 38 islands to date has led to an increase in some marine bird populations in this area.

Norway rats were also introduced on a number of islands in Alaska beginning in about 1800. Rats have always been notorious stowaways on ships, and most rat populations on Alaska islands started with rats escaping from ships that ran aground or visited these islands. Norway rats have a profound negative impact on populations of marine birds, with certain species, such as the red-legged kittiwake, being especially vulnerable to rat predation. Today, a number of islands that formerly supported seabird populations are infested with rats, and seabird populations on these islands as a result, have declined dramatically.

Contaminants

In addition to introducing non-indigenous species, boat and ship traffic also has the potential to result in oil spills and chronic oiling. Both oil spills and dumping of oily bilge water can cause significant mortality of marine birds. As a result of past oil spills and continuous bilge water dumping, marine birds are being exposed to chronic oiling in Alaska. It is not clear to what extent this continuous, low-level oiling adversely impacts marine bird populations, but it is potentially significant.

Airborne persistent organic pollutants are also a concern for marine bird populations. The extent of the impact is not known, but some transport of these pollutants through the food web is likely. With recent improvements in technology and techniques for monitoring the spread of these pollutants, it is hoped that more information on their effects will be known in the near future.

Other contaminants can also significantly affect marine bird populations at a local level. Lead poisoning from the ingestion of lead shot left in wetlands as a result of hunting has been a particular problem for both the spectacled eider and the Steller's eider. Because the impacts are localized, it is unlikely that lead poisoning is a significant contributor to overall marine bird declines.

With recent improvements in technology and techniques for monitoring the spread of persistent organic pollutants, it is hoped that more information on their effects will be known in the near future.

Fisheries

Fisheries are known to have mixed effects on marine bird populations. For gulls, particularly glaucous-winged gulls, the discards from fisheries may have provided supplemental food and possibly caused populations to increase. This population increase may be causing ecosystem-level impacts as a result of competition between gulls and other birds that use the same nesting areas. Alaska Natives who depend on seabirds and eggs for subsistence food are concerned that the increase in glaucous-winged gull populations is having a negative impact on populations of other bird species. These gulls are proficient predators that prey upon the young of other gulls and many other bird species.

For other bird species, fisheries may have had significant impacts on populations through direct mortality. For example, in the early to mid-1970s, the Japanese high seas drift gillnet fishery for salmon operating in the Bering Sea and close to the Aleutian Islands is believed to have resulted in five million seabird deaths over a 20-year period. The passage of the Magnuson-Stevens Fisheries Conservation and Management Act in 1976 ended this fishery near Alaska, but it continued west of 175° W in the Aleutian Islands until the late 1980s. The use of drift gillnets was banned under international treaty in 1994. Since that time, populations of murres, puffins and fulmars have been increasing in western Alaska.

Longline fisheries and nearshore gillnet fisheries can also contribute to marine bird mortality. Fulmars and albatrosses are particularly vulnerable to accidental hooking by longlines as they are deployed off the boat, while diving birds such as Kittlitz's murrelets and common murres are susceptible to being caught in nearshore gillnets. Because of the impact of longline fisheries on the endangered short-tailed albatross, significant research and effort have been invested in reducing bycatch of marine birds from longline fisheries, with some positive effects.

Mammals

Marine mammal populations in Alaska are undergoing changes, with populations of some baleen whales increasing while populations of Steller sea lions have been declining. Marine mammals are long-lived species: their populations take decades to grow and in natural circumstances they would be expected to decline slowly. As a result, impacts that occur during a single breeding season may not become evident in the population for several years or decades. One example of this may have occurred as a result of the early loss of sea ice off western Alaska during 1996 and again in 2001. Alaska Natives reported the stranding of numerous juvenile seals, believed to be associated with the premature breakup of the ice pack. How this will affect populations of these species in the future is not known.

As apex predators, marine mammals are in competition with humans for fish. Marine mammals and fisheries compete and interact in several ways with significant impacts: a fishery can remove marine mammal prey (such as groundfish); it can remove the food of marine mammal prey (forage fish); or a fishery can remove the competitor for a marine mammal (for example, Pacific halibut and sea lions share similar diets).

In their natural state, marine ecosystems do not contain excess biomass that can be harvested by humans through fisheries without some type of corresponding impact to the other predators that would use that biomass. Groundfish fisheries in the Bering Sea remove about two million metric tons of groundfish each year, and similar fisheries in the Gulf of Alaska remove on the order of 200,000 metric tons. According to the data and models used by fisheries managers, the fisheries have reduced pollock stocks in the Gulf of Alaska by 74 percent over what they would be without fishing, and by 55 percent in the Bering Sea. Marine mammals, such as Steller sea lions, compete directly with commercial fisheries for these valued resources. The annual amount of groundfish removed by fisheries from the Bering Sea is equal to the annual food requirements of about 300,000 Steller sea lions (6.4 metric tons per sea lion per year)and it's not available to be eaten by Steller sea lions, or other non-human predators. Because of this competition, researchers are concerned that fisheries have reduced the availability of prey for some marine mammals, and fisheries may therefore be having an adverse impact on marine mammal populations (*figure 3.3*).

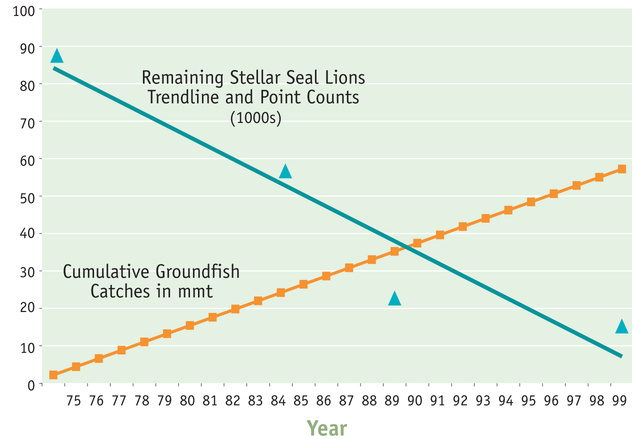


figure 3.3

Comparison of Groundfish Catches and Steller Sea Lion Population Numbers

Credit: Lowry. 2002. Oceans and Watersheds Symposium. Anchorage, AK.

Effects on Indigenous People

Many coastal communities in rural Alaska are dependent on the ocean for food, which is important to a subsistence, cultural, and sharing lifestyle. Because people in these communities use these resources, they are keenly aware of changes in these resources around their villages. Subsistence harvest data could be used as an indicator of relative abundance of some marine bird and mammal species. People in coastal villages are concerned about changes in the ocean ecosystem because, when changes that occur in the oceans cause declines in the animals that people eat, these coastal communities suffer.

Sea lions.
Photo courtesy Alaska Division of Tourism.

4. Impacts of Contaminants on Alaska's Wild and Traditional Foods

Panel Moderator:
Michele Brown, former Commissioner, Alaska Department of Environmental Conservation

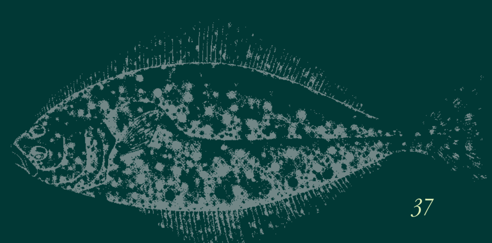
Community Partnerships and Concerns.
Patricia Cochran, Alaska Native Science Commission

Impacts of Persistent Organic Compounds and Heavy Metals on Traditional Foods and Alaska Native Health.
James E. Berner, Alaska Native Tribal Health Consortium

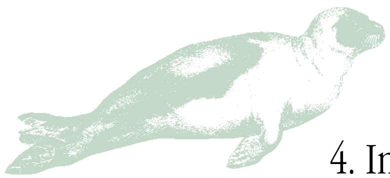
Challenges in Managing, Monitoring and Interpreting the Impacts of Contamination on Wildlife and Traditional Foods.
Todd O'Hara, Department of Wildlife Management, North Slope Borough

Contaminants in Seafood: Marketing Consequences and their Repercussions for Alaskans.
Randy Rice, Alaska Seafood Marketing Institute

The following is a synopsis of the above presentations and does not necessarily represent the views of individual panelists.



Fish camp on the Yukon River.
Photo courtesy ADF&G, John Hyde.



4. Impacts of Contaminants on Alaska's Wild and Traditional Foods

Wild and traditional foods are the dietary and cultural lifeblood of Alaska's indigenous people and the backbone of the Alaska economy — from commercial and sport fishing to tourism. For Alaska Native communities the statewide average annual harvest of wild foods is 400 pounds per person, rising to 600 pound per person in some remote areas. Fish, especially salmon, make up the majority of this harvest (*figure 4.1*). Alaska Natives eat six and one-half times more fish than other Americans. Traditional foods provide inexpensive and readily-available nutrients, anti-oxidants, calories, and high-quality protein. These traditional components protect against diabetes and cardiovascular disease and improve maternal nutrition and neonatal and infant brain development. In most rural Alaska communities often there is no comparable, accessible and economically feasible alternative for traditional foods.

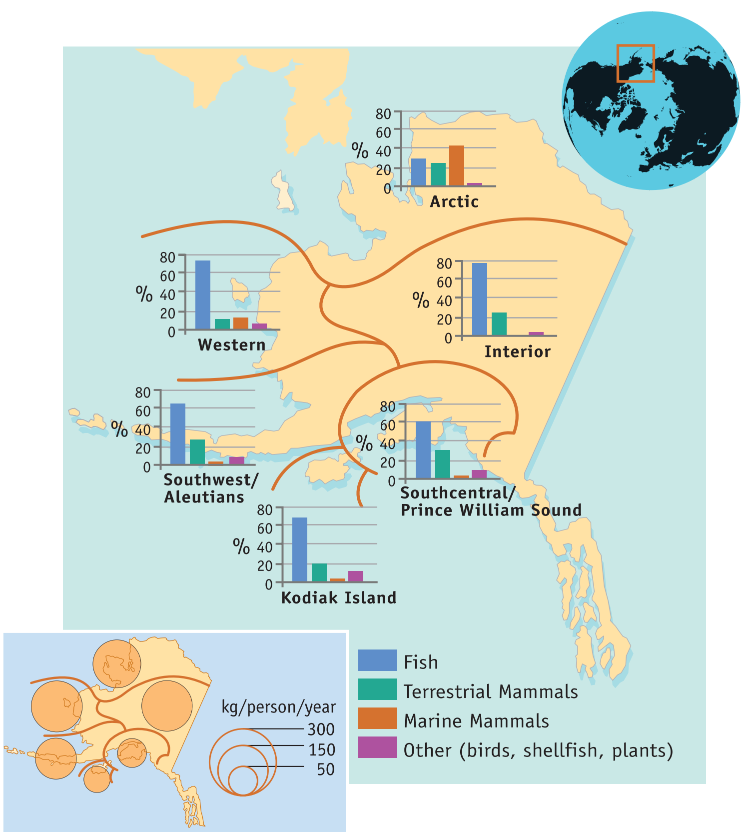


figure 4.1

Total and Composition of Subsistence for Small and Mid-side Communities in Selected Areas of Alaska

For Alaska Native communities the statewide average annual harvest of wild foods is 400 pounds per person, rising to 600 pound per person in some remote areas.

Credit: Arctic Monitoring and Assessment Programme, AMAP Assessment Report, Arctic Pollution Issues, Fig.5.5. 1998.

Presence of Contaminants

The correlation between environment and human health is particularly important when it comes to wild and traditional foods. Potentially harmful contaminants are being found in Alaska's air, water, fish, plants, and wildlife. The most serious of these contaminants are persistent organic pollutants (which include the pesticides aldrin, endrin, chlordane, DDT, heptachlor, mirex, toxaphene, and hexchlorobenzene), PCBs, and dioxins and furans, as well as heavy metals, including mercury, cadmium, and lead.

These contaminants reach Alaska primarily by atmospheric and ocean transport. Persistent organic pollutants and heavy metals remain in the environment long after they are released and move from air and water into soil, plants, animals, humans, and eventually into the food web. Persistent organic pollutants accumulate in fat, whereas heavy metals generally accumulate in organs and muscle. Adverse effects from exposure can result in reproductive, immunological, neurological, and developmental effects and cancer.

Health Effects

While traditional food has a long and robust health literature to support its beneficial effects, there is little research on the effects of potential contaminants in these kinds of food on human health at low levels of exposure. This lack of information, added to the fact that rural Alaskans are exposed to mixtures of these contaminants, makes it very difficult to discern the effect of any specific agent on human health or to provide adequate information to communities on the risks associated with eating traditional foods that may contain chemicals of concern. Contaminant levels have been measured in small studies of selected Alaska Natives. One study analyzed age and gender relationships to PCB concentration levels demonstrating increased levels with age (*figure 4.2*). Because these sample sizes were very low, few conclusions can be drawn and broader research is needed to answer key questions and address community concerns.

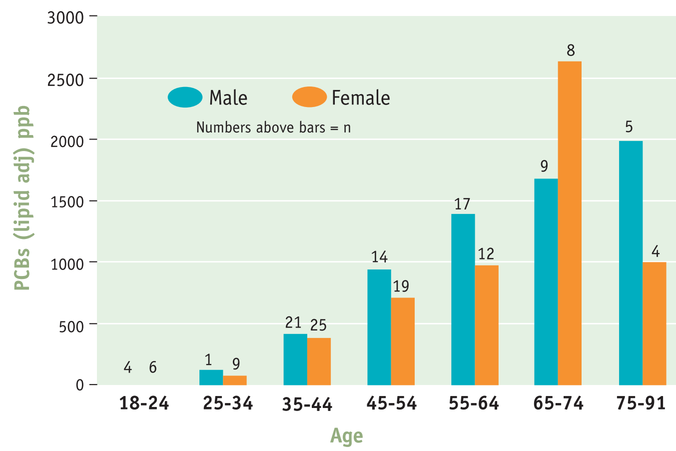


figure 4.2
PCB Levels — Gender Specific

Distribution of serum PCB concentrations in Aleutian volunteers are related to participants' age and gender.

Credit: Middaugh et al. 2000.

In the U.S., research on the health effects of contaminants in traditional foods has been uncoordinated and undirected, creating confusion within rural communities on whether traditional foods are safe to eat. Even though contaminants may not cause detectable morphologic or physiologic diseases in food sources, the knowledge of their presence has a profound impact on the way that Native people view the ecosystem and their interactions with wildlife. Some Alaska Natives have begun avoiding certain traditional foods or have stopped eating certain parts of foods, such as internal organs, because of knowledge that the foods contain contaminants.

In 1997, the Arctic Monitoring and Assessment Program, composed of ministers from the eight arctic rim countries including the U.S., issued its first report highlighting the risks posed to human health and wildlife from persistent organic pollutants. The recommendation from this report was that native peoples should continue to use the traditional foods and to breast-feed infants. When traditional foods, or economically feasible alternatives of equal nutritional value, are not available or are not consumed, Alaska Natives tend to consume more saturated fat and inadequate amounts of key nutrients. Health experts have concluded that the well known benefits of breast feeding and a traditional diet outweigh suspected, but not fully understood, effects of contaminants.

Persistent organic pollutants and heavy metals remain in the environment long after they are released and move from air and water into soil, plants, animals, humans, and eventually into the food web.

Developing fetuses and children are the main concern for low level, chronic exposure to contaminants. Adverse health effects are more likely to be discernible in fetuses and children than in adults. Mercury levels in women and children from the Yukon-Kuskokwim Delta and North Slope participating in the Arctic Monitoring and Assessment Program Human Health Maternal/Infant Monitoring Program averaged 6.1 micrograms per liter of maternal blood. The level of concern for mercury established in Canada is 20 micrograms per liter of maternal blood, indicating that exposure levels in the study participants were relatively low. In contrast, the benefits from breast feeding are known to be significant. For example, a study conducted in the same area showed that the risks of severe respiratory syncytial virus infection were greatly reduced by breast feeding. This virus can be extremely dangerous to Alaska Native infants.

Research Needs

More research is needed on the impacts of environmental contaminants on humans. Currently, contaminant concentrations measured in tissues of wild animals do not allow for interpretation of the health effects on humans that consume those animals. Determining concentrations in biota could address long term trends, but it will not address the question of whether eating these animals is safe. An understanding of natural variability is also critical for interpretation of the data being collected. For many animal populations there is insufficient information to know what constitutes a healthy population and how to draw inferences on the health effects of contaminants on specific species or groups.

Alaska Natives observe changes in the lands and the health of the animals as they go about their daily activities. For this reason it is critical that the end users, the people who most need the information, be involved in designing and implementing studies to assess the health effects of contaminants. Research results need to be presented in a manner that will help rural Alaskans make informed choices on what foods they should be eating and whether the presence of contaminants outweighs the overall benefits of a traditional diet. Native communities need to be involved on every level, including tracking exposures and effects, evaluating risks and benefits, and strengthening educational outreach.

Photo courtesy Alaska Division of Community & Business Development.

Marketing Messages

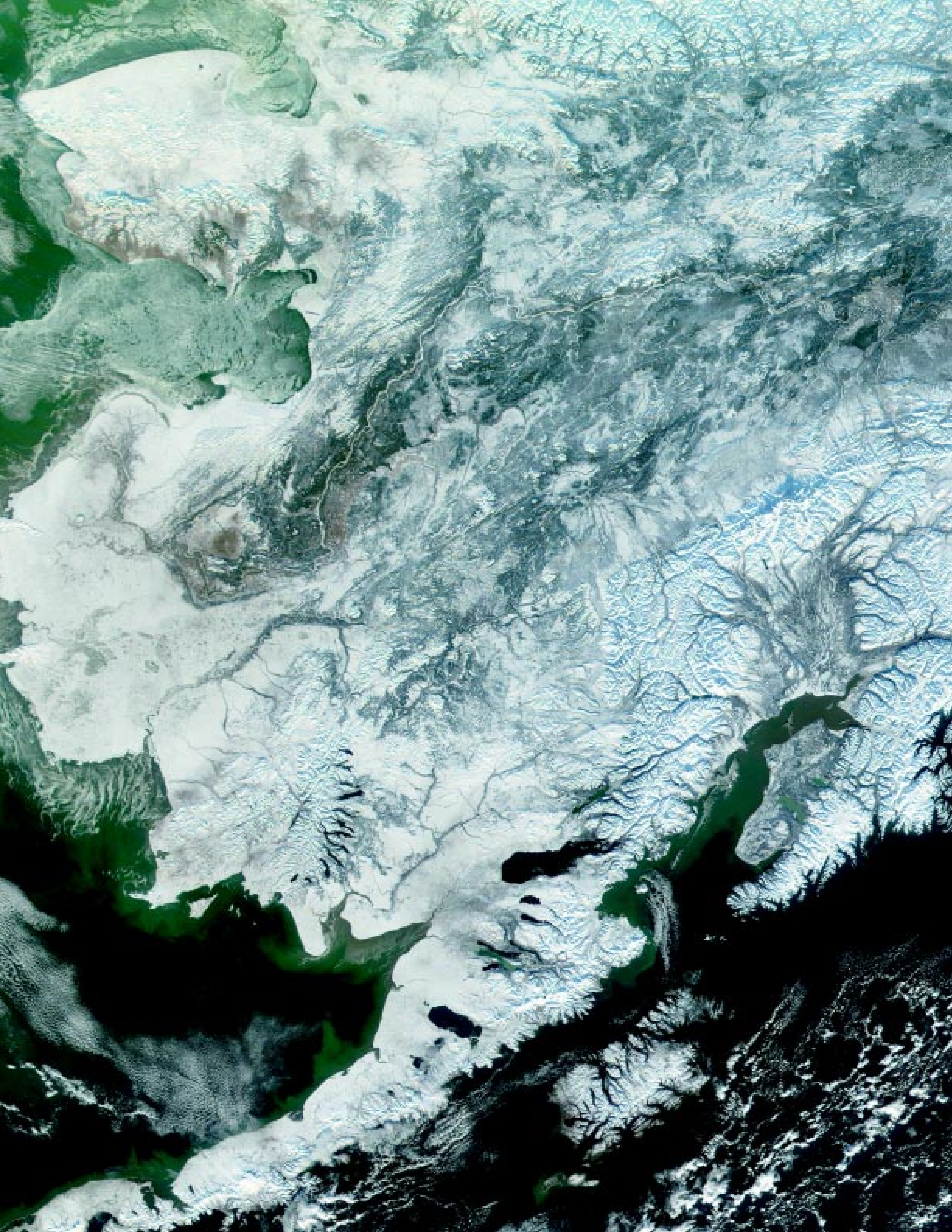
Rural Alaskans are not the only people who eat Alaska wild foods. Alaska fishermen supply 89 percent of the world's wild salmon and 28 percent of the world's commercial seafood harvest. Information on possible contaminants in wild foods must be presented in a manner that puts the issue into a larger context. For example, a 1988 scientific paper reported that organochloride contaminants had been found in sockeye salmon off Alaska. This report specifically stated that the levels of this contaminant were well below the levels of concern for human consumption, and further, that these levels are 10 times lower than those found in salmon in the Baltic Sea and 20 times lower than salmon from Lake Ontario. In spite of this, a newspaper headline read, in part "… toxins catch a ride on salmon: migrating fish bring back pollutants, study finds." Situations like this can cause consumers to stop purchasing Alaska seafood. The perception of the Alaska seafood in the marketplace has a direct link to the economic health of coastal and rural communities in Alaska which, in some areas, depend almost exclusively on commercial fishing.

What's Being Done

The Alaska Department of Environmental Conservation has implemented a fish safety monitoring program that will sample several species of fish at 21 locations throughout the state. The program will help identify current levels of over 135 individual chemicals including heavy metals, pesticides, PCBs, dioxins, furans, and brominated fire retardants. This information will be used to determine the baseline level of contaminants so that the department can track trends. The data from the study will also be compared to federal action levels for each of the contaminants, and this information reported back to communities. The department is also developing a state strategy to begin monitoring contaminant sources, with recommendations for reducing or eliminating exposure from these sources.

An organized approach is needed to properly evaluate the real risks posed by these contaminants to human health. The Alaska Department of Environmental Conservation is working with partners to form a new paradigm for collaborative research and monitoring on wild and traditional foods. The goal is to implement a wild and traditional food safety program modeled after the Canadian Northern Contaminants Program. This program is a collaboration among the Canadian Department of Indian Affairs, other federal agencies, territorial governments, aboriginal organizations, and universities. The aim of the program is to reduce and, where possible, eliminate contaminants in traditionally harvested foods, while providing information that assists informed decision-making by individuals and communities in their use of foods.

An organized approach is needed to properly evaluate the real risks posed by these contaminants to human health.



5. Furthering Ecological Knowledge with Changing Technology

Panel Moderator:
Vera Alexander,
Dean, School of Fisheries and Ocean Sciences,
University of Alaska Fairbanks

Advances in Deep Sea Technology.
Marcia McNutt,
Monterey Aquarium Research Institute

New Jersey Shelf Observing System.
Scott Glenn, Institute of Marine and Coastal Sciences,
Rutgers University

Electronic Tagging and Tracking in Marine Fishes.
Jennifer L. Nielsen, Alaska Science Center,
U.S. Geological Survey

Using Remote Sensing Information to Study Alaska's Oceans.
S. Lyn McNutt,
Geophysical Institute and Institute of Marine Science,
University of Alaska Fairbanks

The following is a synopsis of the above presentations and does not necessarily represent the views of individual panelists.

(photo left)
Satellite image taken on November 7, 2001 with clear skies over Alaska. Cook Inlet appears flooded with sediment, turning waters muddy brown. Across the Aleutian Range of the Alaska Peninsula, the bright blue and green swirls indicate phytoplankton populations.

Credit: Jacquwa Descloitres, MODIS Land Rapid Response Team, NASA/GSFC.

5. Furthering Ecological Knowledge with Changing Technology

Many new technologies developed previously by industry can provide the oceanographic community with the capabilities necessary for the next generation of observational and decision-making solutions. Adaptation of these technologies requires only small incremental investments from the marine science community to apply new cutting-edge strategies to the needs of Alaska's coasts and watersheds. A description of some of the new technologies presented at this meeting follows:

Moorings

Oasis moorings are solar-powered and fitted with a microwave transmitter that allows two-way, real-time communications with the shore. These moorings use physical, chemical and biological sensors located from the surface down to several hundred meters depth to identify and monitor seasonal fluctuations, climate changes, and annual variability in the ocean. These measurements, in turn, provide the information necessary to study climate regime shifts that might affect the ocean environment, such as El Niño.

Data from this type of mooring have been used in Monterey Bay, California, to distinguish times when the ocean is colder and more productive versus times when it is warmer and less productive. For example, an observed temperature increase of +0.4°C in Monterey Bay resulted in a 25 percent decrease in primary productivity for the region, which then affected the habitat of the bay.

Woods Hole Oceanographic Institute's (WHOI) autonomous underwater vehicle (AUV) *Benthic Explorer* being deployed.

Photo courtesy WHOI.

Autonomous underwater vehicles

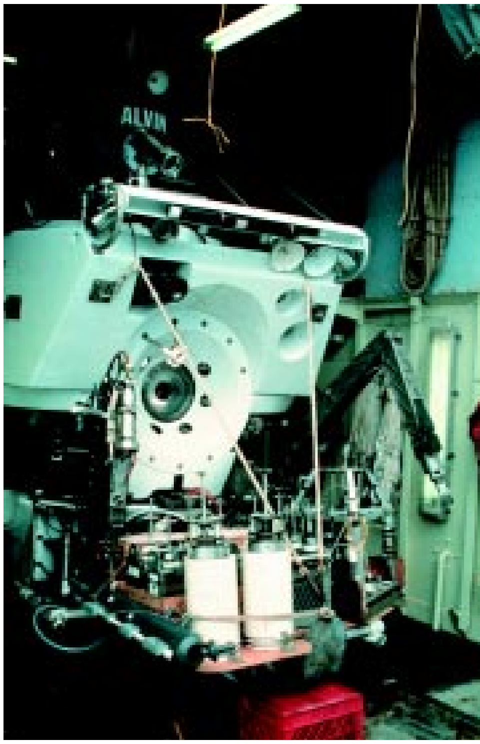
The current generation of autonomous underwater vehicles (AUVs) can execute complex, preprogrammed missions; they can go where remotely operated vehicles and human operated vehicles are unable to travel. Considering the low cost of these AUVs, these capabilities make the Odyssey class vehicles very effective to use in many types of oceanographic studies.

As an example, a Dorado-class AUV recently traveled under the Arctic Ocean as part of the Altex Project. The objective was to track the intrusion of warm, saline Atlantic water through Fram Strait and into the Arctic Ocean, recording the increased ice melt occurring due to this warm water intrusion. This exchange of Atlantic water is believed to be a result of global warming, and may have drastic consequences for the world's climate. The AUVs obtained a more dense sampling, at lower cost, and more quickly than could be achieved using the more traditional data collection method, an ice breaker.

New sensors and sampling technologies

There are new sampling technologies which allow for continuous observation from AUVs and *in situ* moorings. Now, an environmental sampling instrument on a mooring or an AUV, combined with an on-board processor can take water samples on a preprogrammed schedule, analyze the samples, then send the results to a shore-based terminal. An example of the use of such instrumentation is the near-real-time detection of a harmful algal bloom, such as a Red Tide.

Ultraviolet spectrometers offer another type of new instrument using innovative information retrieval. These spectrometers are often deployed to sniff out hydrogen sulfide at cold seeps on the ocean floor, where they detect several different chemical compounds, using the absorption spectrum of ultraviolet light to determine the chemical species present in the ocean. The primary benefit of these *in situ* sensors is that analyzed information, not raw data, is sent back to the lab, thus facilitating data management, increasing information content, and lowering costs. This allows researchers and decision-makers to obtain answers to important issues in critical areas in near-real-time, without the expense of field programs.



Submersible vehicle *Alvin* loaded for sample collection.

Photo courtesy OAR/National Undersea Research Program (NURP); Rutgers University.

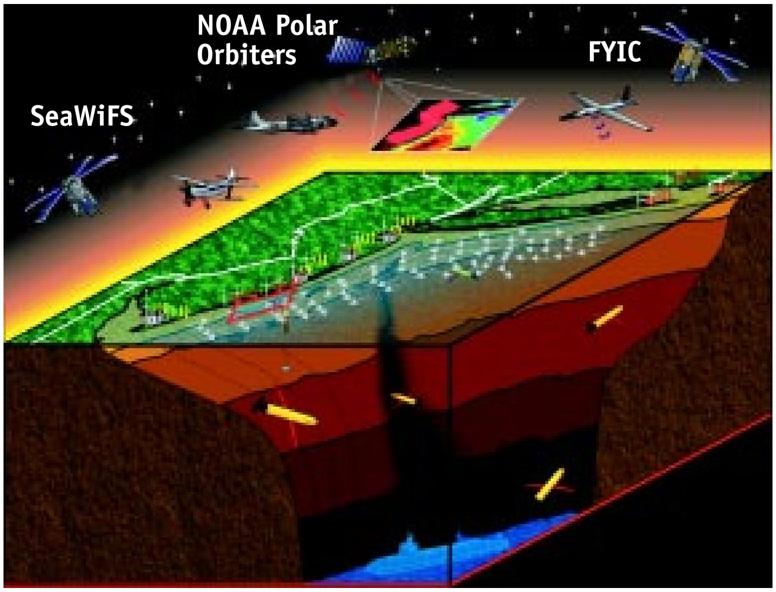
Tagging technology

New electronic tagging technology will allow scientists to undertake comprehensive studies of marine ecology and ecosystem dynamics, not possible with older approaches.

This innovative new electronic tagging system has been used in a significant number of recent studies on: sharks, ocean-caught salmon, halibut, black cod, king crab, and coho salmon smolt. The tagged information includes data on temperature, water pressure, distribution, movement, stock identity, habitat, and predator-prey dynamics. These are all key parameters for understanding and modeling ecosystem dynamics.

Alaska is now collaborating with the International Pacific Halibut Commission to undertake more extensive halibut surveys due to the success of this tagging technology. A new tagging study will look at halibut life history patterns, seasonal movements and migration in the Gulf of Alaska. External tags will be anchored to the animal through a tether. An onboard computer will collect and retain the data and, at a preprogrammed time, a tungsten tip will corrode, detaching the tag from the animal. The tag floats to the top of the ocean, allowing the antenna to download the data from the tag to an ARGOS satellite. The data then arrive at the researcher's office, without the traditional need to recapture the tagged fish.

Adaptation of these technologies requires only small incremental investments from the marine science community to apply new cutting-edge strategies to the needs of Alaska's coasts and watersheds.



New Jersey Shelf Observing System, Rutgers University, Coastal Ocean Observation Laboratory. The Long-term Ecosystem Observatory (LEO) of the New Jersey coast serves as one prototype for regional coastal observations of the future.

Credit: Rutgers http://marine.rutgers.edu/mrs.

Observational Programs for Coastal Regions

New Jersey has some of the nation's first industrialized watersheds and some of the nation's most developed beaches. The Long-term Ecosystem Observatory 15 (LEO-15), is part of Rutgers University's observing system off the New Jersey coast. LEO-15 is one of the most comprehensive and complex interactive systems in the world, designed to answer specific questions related to coastal environments in heavily populated regions, and to provide information to operational and recreational users as well as researchers and decision-makers. Implementing this type of observational system requires the simultaneous operation and analysis of multiple sensors: satellites, aircraft, small and large boats, AUVs, and gliders, all with the goal of developing a real-time capability for rapid environmental assessment and physical/biological forecasting in coastal waters. Having the majority of the data available in real time allows for adaptive sampling of episodic events and assimilation into ocean forecast models.

Despite the wide variety of communications technology necessary in LEO-15, the project emphasizes bringing people and technology together. The operational environment for the project is called the Skunk Works model, a collaborative effort bringing together researchers in one location, a unique environment for academic research. In this shore-based location, data from all the instruments are online and viewable; information can be seen by the general public, military, government and recreational users, and commercial fishermen. This systems approach, or what is now called "operational oceanography," provides information that is useful in near-real-time, allowing for timely forecasting of ocean conditions on the human scale.

The LEO-15 system has operated during four annual coastal predictive skill experiments, from 1998 through 2001. Participants report that for an observational program of this nature to succeed, it must be sustainable, well-integrated, and able to create data sets that can be assimilated by modelers. The project is part of the expanding network of ocean observatories that will form the basis of a national observation network. These regional efforts will eventually be linked, and their combined data will be available through a network of virtual labs capable of rapid data visualization and dissemination of information. Alaska plans to implement an observational system as part of the U.S. and International Ocean Observing Systems under the guidance of CAOS (the Coastal Alaska Observatory System).

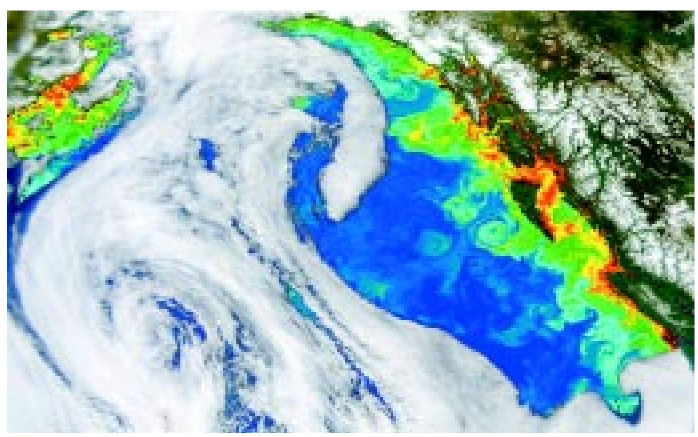
Creating Information from Data

Alaska is data rich and information poor. Data and information, however, are not the same. Remote sensing data offer a potentially rich source of information for the oceanic community by observing ocean waves, sea surface winds, eddies, chlorophyll, sea ice, nearshore areas (including coastal erosion and turbidity), sea surface temperatures, clouds, water vapor, aerosols, pollutants, radiation, and particulates. These data are underused, particularly in Alaska. The prevailing approach is for researchers to collect and archive data, use it to investigate hypotheses and problems, and publish results of their analyses. Unfortunately, the process of turning data into useful information often ends after the study is completed, with data placed in archives, and not turned into routinely available, value-added information products. Potential users, especially decision-makers, policy analysts and the general public, are frequently not equipped to take raw data sets and turn them into usable information.

One factor that makes Alaska so data rich in remote sensing is its location. Most Earth observing satellites are in a polar orbit; they collect and downlink more information at the poles. Alaska has the distinction of being the only high-latitude satellite data acquisition facility in the United States, which means that it collects a wealth of data every day. Unfortunately, most of the data currently collected are underused, and may not even be processed within the state. Many of the existing data archives are not used to study important state issues.

A baseline strategy is needed where information products are produced routinely from raw data collected in Alaska, and then archived and made available to a wider audience. Another long term need exists to synthesize data from multiple sensors and auxiliary information and thereby provide information products that answer specific user needs and questions.

The time is right for Alaska to work toward an effective program for acquisition, archival, retrieval, integration, analysis and distribution of data to serve Alaska marine research and observations. The University of Alaska hopes to address some of these issues by devising an end-to-end "data as information" strategy to facilitate the use of remote sensing and other geospatial data. This strategy will be based mainly on resources available through the University of Alaska system, and will be designed to serve both the University's research and educational requirements and the State of Alaska's needs. To begin this process, we need to determine who needs what information, when they need it, and how they want to receive it. By understanding the functional needs of each user group we can target appropriate technological solutions, instead of defining needs by technology.

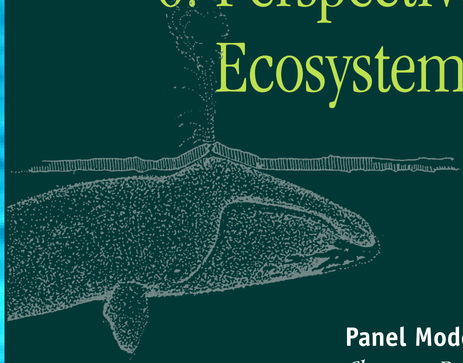


The bright red, green and turquoise patches to the west of Alaska's Alexander Archipelago and British Columbia's Queen Charlotte Islands highlight the presence of high concentrations of chlorophyll found in phytoplankton. The eddies visible are formed by the strong outflow currents from rivers.

Credit: SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE.

The end-to-end strategy will pull together several existing and planned activities including: the Geographic Information Network for Alaska (GINA), the International Observatory of the North (ION), the Arctic Region Supercomputing Center (ARSC), and the Coastal Alaska Observatory System (CAOS). These will be combined through the thematic research interests of the University: Ocean Sciences, Terrestrial Sciences, Atmospheric and Space Sciences, and Human Dimensions.

6. Perspectives on Ecosystem-based Management



Panel Moderator:
Clarence Pautzke, Executive Director,
North Pacific Research Board

Scientist Perspective.
George Hunt, University of California Irvine

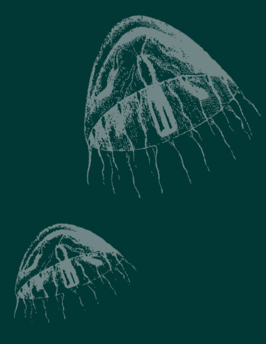
Implementing Ecosystem-based Management of Fisheries.
David Fluharty, School of Marine Affairs, University of Washington

Environmental Perspective.
David R. Cline, World Wildlife Fund, Bering Sea Program

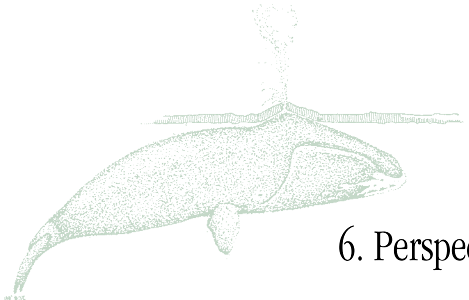
Canadian Fisheries Perspective.
Richard Beamish, Fisheries and Oceans Canada

Alaskan Inuit Whaling Perspective.
Marie Adams Carroll, Arctic Native Association

The following is a synopsis of the above presentations and does not necessarily represent the views of individual panelists.



EVOS photo library, Craig Matkin.



6. Perspectives on Ecosystem-based Management

NMFS scientists on research cruise in Alaskan waters.
Photo courtesy NMFS Auke Bay Laboratory Library.

As scientists and managers decipher the complex variety of factors influencing the aquatic environment, an ecosystem-based management approach has the potential for bringing us closer to realizing more sustainable fisheries and marine ecosystems and economically robust coastal communities.

Managing any one resource affects the other resources in that ecosystem. Therefore, resource managers must consider how management actions affect all resources, not just individual species in isolation. An ecosystem is comprised of all the interconnected elements of a geographic area, including all the living organisms, people, plants, animals, micro-organisms and their physical surroundings.

The ecosystem-based approach works *with* nature to produce healthy functioning ecosystems or habitats. As humans continue to put pressure on natural resources, an ecosystem-based approach, balanced with current management techniques, can prevent the deterioration of ecosystem elements and maintain the long term health of fisheries and other marine populations.

Policy and Management Perspective

Resource managers are frequently called upon to quickly assimilate information and make decisions within a short timeframe. Therefore, it is important to provide them with the best possible information that is not only species-specific, but also contextually relevant and inclusive. Information derived from a broader ecosystem approach could likely aid the decision-makers in making appropriate decisions.

Maintaining ecosystem health and sustainability is a management goal that most people can understand, whether they are scientific, social or economic stakeholders. The players in Alaska's fisheries management are starting to work together to move management forward. A period of transition is necessary because we don't have a complete understanding of ecosystems and the management institution in place is not configured around ecosystems.

It is important to distinguish ecosystem-based fishery management versus broader ecosystem management. The first task is to identify ecosystem principles:

- Our ability to predict ecosystem behavior is limited.
- Ecosystems have thresholds and limits affecting ecosystem structure.
- If limits are exceeded, changes can be irreversible.
- Diversity is important in ecosystem functioning.
- Multiple time scales interact in and among ecosystems.
- Components of ecosystems are linked.

- Ecosystem boundaries are open.
- Ecosystems change with time.

The primary law that allows us to manage fisheries in the federal zone is the Magnuson-Stevens Fisheries Management Conservation Act signed into law in 1976 and amended as the Sustainable Fisheries Act in 1996. The Magnuson-Stevens Act established the 200-mile federal limit and set in place the regional fishery management councils. The Sustainable Fisheries Act (SFA) called for a reduction in bycatch and an identification of harvest levels, added fish habitat requirements, and established an advisory panel to analyze how ecosystem principles apply to fishery management in the U.S. The panel was tasked with reporting back to science, management, industry, and environmental groups in 1999.

A prerequisite for ecosystem-based fishery management was to fully implement the SFA. The Ecosystem Advisory Panel's recommendations on how to better manage fisheries around the country are incorporated into legislation currently pending before Congress in 2002 that would reauthorize the Magnuson-Stevens Act. In anticipation of this legislation passing, a National Marine Fisheries Service group is working on a further elaboration of some of these recommendations. In addition, the PEW Oceans Commission and the President's Commission on Ocean Policy are also considering similar recommendations.

Currently, Alaska is one of the few places in the world where there is a conscious effort to understand what is happening with the ecosystem as a context for managing fisheries.

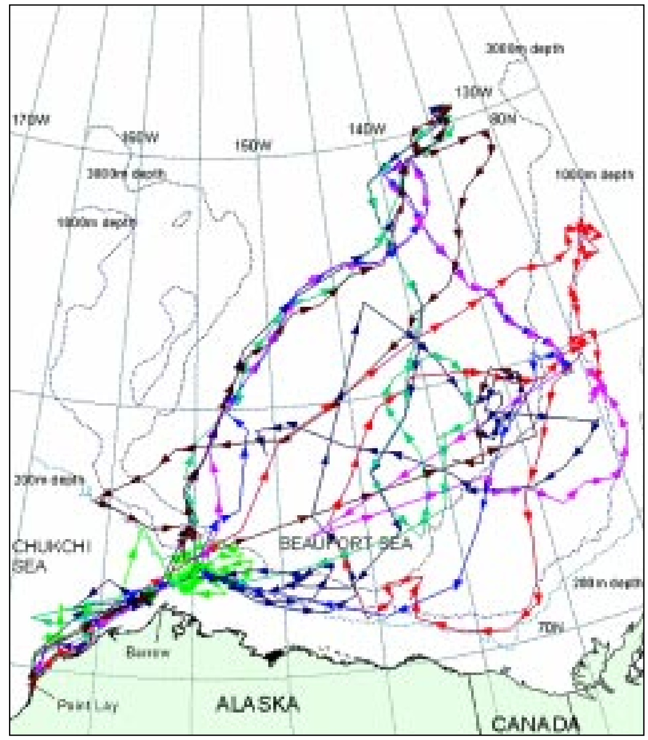


figure 6.1
Movements of Beluga Whales

Colored points show movements of beluga whales satellite tagged at Point Lay, Alaska, 30 June - 7 October 1998 and 30 June - 25 September 1999. From NMFS "Summary of Beluga Tagging Results, 1998-2000".

Credit: Adams-Carroll. 2002. Oceans and Watersheds Symposium. Anchorage, AK.

Scientific Perspective

The rules that have allowed us to predict fisheries impacts may no longer apply, and the ways fisheries are operating may be changing. Climate-driven changes in the marine environment and changes in fish stocks are influencing managers' thinking.

Climate-induced changes in food (phytoplankton) availability, possibly switching an ecosystem from a "bottom-up" to a "top-down" feeding scenario, may dynamically affect fish stocks and alter whole ecosystems.

Within fisheries, there is a tremendous range of data available to further understand what is happening with the stocks, but information about how fisheries fit into marine ecosystems is scarce. Obtaining data without knowing why it is being gathered and how it will be used is less than useful.

Under the maximum sustained yield management concept and only using stock assessment data, disturbing levels of bycatch can occur. Bycatch of this extent can damage benthic communities and risk depleting marine wildlife, further emphasizing the need for targeted data gathering. Destruction of ancient deep sea corals by Bering Sea trawling operations is a vivid example of how fisheries can affect other populations: fishing in this area in this manner is changing the benthic habitat, which may be important for the recruitment of a commercial species. In this case, it would be important to survey changes in the benthic habitat.

Discarded bycatch also can seriously impact other animal populations. The discards bring energy to surface waters, making it available to gulls, which can cause havoc in mixed species colonies of seabirds. When the bycatch is controlled and no longer available, the gulls that have been on the fisheries dole will shift to foraging on other seabirds, again indicating the need for targeted data gathering.

In order to understand fisheries management, it is important to obtain the right targeted data, and correctly analyze and make sense of it by reviewing the impacts in context.

Harbor seal research.
EVOS photo library.

Environmental Perspective

From an environmental point of view, the goal of ecosystem-based management is simply to maintain healthy oceans, which can be measured by the health of the key predators at the top of the marine food chain—species like Steller sea lions, northern fur seals and killer whales. If fish populations are healthy and in good shape, chances are that predator populations will be also, exhibiting a healthy ecosystem balance.

Pressure on resource management exerts itself from multiple directions—business, fishing industry, citizen conservationists and conservation-minded scientists, tribal governments and fishermen—resulting in some real risks to the marine environment.

Frequently, the response is to take an issue to court, which is not only polarizing, but also puts judges in the position of making resource management decisions. Neutral ground is needed so that responsible parties can do what's best for Alaska's oceans and watersheds.

Intensive bottom trawling zones are being pushed into the home range of the fur seals as a result of the Steller sea lion protective measures—a clear example of how single species management does not work.

Averting Disaster

A potentially serious issue in the making is in the central Bering Sea around the Pribilof Islands. Native observers and biologists indicate that the northern fur seal population is in decline. The World Wildlife Fund is working with St. Paul and St. George Islands to avoid repeating population problems that occurred with Steller sea lions.

A sample of over 121 females with attached radio telemetry devices demonstrated that lactating female fur seals sometimes must travel 100 miles or more and dive to several hundred feet at night to get enough food to feed their pups.

Intensive bottom trawling zones are being pushed into the home range of the fur seals as a result of the Steller sea lion protective measures—a clear example of how single species management does not work. If scientists, management agencies and Native Alaskans work together to consider ecosystem impacts, perhaps another Steller sea lion dilemma can be averted. The National Marine Fisheries Service will be conducting a comprehensive population survey and redrafting conservation plans for the northern fur seal. Researchers support development of a Bering Sea International Marine Ecosystem Research Station on the Pribilof Islands.

The goals of ecosystem management are achievable if we keep them in sight and stay out of the courtrooms. If the research community can produce simple measures of ecosystem biodiversity and productivity, resource managers may look toward an ecosystem-based management approach.

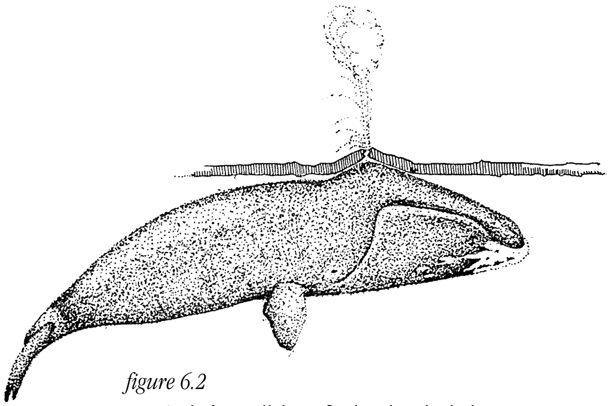


figure 6.2

Artist's rendition of a bowhead whale breaking through the ice to breathe.

Credit: Adams-Carroll. 2002. Oceans and Watersheds Symposium. Anchorage, AK.

Native Perspective

Resource co-management agreements can prove workable as evidenced by the success of the bowhead whale agreements between Alaska Native whalers and government agencies.

Initially, bowhead management conflicts between North Slope Natives, the federal government and the International Whaling Commission were intense, leading to a federal grand jury investigation in 1980. North Slope Natives were told that they needed to cease whaling—a definite lifestyle intrusion. To add further pressure to the resource, a major Beaufort Sea oil and gas lease sale was planned in the bowhead's habitat.

The North Slope Native group signed a co-management agreement with the National Oceanographic and Atmospheric Administration to resolve their differences. In 1981 the group also signed an agreement with the North Slope Borough and the Alaska Eskimo Whaling Commission regarding offshore development, scientific research, and problems with noise impact, specifically helicopter and seismic activity, during bowhead migration.

The ban on hunting bowheads in the 1970s was based on scientific estimates of 600-800 whales. Whaling captains, however, estimated the population to be closer to 3,000 whales, but agreed to work through the Alaska Eskimo Whaling Commission. The captains insisted that the researchers were not counting the whales that travel through and under the ice. Bowheads are able to break through two-foot thick ice (*figure 6.2*). The whalers and scientists together developed an acoustics program that eventually resulted in a more accurate population number of about 3,000 bowheads as the Natives had first estimated. The latest population estimate reported at the International Whaling Commission in 1993 is approximately 8,000 (http://www.iwcoffice.org/estimate.htm).

The co-management agreement increased hunting efficiency and more acceptance of traditional knowledge and serves as a powerful example of how things can work in isolated communities.

From a Native perspective, there are three important areas to consider in managing our resources: the resource, the habitat and the user group.

Photo courtesy Alaska Division of Tourism.

Good Neighbors

Canada is in the process of establishing marine protected areas near the Queen Charlotte Islands—for this country the beginnings of managing according to ecosystem-based principles. Resource scientists and managers hold that conservation based on an ecosystem approach is of fundamental importance to maintaining biological diversity and productivity in the marine environment. The Canadians are implementing an ecosystem-based approach that treats all species equally with their Species at Risk program.

A precautionary management approach makes sense to a whole new generation of biologists in fisheries around the world. Many believe that an ecosystem bill of rights is long overdue.

7. Ocean and Watershed Policies and Governance

Panel Moderator:
Rob Bosworth, former Deputy Commissioner, Alaska Department of Fish and Game

Where the Law Meets the Ocean: Proposed Changes to the Magnuson-Stevens Act.
Jim Balsiger,
Alaska Region, National Marine Fisheries Service,
National Oceanic and Atmospheric Administration

Co-management: A Way to Involve Local and Regional Interests in Conservation and Management Issues.
Charlie Johnson, Alaska Nanuuq Commission

Alaska Oceans and Watersheds: What Needs to Change?
Jim Ayers, North Pacific Office, Oceana

Sound Management in North Pacific Fisheries.
Trevor McCabe, At-Sea Processors Association

Government Perspective.
Pat Galvin, State of Alaska

The following is a synopsis of the above presentations and does not necessarily represent the views of individual panelists.

Fishermen handling catch on a trawler.
Photo courtesy NMFS Observer Program.

7. Ocean and Watershed Policies and Governance

The Magnuson-Stevens Fisheries Management Conservation Act of 1976 was a giant step toward conserving ocean wildlife, particularly declining species. It represents a balancing act between the interests of the fishing community to make a reasonable living and the need to maintain a healthy and diverse marine environment.

When the act was amended by the Sustainable Fisheries Act of 1996, it was further strengthened by including issues of bycatch, overcapacity, data collection, ecosystem-based fisheries management, observer coverage, habitat, and IFQs (Individual Fishing Quotas), plus establishment of an advisory panel to analyze how ecosystem principles apply to fishery management.

The basic structure of the Magnuson-Stevens Act has withstood the test of time and served as a strong management foundation. However, because ocean processes are dynamic, the act is continually subject to change. Changes currently (summer and fall of 2002) under consideration include:

Bycatch: Change to include individual boat restrictions so that every skipper has some responsibility rather than having a global or fleetwide responsibility. Create individual boat incentives.

Trawler in the Bering Sea.
Photo courtesy NMFS Observer Program, NOAA.

Capacity: National Marine Fisheries Service is asking for better capability to reduce fleet sizes, either through buyback programs or other types of capacity reduction, possibly including individual fishing quotas and vessel bycatch allowances. The general direction is to bring the responsibility to the individual fisherman.

Fisheries observers: Despite the difficulty of finding funding, the goal is to have observers in all fisheries. Although it is an expensive program, it is a good way of collecting data and managing fisheries. As of 2002, there are 36,500 observer days on fishing boats off Alaska.

Law enforcement: Develop the ability to use high tech information such as vessel monitoring systems (VMS) and satellite transponders so fishing vessel locations can be pinpointed. Steller sea lion recovery requirements have made it mandatory for cod, pollock and Atka mackerel fishing boats to be VMS-equipped.

Ecosystem management principles: The time is right to meld them into the Magnuson-Stevens Act.

Communities: Closer work with stakeholders in coastal communities is needed to avoid post-decision, post-regulation confusion.

The National Marine Fisheries Service and other agencies are looking forward to these changes as one more step toward sensible coordinated ocean governance and regulation. The status of the pending legislation can be checked on the Library of Congress website (http://www.thomas.loc.gov).

Photo courtesy Alaska Division of Community & Business Development, Robert Angell.

Progress in Co-management

Co-management is essentially a function of the political process. In Alaska, the process has historically been primarily between Alaska Native groups and tribes and the Federal government. Although there are a few agreements around birds, most co-management agreements center around subsistence hunting of marine mammals because the Federal government has management authority over these animals.

New agreements are modeled after that of the Alaska Eskimo Whaling Commission because of its success. The bowhead whale co-management agreement was negotiated in good faith, and both parties respected each other. Whalers were willing to share their knowledge, while the management agency was willing to consider and accept traditional knowledge and share management responsibility.

The process brought good science to the forefront and made it available. In the 1970s the National Oceanic and Atmospheric Administration estimated the bowhead population at 600-700 whales, while the Native whaling captains estimated the population to be about 37,000 whales. The current bowhead count is approximately 10,000. More accurate counting is a result of working together as co-managers.

The Alaska Nanuuq Commission participated with the U.S. Fish and Wildlife Service in the negotiation of a bilateral treaty with Russia, signed in October 2000, on the shared Alaska-Russia polar bear population. Both governments accepted the Native people as equal participants in the negotiations. The Russian Ambassador described it as the most democratic treaty Russia had ever signed. The commission operates on a unanimous consent basis among Native and government representatives from both countries—true co-management. Similar to the Alaska Eskimo Whaling Commission, the commission will be setting quotas. As a result of the treaty, the United States will gain data from Chukotka about the denning habitat, feeding areas and movements of polar bears located here.

Co-management makes traditional knowledge and local knowledge available to the management agencies, allows user groups to participate in setting research priorities, promotes sustainability, and spreads out the economic benefits among a broader group of people.

Co-management makes traditional knowledge and local knowledge available to the management agencies, allows user groups to participate in setting research priorities, promotes sustainability, and spreads out the economic benefits among a broader group of people.

Approaches to Resource Management

Several approaches to resource management are frequently pressed into usage: crisis management, political power-based and research-based.

Crisis management approach

When influence and management are focused on single species harvest, value and location, the structure fails to consider the health of the ecosystem. A strong example of crisis management is the Steller sea lion scenario in which decisions were made without sufficiently considering their effects in a broader context. Clearly the decline in Steller sea lions is a serious problem that will not be resolved in court; it needs collaborative attention. The problem has, however, stimulated discussion on ecosystems and the cumulative impacts of decisions regarding ecosystems.

Political power-based approach

When people in Congress or a state legislature decide that something is a bad idea, they can block forward progress. If we want healthy oceans, it's advisable for Alaskans to discuss, converse and resolve problems before individuals with political power start adding riders to bills to satisfy their interests.

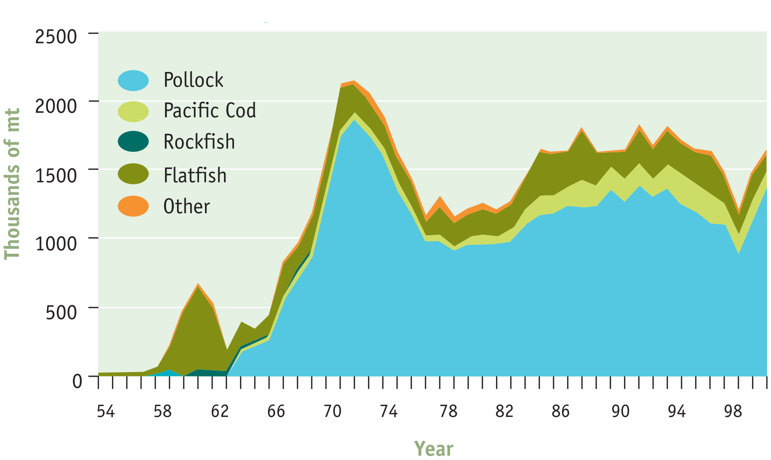
Research-based approach

The research-based approach requires the cooperation of scientists and those holding traditional knowledge, meeting locally and regionally, to make decisions about what is good and right for the health of our oceans, instead of letting commercial or interest groups make decisions.

An example of unhealthy ecosystem decisions is the destructive practices decimating Alaska's coral and sponges. These 500-1000 year-old animals are torn up regularly as fisheries bycatch. Most scientists are in agreement that this situation should be rectified, but the situation is allowed to continue. With cooperation between research centers and research institutions, we could have an ecosystem management system that includes an ecosystem council and a national agency dedicated to the protection of our oceans. Alaska can lead the way; no one in the country is having this kind of a conversation on a regional basis.

figure 7.1
Bering Sea Groundfish Catch 1954-2001

Trevor McCabe. 2002. Oceans and Watersheds Symposium. Anchorage, AK.



Current Management

Alaska has a great management system in place and one of the most progressive fishing industries in the world that cares about long term resource sustainability.

The system is far from stagnant. It's a dynamic process that continues to change—the laws change, Magnuson-Stevens amendments change, and regulations change. Lawsuits are also a significant catalyst for change.

The ecosystem principles taken from the National Research Council and National Academy of Sciences have guided our management efforts:

- Strong science and research
- Precautionary and conservative catch limits *(figure 7.1)*
- Effective reporting and in-season management
- Comprehensive observer program
- Bycatch and discard limits
- Habitat protection *(figure 7.2)*
- Limited entry programs
- Ecosystem considerations

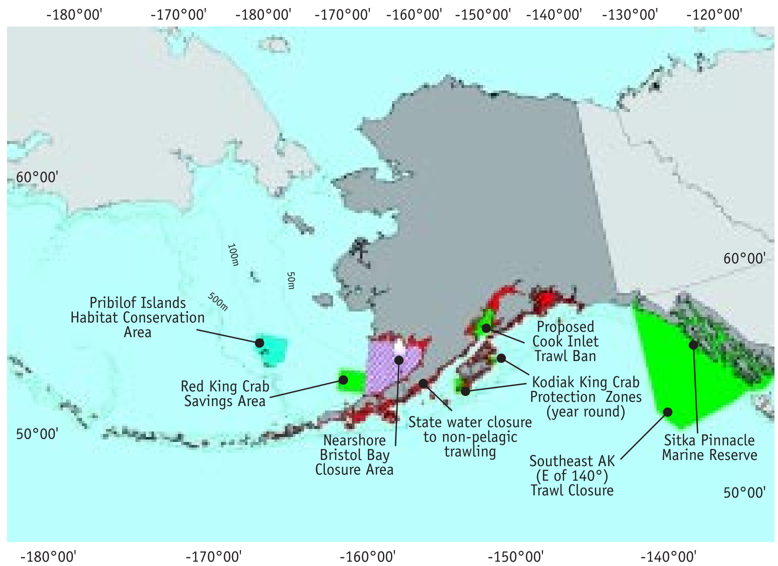


figure 7.2
Habitat Protection

Marine protected areas have been established to protect sensitive habitats from potential effects of fishing. Year-round bottom trawl closure areas (>90,000 nm^2) are shown on this map.

Credit: North Pacific Fisheries Management Council.

North Pacific Fisheries Management Council

All of these concepts have been implemented in the North Pacific, but are lacking in many other parts of the country. The North Pacific Fisheries Management Council has also successfully expanded on the checklist with solid abundance surveys, conservative catch limits, no over-fished groundfish species, good in-season reporting, a comprehensive observer system, and an expansive system of marine protected areas.

All the information from these expanded elements is used to open and close fisheries, close designated areas, enforce bycatch limits, and monitor harvests and the taking of mammals under the Marine Mammal Protection Act.

Although this same information has reduced arguments with conservation groups, there are still frequent legal actions. If the groups came up with a comprehensive prioritized plan, the ecosystem would be better served. It is important from a management and economic perspective however, that a healthy ecosystem does not translate to an ecosystem with no fishing.

Where We're Headed

As always, we need more science, but we are well-positioned to get it and use it, responding as the science comes in and tells us what to do to protect the ecosystem. We have the support of Alaska's Congressional delegation, targeted Steller sea lion funding, the North Pacific Research Board, the *Exxon Valdez* Oil Spill Trustee Council's GEM Program, the fishing industry, and others.

Second, it's important to complete the rationalization effort. Rationalization means developing an integrated management approach to fisheries that is rational from the perspective of resource conservation and the economics of the harvesting industry. Rationalizing the fisheries will never happen quietly, but the participants in all of the North Pacific fisheries are largely ready. The Magnuson-Stevens model has many strengths, but one frequent criticism is that almost every decision the North Pacific Fisheries Management Council makes has an allocative flavor, with decisions benefiting one group and possibly negatively affecting another. With rationalization systems, you find a cleaner discussion of conservation measures, with a focus on ways to harvest fish with the least environmental impacts.

Governance Models

Ocean governance is very much at the forefront at this time in history, akin to 30 years ago when the Stratton Commission was brought together to look at similar issues. That commission's findings resulted in the formation of the National Oceanic and Atmospheric Administration and the creation of the Coastal Zone Management Act, structures we have been working with for 30 years.

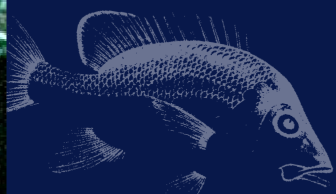
Some of the current larger themes of ocean governance include a need for some sort of national policy, a need for coordination among Federal, state, and local authorities, incentive-based participation, and a regional effort to facilitate a more ecosystems-based approach.

There are a number of models of how governance structures could be put together, but an effective model to examine is the Coastal Zone Management Act. When it was first created by Congress in 1972, it established a number of things present in discussions today regarding the governance structure: emphasizing state or local goals and objectives, and allowing for enforceable policies to be brought together at a local, rather than a national centralized, level.

With the incentive of money and Federal consistency, states could, but were not required, to participate in the Coastal Zone Management program. Participating states developed local plans and did what they could in the area of coastal management, identified at the time as one of the nation's biggest concerns. Eventually, a few weaknesses showed up in the Coastal Zone Management system: no national standards, and a recognized failure to be able to handle issues of national needs, such as non-point source pollution.

Anyone looking at governance structures should examine what other states have tried to do in with their Coastal Zone Management program to bring local, state and Federal authorities together to create collaborative opportunities.

Section II:
Invited Papers



8. Large Scale Climate Variability and the Carrying Capacity of Alaska's Oceans and Watersheds
Nathan J. Mantua, University of Washington, Joint Institute for the Study of the Atmosphere and Ocean
Steven R. Hare, International Pacific Halibut Commission 62

9. Status and Trends of Alaska's Marine Resources: Fish, Birds and Mammals
Douglas P. DeMaster, Alaska Fisheries Science Center
Alan M. Springer, University of Alaska Fairbanks 74

10. Persistent Organic Pollutants in the Alaskan Environment
Michael Smolen, World Wildlife Fund 84

11. Contaminants in Alaska: Is America's Arctic at Risk?
Carl Hild, Institute of Circumpolar Health Studies, University of Alaska Fairbanks 95

12. Oceans, Watersheds and Humans: Facts, Myths and Realities
Steve Colt, Institute of Social and Economic Research, University of Alaska Anchorage
Henry P. Huntington, Huntington Consulting, Inc. 109

Kittiwake and common murre research, Barren Islands, AK.
EVOS photo library.



8. Large Scale Climate Variability and the Carrying Capacity of Alaska's Oceans and Watersheds

Nathan J. Mantua, University of Washington,
Joint Institute for the Study of the Atmosphere and Ocean
Steven R. Hare, International Pacific Halibut Commission

Introduction

Alaska's oceans and watersheds are among the most productive marine environments in the world. There is an enormous wealth of diversity and productivity, from commercially harvested fish and invertebrate populations to scores of species of seabirds and marine mammals. As vital as the ecosystem appears to be, it is certainly different from how it existed 50 years ago, 100 years ago, and 1,000 years ago. Considerable evidence indicates that through time the mix of species has been in constant flux, even before the advent of industrial scale high seas fisheries.

Today, there is a growing acceptance in scientific circles that past changes in important properties of large marine ecosystems were driven in part by changes in climate (e.g., Francis et al. 1998). Climate forcing continues to the present, though now acting in concert with the influence of far-reaching human activities like industrial scale high seas fisheries, pollution and ocean ranching. Over the past decade, our understanding of the nature of climate variability and how it impacts species has been continually refined. In this paper, we review how marine carrying capacity has varied in recent times and characterize the important climate forces affecting the ecosystem.

(above)
Salmon eggs and alevin.
Zooplankton.
Kittiwake on nest.

Terms and Definitions

The notion of carrying capacity has a long history in ecology and has played an important role in the fields of population dynamics and resource management. There are a variety of definitions which have evolved over time (see Pulliam and Haddad 1994 for a recent review). Bottom (1995) summarizes four general working definitions of carrying capacity: maximum population of individuals attainable for a particular level of resources (e.g., food or nutrients); the maximum population above which no increase will occur even if resource levels are increased; a population threshold where all available cover has been saturated and mortality from predation increases rapidly; and the upper limit where no population increase can occur as represented by the S-shaped (logistic) growth curve.

None of these definitions expressly acknowledges the concept of time-varying change in carrying capacity. Early ecological (and fisheries) population dynamics models used the variable K as a measure of carrying capacity. In this format it was often implicit that there existed some unique static "pristine" population level that could be estimated. Few ecologists would now accept such a notion, recognizing that not only does carrying capacity for any marine species change over time, but it is almost impossible to actually measure in ecosystems.

Recognizing the time-varying nature of carrying capacity as a measure of the upper population threshold for a given species, U.S. GLOBEC (1996) produced the following definition: Carrying capacity is a measure of the biomass of a given population that can be supported by the ecosystem. The carrying capacity changes over time with the abundance of predators and resources (food and habitat). Resources are a function of the productivity of prey populations and competition. Changes in the physical and biotic environment affect the distributions and productivity of all populations involved.

We will use this definition of carrying capacity to illustrate how Alaska's marine resources have varied over the past century and longer. Variable carrying capacity may be driven by a single or interacting set of forces: climatic, ecological and/or anthropogenic. Our focus in this paper is primarily on climatic processes, though certainly the other forces are sometimes more important, such as in cases of severe overfishing or habitat destruction. The point we wish to make is that large scale variability occurs across all trophic levels in Alaska's large marine ecosystems, and much of this variability is coherent with recognized climatic processes.

Variability, both biological and climatic, occurs across a spectrum of spatial and temporal scales – from the local (1-10 km) to Pacific basin wide (1000s of km), from seasonal to multidecadal and longer. Much recent research in Alaska has been focused on what appears to be broad coherence in variability at the gyre spatial scale and multidecadal time scale. In particular, the notion of "regime shifts" has been used to characterize observed ecosystem changes. As with the term carrying capacity, so too does "regime shift" have different meanings to different people. One of the first to define regimes in a fisheries oceanography context was Isaacs (1976).

It is useful to consider both climate regimes and biological regimes. What defines a biological regime is the relative stability of some characteristic of the population—recruitment, survival, growth, or abundance—around some mean level. A biological regime shift is an abrupt switch to a new mean level of the biological characteristic. Likewise, parallel regimes in the climate system are marked by relative stability in properties of the physical environment, such as wind and weather patterns and associated patterns of ocean currents and temperatures. The forcing of biological regime shifts by climate shifts leads to ecological regime shifts.

As will be illustrated in the following pages, this rather surprising variability has been identified in species ranging from the plankton to marine mammals, as well as a variety of North Pacific and North American climate factors. As identified for Alaska's marine resources, 20th century ecosystem regimes have tended to persist for one to three decades before changing to a new regime in the course of just one to a few years. Owing to other sources of year-to-year variability and imperfect monitoring, ecosystem regime shifts now are generally not recognizable until at least several years after the fact (Hare and Mantua 2000).

...not only does carrying capacity for any marine species change over time, but it is almost impossible to actually measure in ecosystems.

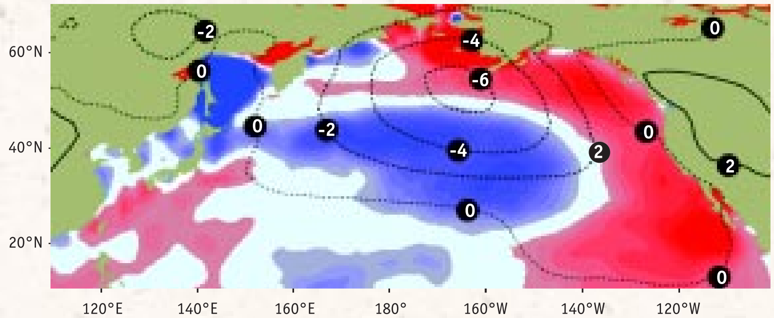


figure 8.1

North Pacific Sea Level Pressure and Sea Surface Temperature

Observed wintertime (November – April) North Pacific sea level pressure (contours) and sea surface temperature (shading) from 1965-76 to 1977-88 . Data were obtained from the NCEP/NCAR reanalysis data.

Credit: Kalnay et al. 1996.

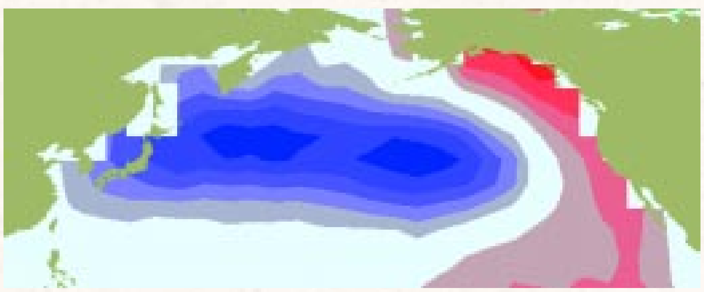


figure 8.2

The Canonical PDO Sea Surface Temperature Anomaly Pattern

When SSTs are above average in the northeast Pacific, they tend to be below average in the central and western North Pacific, and vice versa.

Credit: After Mantua et al. 1997. See also the University of Washington's PDO website at http://jisao.washington.edu/pdo.

Regime Shifts and Large Scale Interdecadal Climate Variability in the North Pacific and Alaska

In the late 1980s and early 1990s, a wide array of evidence suggested that a major Pacific climate event had transpired between 1976 and 1977 (Nitta and Yamada 1989, Trenberth 1990). Ebbesmeyer et al. (1991) assembled a suite of 40 physical and biological variables to first demonstrate a step-like change in the ecosystem. In the decade after 1977, wintertime sea level pressures over the North Pacific were significantly lower than in the previous decade, with a maximum drop of more than 6mb centered over the Aleutian Islands *(figure 8.1)*.

These changes indicated a basin-wide intensification (deepening) of the wintertime Aleutian Low (AL) pressure cell. The AL itself is an annual feature that forms every winter as a consequence of the numerous winter storms that develop and track from west to east across the North Pacific in the vicinity of the Aleutian Islands. With the deeper AL came stronger eastward blowing winds over the Pacific south of the Aleutians that enhanced upwelling and vertical mixing of the upper ocean, effectively cooling ocean surface temperatures in the interior North Pacific.

The deeper AL also enhanced northward and northeastward blowing winds along the Pacific coast of British Columbia and Alaska, enhancing coastal downwelling and reducing the heat loss from the ocean to the atmosphere, a combination that warmed upper ocean temperatures in the northeast Pacific and Gulf of Alaska by ~1°C (~2 °F). The enhanced northward and onshore winds in Alaska brought relatively warm air over the state and warmed average winter temperatures by as much as 3°C (6°F) in southwest Alaska, and ~2°C (~4°F) along the coastal regions of western, central and southeast Alaska. Winter precipitation and annual river runoff in coastal southeast, central and southwest Alaska also increased by 10 to 20 percent (Mantua et al. 1997).

The "event" was eventually labeled as "the 1976/77 North Pacific regime shift," and several published studies document the large-scale climate changes that took place (e.g., Graham 1994, Miller et al. 1994).

Recognition of the 1977 regime shift opened the question of whether that event was unique or merely one of many historical events. Based on analyses of temperature, pressure, tree ring, and even salmon catch records, several researchers hypothesized climatic regime shifts in the Pacific have occurred in the early 1920s and mid 1940s (Francis and Hare 1994, Mantua et al. 1997, Zhang et al. 1997, Minobe 1997, Ingraham et al. 1998), in 1989 (Hare and Mantua 2000, McFarlane et al. 2000) and perhaps most recently in 1998 (Hare and Mantua 2000, Schwing and Moore 2000).

The Pacific Decadal Oscillation and North Pacific Regime Shifts

Mantua et al. (1997) coined the term "Pacific Decadal Oscillation" (PDO) to describe the interdecadal climate variability associated with regime shifts initiated in 1925, 1947, and 1977. The canonical pattern of PDO sea surface temperature (SST) variations is shown in *figure 8.2,* indicating an east-west see-saw in anomalies: when SSTs are above average in the northeast Pacific, they tend to be below average in the central and western North Pacific, and vice versa. This pattern is clearly evident in the decadal changes observed following the 1976/77 regime shift (compare with *figure 8.1)*.

The PDO is often described as a long-lived El Niño-Southern Oscillation (ENSO)-like pattern of Pacific climate variability (Zhang et al. 1997). As seen with ENSO, extremes in the PDO pattern are marked by widespread variations in Pacific Basin and North American climate. Viewed from another perspective, extremes in the (tropical) ENSO cycle often influence North Pacific climate in PDO-like ways. The exceptional tropical El Niño event of 1997-1998 is a clear case in point, wherein changes in tropical rainfall and atmospheric circulation "forced" strong and persistent climate anomalies over the North Pacific (Barnston et al. 1999).

Two main characteristics distinguish the PDO from ENSO. First, typical PDO "events" have shown remarkable persistence relative to that attributed to ENSO events. In this century, major PDO regimes have persisted for 20 to 30 years. Second, the climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics. The opposite is true for the year-to-year climate changes associated with ENSO.

A PDO index developed by Hare (1996) and Zhang et al. (1997) tracks the status of the leading spatial pattern of 20th century North Pacific SST variability (*figure 8.4*). The PDO index simply quantifies the resemblance of observed SST anomaly patterns with the canonical SST pattern shown in *figure 8.2:* when the observations match the PDO pattern with warm SST anomalies in the northeast Pacific but cold SST anomalies in the interior North Pacific, the index has a value of +1; when the observations show the opposite pattern of cold SST anomalies in the northeast Pacific and warm SST anomalies in the central north Pacific, the index has negative values. A remarkable characteristic of this index is its tendency for multiyear and multidecade persistence, with a few instances of abrupt sign changes. Warm (positive) phases of the PDO prevailed from 1925-1946 and from 1977-1998, while cool (negative) phases prevailed from 1890-1924 and 1947-1997.

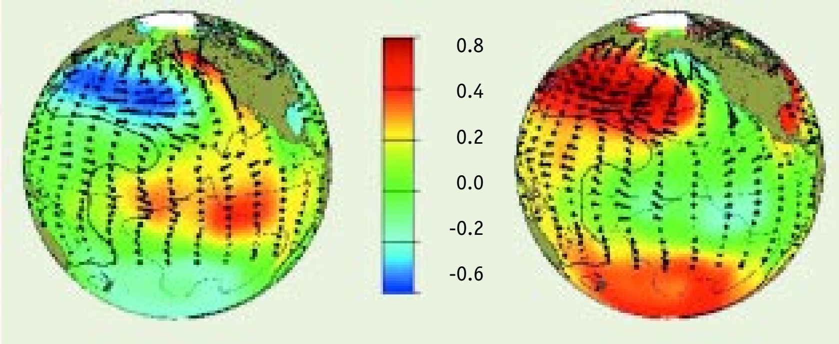


figure 8.3
Pacific Decadal Oscillation (PDO)

Typical wintertime Sea Surface Temperature (colors), Sea Level Pressure (contours) and surface windstress (arrows) anomaly patterns during warm and cool phases of PDO.

Major changes in northeast Pacific marine ecosystems have been correlated with phase changes in the PDO; warm eras have seen enhanced coastal ocean biological productivity in Alaska and inhibited productivity off the west coast of the contiguous United States, while cold PDO eras have seen the opposite north-south pattern of marine ecosystem productivity.

Credit: Hare. http://tao.atmos.washington.edu/pdo/graphics.html.

While the PDO index is based on SST data by construction, it is highly correlated with an index tracking variations in the intensity of the wintertime AL. Thus, the PDO pattern is perhaps better understood as the leading pattern of ocean/atmosphere climate variability for the North Pacific and western North America.

Evidence also exists for other (non-PDO) types of North Pacific climate and ecosystem regime shifts. Hare and Mantua (2000) examined 31 climate records and 69 fishery and biological survey records for the North Pacific and Bering Sea in a search for climate and fishery regime shifts in the period from 1965-1997. Their analyses identified the 1977 PDO regime shift and a distinctly different 1989 regime shift. The 1989 changes were not a simple reversal of climate (and ecosystem) conditions established by the 1977 regime shift. Instead, climate changes from 1989-1997 marked an era with an AL intensity slightly weaker and Alaska winter temperatures slightly cooler than those for the 1977-88 period. Brodeur et al. (1999) also note that 1989-1997 marked an era wherein springtime sea ice in the Bering Sea persisted about two weeks longer, on average, than it did in the period from 1977-88.

Speculation suggests that 1998 may have witnessed the latest PDO climate regime shift (Hare and Mantua 2000, Schwing and Moore 2000), in this case shifting from warm (positive) to cool (negative) PDO conditions. Coincident with the demise of the extreme 1997-98 (tropical) El Niño event, SSTs along the Pacific coast of North America and in the Bering Sea cooled to below average values while SSTs warmed to above average values in the interior north Pacific. This pattern of SST anomalies bears some resemblance to the cool PDO pattern, and the PDO

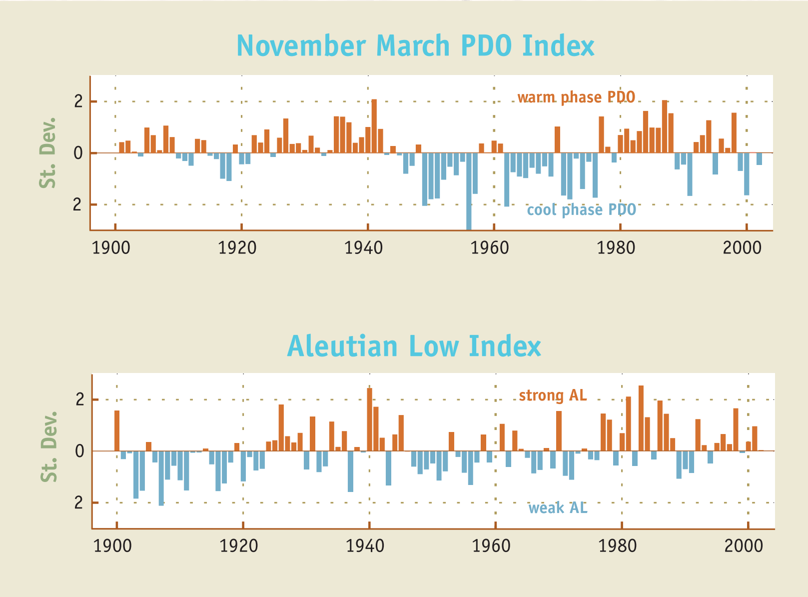


figure 8.4

PDO Index and Aleutian Low Index

November-March values for the PDO index (top), which tracks projections of SSTs onto the canonical PDO SST pattern from figure 8.2, and an index for variability in the November-March Aleutian Low (bottom).

Credit: The AL index is available via the WWW at: http://www.cgd.ucar.edu/~jhurrell/np.html. The PDO index data are available via the internet at: http://jisao.washington.edu/pdo.

index has been mostly negative from mid-1998 to mid-2002 *(figure 8.4)*.

In addition to the PDO, researchers have identified several other climate oscillations including the Quasi-Biennial (2-3 yr. Periodicity), the El Niño Southern Oscillation (5-7 yr.), and Bidecadal and Pentadecadal Oscillations (20 and 50 yrs.) among others. We focus on the PDO here because its periodicity best matches changes in the ecosystem of the North Pacific. The other climate cycles can vary in or out of phase with the PDO, thereby creating very warm or very cold periods of different durations.

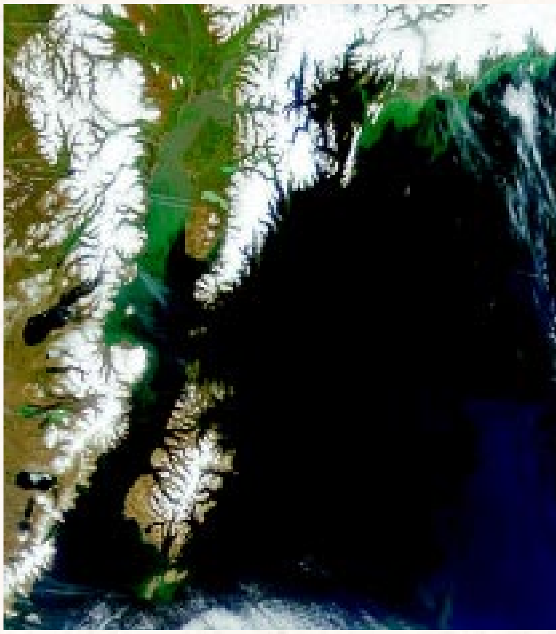
Variability in Carrying Capacity of Alaska's Marine Resources

Continual change is the one constant characterizing Alaska's marine resources. Concepts such as "equilibrium" or "maximum sustained yield" cannot be viewed as unique, static time-invariant values. A great deal of recent research has been done to establish the historical record of resource variability. However, because we are dealing with difficult-to-observe marine populations, the data on key life history parameters such as recruitment, biomass and growth are often non-existent or spotty. While we may not have ideal measures of carrying capacity, we have measures that serve as proxies or indicators for carrying capacity. At the lower, unexploited, trophic levels such as the plankton, measures of standing biomass are available. For fish, recruitment estimates are available for a number of commercially harvested species – indicators of the environment's ability to sustain new production. For the vast majority of fish species there are no abundance or productivity data. For salmon, catch numbers are available going back over 100 years. While an imperfect measure, catch history gives an indication of the population production over time. Growth rates over time are sometimes available – a change in growth rates is often used as a measure of density dependence: a sharp decrease in growth rates indicating that a population may be at its carrying capacity. For marine mammals, juvenile survival is the most commonly measured metric while for birds breeding, or fledging, success is generally measured. In the following section, we summarize historical variability starting at the lowest trophic level (plankton) and proceed to the highest tropic level (marine mammals).

Plankton

At the base of the food chain that supports Alaska's living marine resources are the plankton. The lowest trophic level is the phytoplankton, small plant life that convert sunlight and nutrients to living organic matter. There are very limited observations on the productivity or standing biomass of phytoplankton. Customarily, phytoplankton biomass is estimated by measuring its chlorophyll *a* content. In the open ocean, there have been few broadscale measures of phytoplankton productivity.

One of the earliest, and most important findings of variable plankton carrying capacity came from a study of the region several hundred miles north of Hawaii. A doubling in chlorophyll *a* was documented to have occurred between the mid-1960s and mid-1980s (Venrick et al. 1987). The researchers attributed the change to an abrupt deepening of the upper ocean "mixed layer" with greatly enhanced production in the deeper section of the mixed layer. The deepening of the mixed layer resulted from an enhancement of the westerly winter winds, which in turn stimulated vertical mixing in the water column. Because the central North Pacific is a nutrient-limited system, the sudden surge in vertical mixing brought deep



NASA satellite image shows phytoplankton bloom in the Gulf of Alaska.

Credit: SeaWiFS Project, NASA/ Goddard Space Flight Center and ORBIMAGE.

nutrient-rich water into the euphotic zone, where it sparked the doubling in phytoplankton biomass.

The same atmospheric forces that increased phytoplankton production in the central North Pacific also affected production in the Gulf of Alaska (Polovina et al. 1995). The main oceanographic feature of the Gulf of Alaska is the Alaska gyre, a cyclonic gyre that transports water along and around the coast of Alaska. The effect of enhanced winds over the gyre was to "speed up" the rotation of the Alaska gyre, which resulted in both increased upwelling and a shallowing of the mixed layer depth. Whereas the central North Pacific was a nutrient-limited region, the Gulf of Alaska is light-limited: a shallower mixed layer region keeps more primary production in the euphotic zone, thereby boosting production.

At the trophic level above the phytoplankton, zooplankton biomass in the Gulf of Alaska was also shown to have doubled between the 1960s and 1980s (Brodeur and Ware 1992). Importantly, not only did the amount of zooplankton biomass increase, but the spatial distribution changed as well. Prior to the 1970s regime shift, the highest density of zooplankton was in the center of the Alaska gyre and decreased towards the periphery. With the atmospheric and oceanographic changes accompanying the regime shift, higher productivity moved to the periphery of the gyre resulting in greatly increased availability of secondary production in the nearshore areas along Alaska's Pacific coast.

In addition to an overall increase in the level of secondary productivity, other sweeping changes were noted in the zooplankton community following the mid 1970s regime shift. The copepod species *Neocalanus plumchrus* was found to have shifted its developmental timing by more than a month: the biomass maximum now occurs in May as opposed to July (Mackas et al. 1998). This copepod makes up much of the zooplankton biomass in Alaska waters and is an important component of the diet of many species of fish, including salmon. The ecological consequences of such a shift in developmental timing are likely enormous, particularly concerning annual recruitment of juvenile fish which are highly dependent on seasonal "matching" with prey. In the offshore waters of British Columbia, zooplankton community composition has been documented to change with oceanographic conditions (Mackas et al. 2001). During the period of 1990-1998, a large suite of zooplankton species normally endemic to the Northeast Pacific continental shelf was displaced by "southerly" species generally found in the California Current. In 1999, the situation abruptly reversed and the "northern" species again dominated the zooplankton assemblage.

In the Bering Sea, large scale changes in chlorophyll *a* and zooplankton have also been noted though the timing of changes differs somewhat from those in the North Pacific Ocean. Both chlorophyll *a* and total zooplankton biomass increased severalfold in the mid-1960s and remained at a high level until the end of the 1980s, at which time they returned to the low levels seen earlier (Sugimoto and Tadokoro 1997). A positive correlation between wind speed and plankton biomass was documented; thus, the highest biomass years occurred during active windy winters.

Invertebrates

In the 1960s and early 1970s, the most valuable fisheries in Alaska were for king crab (red and brown) and pink shrimp. Each of these species experienced spectacular declines in the mid-1970s, and by the early 1980s a fishing moratorium was established in most areas and remains in effect to this day. Subsequently, large fisheries developed for other crab species, including Tanner crab (*Chionoecetes bairdi*) and snow crab (*Chionoecetes opilio*). Most Tanner crab fisheries peaked and then crashed in the early to mid-1990s; snow crab catches peaked in the early 1990s, dropped precipitously but recovered briefly, and are again at critically low levels. There has been a great deal of speculation as to the highly cyclic nature of the crustacean resources. There is evidence for both oceanographic influences (Zheng and Kruse 2000), "serial depletion" from overfishing (Orensanz et al. 1998), and "match-mismatch" between crab larva and preferred plankton prey (Anderson and Piatt 1999).


©Art Sutch

Crab recruitment is strongly periodic and autocorrelated (i.e., good years tend to follow good years, and vice-versa). The strong vertical mixing that occurs during strong Aleutian Low winters coincides with weak crab recruitment. One hypothesis is that an unstable water column deriving from strong vertical mixing inhibits growth of *Thalassiosira* spp., diatoms favored by early stages of crab larvae (Zheng and Kruse 2000). In Bristol Bay, a positive relationship was found between water temperature during egg incubation and subsequent year class strength (Rosenkranz et al. 2000). If crab recruitment is truly cyclical on a decadal scale—as has been the case for the past 30 years—it may be a species whose carrying capacity varies regularly, and population declines are inevitable. The role of fishing, at least in accelerating declines, however, cannot be ruled out.

Jellyfish populations in the Bering Sea increased dramatically in the 1990s. The standing biomass grew almost 1000 percent between 1990 and 2000. As this is an unexploited resource, clearly there has been a radical change in the carrying capacity for jellyfish. Some speculative links to climate have been suggested (Brodeur et al. 1999), though the possibility that the increase was a response to decreased forage fish biomass has also been noted (Brodeur et al. 2002). Whatever the ultimate cause of the change in jellyfish carrying capacity, there are important implications for the ecosystem as jellyfish feed on zooplankton and juvenile pollock.

While salmon show a strong response to climate, the influence of human activities has also impacted many populations.

Salmon

Pacific salmon have served as the poster child for climate impacts on marine resources. Large scale, long term swings in Alaska salmon catches have long been noted. The synchrony in catches among certain species has been characterized as production regimes of 20-30 years duration, tied to the phases of the PDO (Beamish and Bouillon 1993, Francis and Hare 1994, Mantua et al. 1997). When the PDO was in its positive phase from 1925-1946 and again from 1977-1998, Alaska salmon production was high. Conversely, the negative PDO regime of 1947-1976 coincided with a period of low salmon catches.

Salmon production along the west coast of the U.S. has been shown to vary inversely with salmon production in Alaska (Hare et al. 1999). It seems clear that the carrying capacity for salmon in the ocean changes on interdecadal time scales, and that oceanographic changes driven by the PDO are largely responsible. Since the regime shift of 1976/77, the number of salmon in Alaska's marine waters has increased by a factor of two to three. As the numbers of salmon have increased, the average size of most species of salmon has decreased slightly (Bigler et al. 1996). Thus, it appears that while carrying capacity has increased, the biomass maximum that can be supported has been reached, leading to a density-dependent growth response in salmon.

Salmon landings give us a view of variable carrying capacity going back about 100 years in time. Recently, sediment cores from several nursery lakes have extended our view back over 2,000 years (Finney et al. 2000, 2002). In these sediment cores, historical abundance is reconstructed from $\delta^{15}N$ which accumulates in salmon while feeding in the open ocean. As salmon spawn and die, the carcasses release nitrogen-15 which accumulates in the sediment. In addition to decadal variability, multi-centennial variability was recorded in sockeye salmon on Kodiak Island. Sockeye were found to be in very low numbers from ~100 BC to AD 800, but consistently abundant from AD 1200 to 1900.

While salmon show a strong response to climate, the influence of human activities has also impacted many populations. Alaska has been fortunate in that much salmon freshwater habitat remains in pristine condition, allowing those populations to flourish when ocean conditions favor high productivity. The role of hatcheries, particularly the effect of hatchery fish on wild, native populations, is being increasingly scrutinized. Another potential anthropogenic force that may alter salmon carrying capacity is altered ocean temperatures due to global warming. It has been hypothesized, on the basis of limited evidence, that salmon are sharply temperature limited: a warming of a few degrees might substantially reduce salmon habitat in the open ocean (Welch et al. 1995).

Groundfish and forage fish

Alaska's industrial groundfish fisheries are the largest and most robust fisheries in the United States. This situation has existed for the past 30 years and is the synergistic result of conservationist fisheries management and good ocean conditions.

The 1976/77 regime shift had a profound impact on the large marine ecosystems of the Gulf of Alaska and Bering Sea. A long series of "small mesh" trawl surveys conducted in the Gulf of Alaska document the transition in the biotic community (Anderson and Piatt 1999). Because of the small mesh used in the trawl nets, virtually all animals encountered—including shrimp and juvenile fish—are captured in the survey. Trawl catches in the early 1970s were dominated by crustaceans such as shrimp. By the late 1970s and continuing through the late 1990s, the trawl catches were dominated by flatfish, cod and pollock. Catch rates for the survey initially decreased in the early 1980s but then increased strongly in the 1990s. The cause of the decline was the gradual disappearance of forage fish, the increase the result of accumulating strong year classes of cod, pollock and flatfish.

Following the regime shift, total groundfish biomass species increased substantially, but the increase was not uniform across species. In the Bering Sea, pollock biomass more than doubled. Most commercially harvested flatfish species also increased in numbers and biomass, some by an order of magnitude. In the Gulf of Alaska, pollock biomass also increased in the late 1970s and early 1980s, but then dropped off, and by the late 1990s, was back at the levels seen in the 1960s. Flatfish, in particular arrowtooth flounder and Pacific halibut, showed the largest increases. Some species began showing signs of density-dependent growth responses in the 1980s as biomasses reached their peak. In the Gulf of Alaska, Pacific halibut size-at-age dropped by more than 60 percent for fish over 14 years old (Clark and Hare 2002). A less steep decline was also documented for eastern Bering Sea rock sole (Walters and Wilderbuer 2000).

The Bering Sea is unique in that a major seasonal feature is sea ice. The distribution of many species is affected by the extent and duration of ice cover. Ice extent over the Bering Sea has generally been much less since the 1976-1977 regime shift. The spring retreat of the ice cover generally leaves a "cold pool" in the central Bering Sea, a body of water around 2°C. It was found that pollock tended to avoid this cold water, but Arctic cod were more abundant in the cold pool (Wyllie-Echeverria and Wooster 1998). The implication is that a warmer Bering Sea expands the habitat for pollock but decreases it for Arctic cod. This is an example where climate is not necessarily changing the carrying capacity of species but is affecting the ability of the animals to utilize their habitat.

Marine mammals and seabirds

The carrying capacity for Alaska's marine mammals and birds also varies on decadal to interdecadal time scales. Stellar sea lion numbers declined by 83 percent at a series of index sites and the species was listed as Threatened under the Endangered Species Act in 1990. The cause of the decline is under intense debate however, with at least six competing hypotheses, ranging from environmental change to anthropogenic effects. The environmental hypothesis is a reduced carrying capacity argument: the regime shift of 1976-77 altered the ecosystem such that preferred sea lion prey decreased or altered their distribution. It has also been suggested that sea lions are now in a "predator pit" with orca whale predation limiting population growth despite large increases in walleye pollock, a preferred sea lion prey. Fur seals, harbor seals and sea otters have also undergone large scale declines, and these decreases are similarly poorly understood. It may or may not be coincidence, but the timing of these pinniped declines also matches the PDO and ecosystem regime shift.

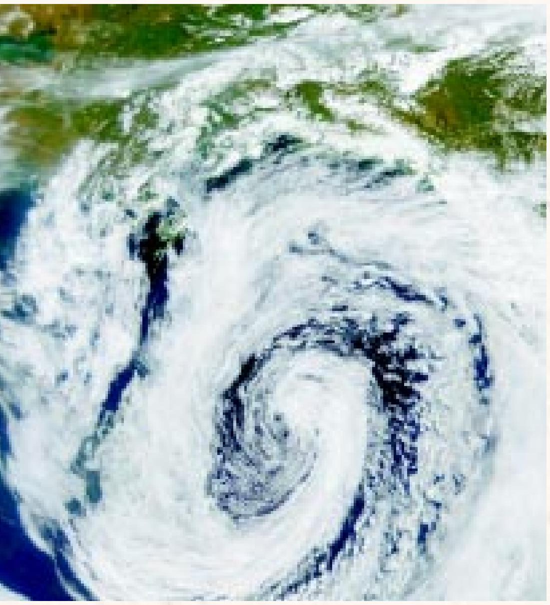
Many species of piscivorous sea birds in the Gulf of Alaska have shown a general downward trend in population numbers during the past two to three decades. While the *Exxon Valdez* oil spill impacted several species, most notably murres, studies have shown that almost all populations were already in decline (Piatt and Anderson 1996). Examples of species that declined at least 50 percent in summer at-sea counts include cormorants, glaucous-winged gulls, black-legged kittiwakes, pigeon guillemots, and horned puffins. In the scientific literature, explanations for the decline of so many species generally point to the ecosystem change in the Gulf of Alaska. Seabirds are highly dependent on energy-rich forage fish such as capelin and sand lance which declined sharply after the mid1970s regime shift. It should be noted that other bird

Murres.

species did not show the same pattern of decline, indicating that carrying capacity differs among these species, likely due to a difference in preferred prey, local environmental dynamics or life history strategies.

Mechanisms for Physical-Biological Interactions

Scientists offer two general pathways for linking climate variations to impacts on marine ecosystems. The first is generally considered to be "direct," wherein climate and associated environmental changes lead to changes in habitat suitability for a particular species or suite of species in an ecosystem. Examples of direct climate impacts on ecosystems include things like: rising temperatures that either cause thermal stress or exceed thermal tolerances for particular species; reduced sunlight due to increases in cloud cover that lead to reduced phytoplankton productivity; or increased current speeds that sweep larval fish away from nursery habitats in ways that reduce survival rates. Such direct environmental impacts are known to be important, as physical properties like those discussed above are integral to marine habitat. The second pathway is generally labeled "indirect," wherein physical environmental changes prompt changes in predator-prey interactions that can in turn yield changes in ecosystem properties like species abundance and distributions. In both cases, nonlinear biological responses to either physical or biological forcing may be an important dynamic within ecosystems, and part of the basis for the observed rapidly cascading changes seen in ecosystem regime shifts.



Low pressure system over the Gulf of Alaska, June 19, 2001.

Credit: SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE.

Indirect climate impacts on ecosystems have received a great deal of attention in the fishery oceanography community. Indirect mechanisms are often further distinguished as either being "bottom-up" or "top-down." A bottom-up process is one in which changes in the lower trophic levels of the marine food-web (the plankton) lead to changes in the carrying capacity of the ecosystem as a whole. A top-down process is one in which changes in the higher tropic levels (predators) cascade downward throughout the lower levels of the ecosystem. In recent studies of climate impacts on the large-marine ecosystems of the North Pacific, most attention has focused on bottom-up processes (e.g., Francis et al. 1998). Two examples of bottom-up processes linking variations in the PDO via the Aleutian Low (AL) to the observed north-south inverse production pattern in Pacific salmon follow.

Assuming that phytoplankton production is light-limited in the Gulf of Alaska, but nutrient-limited in the California Current, Gargett (1997) hypothesized that the coastwide coherent changes in northeast Pacific stratification linked to AL variability may explain the observed north-south inverse production pattern in Pacific salmon. Increased stratification in the coastal waters of the Gulf of Alaska related to the warmed and shoaled mixed layer keeps phytoplankton in the euphotic zone and enhances zooplankton productivity. In contrast, increased stratification via a warmed and deepened mixed layer in the California Current reduces the entrainment of nutrients into the euphotic zone, thereby reducing phytoplankton and zooplankton production and resulting in decreased salmon production.

Hare (1996), following an earlier hypothesis from Chelton and Davis (1982), proposed that AL variations cause north-south differential changes in horizontal currents and transports of subarctic zooplankton to the coastal waters of the northeast Pacific. This differential advection idea posits that when the AL is intense, there is an increase in subarctic zooplankton transports into the Alaska Current, but a compensating decrease in subarctic zooplankton transports into the northern end of the California Current. The opposite changes are linked to periods with a weakened AL circulation.

In both hypotheses, changes in the plankton filter "up" to the abundance of Pacific salmon via zooplankton-linked changes in juvenile salmon survival rates. Observational evidence required to test these (and other) hypotheses from Alaska's marine waters is generally sparse and insufficient to arrive at definitive conclusions.

One other physical biological mechanism worth mentioning again is the "match-mismatch" hypothesis.

The crux of this mechanism is that year class strength (recruitment) is determined by the availability of food during the larval phase. The match-mismatch hypothesis may help explain the abrupt shift in species composition in the Gulf of Alaska following the mid-1970s regime shift. With the warming of surface waters in the Gulf of Alaska, copepod blooms were much larger and began as much as four to six weeks earlier. This change in timing favored species with an earlier emergence schedule. As noted by Anderson and Piatt (1999), capelin, crab and shrimp larvae (all of which declined) emerge in May-June, while groundfish such as pollock, cod and halibut (all of which increased) emerge in February-April.

Summary and Discussion

From several disciplinary angles, there is a wealth of evidence for regionally coherent 20th century changes in the productivity and abundance of many species in Alaska's oceans and watersheds. Many of the observed 20th century ecosystem changes are coherent with multidecadal changes in the large-scale PDO climate pattern. Considering climate and ecosystem evidence together, the case for 20th century North Pacific regime shifts is compelling.

A major difficulty in diagnosing cause and effect relationships between 20th century climate and marine ecosystems comes from the presence of intense and time-varying industrial scale fisheries (and myriad other anthropogenic activities) throughout the North Pacific and Bering Sea. However, paleo (pre-settlement era) data offer independent lines of evidence supporting the existence of large, natural changes in Alaska sockeye salmon production over the past 2,200 years. The interdecadal to millennial scale changes documented for Alaska sockeye have also been associated with hemispherically warm and cool climate eras.

Mantua et al. (1997) proposed that the PDO represents a special class of Pacific climate variability defined by a preferred spatial pattern with a range of interdecadal time scales of variability. Whether there is a preferred PDO time scale is critical for several reasons, including the issue of mechanisms and how understanding those mechanisms should aid the development of a PDO monitoring and prediction system.

However, at this time mechanisms for PDO-related regime shifts remain mysterious (see Miller and Schneider 2000 for a comprehensive review of different hypotheses). In contrast, recent advances in understanding mechanisms for persistence and slow changes in extratropical SST anomalies offer improved confidence for PDO predictability at lead times of one to a few years (Seager et al. 2001, Schneider and Miller 2001). The potential for skillful PDO predictions at lead times beyond a few years hinges on the premise that unstable coupled ocean-atmosphere interactions and delayed negative feedbacks contribute to PDO variations. The potential for skillful ecosystem predictions at lead times beyond a few years hinges on the combination of a demonstrated ability to predict environmental change and the associated biophysical responses.

Today's skill in PDO-related forecasts and associated ecosystem forecasts comes from simple persistence. This skill disappears when there is an unforeseen sign change in the PDO pattern, like that which appears to have taken place in 1998. Unfortunately, because no one is certain how the PDO works it is not possible to say with confidence that the 1998 changes in Pacific climate mark the beginning of a 20-to-30 year long cool phase of the PDO.

One of the outstanding challenges facing scientists, resource managers and fishers today is how to improve resource stewardship in the face of a powerful and unpredictable agent of change like the climate system. There is far more that we don't understand than we do understand. We have mostly chosen to focus on the PDO in this essay, but the influence of other climate cycles is likely also quite large, particularly when in phase with the PDO. Global warming will quite likely add a new dimension of complexity as the ecosystem is subjected to new environmental stresses. The task is daunting, yet one we must continually tackle if we are to preserve our living aquatic resources.

One of the outstanding challenges facing scientists, resource managers and fishers today is how to improve resource stewardship in the face of a powerful and unpredictable agent of change like the climate system.

Literature Cited

©Art Sutch

Large Scale Climate Variability and the Carrying Capacity of Alaska's Oceans and Watersheds

Anderson, P.J. and J.F. Piatt. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series. 189, 117-123.

Barnston, A.G., and co-authors. 1999: NCEP forecasts of the El Niño of 1997-98 and its U.S. impacts. Bulletin of the American Meteorological Society, 80, 1829-1852.

Beamish, R.J. and D.R. Bouillon. 1993. Pacific salmon production trends in relation to climate. Canadian Journal of Fisheries and Aquatic Science 50, 1002-1016.

Bigler, B.S., D.W. Welch and J.H. Helle. 1996. A review of size trends among North Pacific salmon (Oncorhynchus spp.). Canadian Journal of Fisheries and Aquatic Science 53:455-465.

Bottom, D.L. 1995. The carrying capacity concept in fisheries management. [In] Proceedings from a workshop on ecological carrying capacity of salmonids in the Columbia River Basin: Measure 7.1A of the northwest Power Planning Council 1994 Fish and Wildlife program. Report 3 of 4, Final Report. (available on the web at http://www.efw.bpa.gov/Environment/EW/EWP/DOCS/REPORTS/HABITAT/H62611-8.pdf), Pages 23-32

Brodeur, R.D., C.E. Mills, J.E. Overland, G.E. Walters, and J.D. Schumacher. 1999. Evidence for a substantial increase in gelatinous zooplankton in the Bering Sea, with possible links to climate change. Fisheries Oceanography 8, 296-306.

Brodeur, R.D., H. Sugisaki, and G.L. Hunt Jr. 2002. Increases in jellyfish biomass in the Bering Sea: implications for the ecosystem. Marine Ecology Progress Series 233: 89-103.

Brodeur, R.D., and D.M. Ware. 1992. Interannual and interdecadal changes in zooplankton biomass in the subarctic Pacific Ocean. Fisheries Oceanography 1: 32-38.

Chelton, D.B. and R.E. Davis. 1982. Monthly mean sea level variability along the west coast of North America. Journal of Physical Oceanography 12:757-784.

Clark, W.G. and S.R. Hare. 2002. Effects of climate and stock size on recruitment and growth of Pacific halibut. North American Journal of Fisheries Management 22: 852-862.

Ebbesmeyer, C.C., D.R. Cayan, D.R. Milan, F. H. Nichols, D.H. Peterson and K.T. Redmond. 1991. 1976 step in the Pacific climate: forty environmental changes between 1968-1975 and 1977-1984, pp. 115-126. In J.L. Betancourt and V.L. Tharp, [eds]. Proceedings of the Seventh Annual Climate (PACLIM) Workshop, April 1990. California Department of Water Resources. Interagency Ecological Studies Program Technical Report 26.

Finney, B.P., I. Gregory-Eaves, J. Sweetman, M.S.V. Douglas, and J.P. Smol. 2000. Impacts of climatic change and fishing on Pacific salmon abundance over the past 300 years. Science 290:795-799.

Finney, B.P., I. Gregory-Eaves, M.S.V. Douglas, and J.P. Smol. 2002. Fisheries productivity in the northeastern Pacific Ocean over the past 2,200 years. Nature 416:729-733.

Francis, R.C. and S.R. Hare. 1994. Decadal-scale regime shifts in the large marine ecosystems of the Northeast Pacific: a case for historical science. Fisheries Oceanography 3: 279-291.

Francis, R.C., S.R. Hare, A.B. Hollowed, and W.S. Wooster. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. Fisheries Oceanography 7:1-21.

Gargett, A.E. 1997. The optimal stability "window": A mechanism underlying decadal fluctuations in North Pacific salmon stocks? Fisheries Oceanography 6:109-117.

Graham, N.E. 1994. Decadal-scale climate variability in the tropical and North Pacific during the 1970s and 1980s: observations and model results. Climate Dynamics 10:135-162.

Hare, S.R. 1996. Low frequency climate variability and salmon production. Ph.D. Dissertation. University of Washington, School of Fisheries. 306 pp.

Hare, S.R., N. J. Mantua, and R.C. Francis. 1999. Inverse produc-tion regimes: Alaskan and west coast salmon. Fisheries 24(1):6-14.

Hare, S.R. and N.J. Mantua, 2000: Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography Vol 47, pp.103-145.

Ingraham, J.W., C.C. Ebbesmeyer, and R.A. Hinrichsen. 1998. Imminent climate and circulation shift in northwest Pacific ocean could have major impacts on marine resources. EOS, Transactions of the American Geophysical Union 79, 197-201.

Isaacs, J.D. 1976. Some ideas and frustrations about fishery science. California Cooperative Oceanic Fisheries Invest Report 18: 34-43.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, A. Leetmaa, B. Reynolds, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, R. Jenne, and D. Joseph. 1996. The NCEP/NCAR Reanalysis 40-year Project. Bulletin American Meteorological Society 77:437-472.

Mackas, D.L., R. Goldblatt, and A.G. Lewis. 1998. Interdecadal variation in developmental timing of *Neocalanus plumchrus* populations at Ocean Station P in the subarctic North Pacific. Canadian Journal of Fisheries and Aquatic Sciences 55:1878-1893.

Mackas, D.L., R.E. Thomson, and M. Galbraith. 2001. Changes in the zooplankton community of the British Columbia continental margin, 1985-1999, and their covariation with oceanographic conditions. Canadian Journal of Fisheries and Aquatic Sciences 58:685-702.

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

Mantua, N.J. and S.R. Hare 2002: The Pacific Decadal Oscillation. Journal of Oceanography Vol. 58 (No. 1), pp. 35-44.

McFarlane, G.A., J.R. King and R.J. Beamish, 2000. Have there been recent changes in climate? Ask the fish. Progress in Oceanography Vol 47, Nos 2-4: 147-170.

Miller, A.J., D.R. Cayan, T.P. Barnett, N.E. Graham, and J.M. Oberhuber. 1994. The 1976-77 climate shift of the Pacific Ocean. Oceanography 7:21-26.

Miller, A.J. and N. Schneider (2000): Interdecadal climate regime dynamics in the North Pacific Ocean: theories, observations and ecosystem impacts. Progress in Oceanography 47, 355-379.

Minobe, S. 1997. A 50-70 year oscillation over the north Pacific and north America. Geophysical Research Letters 24: 683-686.

National Research Council (NRC) (1998): Decade-to-Century scale climate variability and change: A science strategy. National Academy Press, Washington D.C., 141 pp. (http://www.nap.edu).

Nitta, T. and S. Yamada (1989): Recent warming of tropical sea surface temperature and its relationship to the Northern Hemisphere circulation. Journal of the Meteorological Society Japan, 67, 375-383.

Orensanz, J. M., J. Armstrong, D. Armstrong, and R. Hilborn. 1998. Crustacean resources are vulnerable to serial depletion – the multifaceted decline of crab and shrimp fisheries in the greater Gulf of Alaska. Reviews in Fish Biology and Fisheries 8: 117-176.

Piatt, J.F. and P. Anderson, 1996: Response of common murres to the *Exxon Valdez* oil spill and long-term changes in the Gulf of Alaska marine ecosystem. In Rice et al. (eds) *Exxon Valdez* Oil Spill Symposium Proceedings, AFS Symposium No. 18, pp. 720-737.

Polovina, J.J., G.T. Mitchum, and G.T. Evans. 1995. Decadal and basin-scale variation in mixed layer depth and the impact on biological production in the Central and North Pacific, 1960-88. Deep Sea Research 42: 1701-1716.

Pulliam, H.R. and N.M. Haddad. 1994. Human population growth and the carrying capacity concept. Bulletin of Ecological Society America 75: 141-156.

Rosenkranz, G.E., A.V. Tyler, and G.H. Kruse. 2001. Effects of water temperature and wind on year-class success of Tanner crabs in Bristol Bay, Alaska. Fisheries Oceanography 10: 1-12.

Schneider, N. and A.J. Miller 2001: Predicting western North Pacific Ocean climate. Journal of Climate 14: 3997-4002.

Schwing, F. and C. Moore. 2000: A year without a summer for California, or a harbinger of a climate shift? EOS Transactions of the American Geophysical Union, 81: 301, 304-305.

Seager, R., Y. Kushnir, N.H.Naik, M.A. Cane, and J. Miller 2001: Wind-driven shifts in the latitude of the Kuroshio-Oyashio Extension and generation of SST anomalies on decadal time scales. Journal of Climate 14: 4249-4265.

Sugimoto, T. and K. Tadokoro. 1997. Interannual-interdecadal variations in zooplankton biomass, chlorophyll concentration and physical environment in the subarctic Pacific and Bering Sea. Fisheries Oceanography. 6:74-93.

Trenberth, K.E., 1990: Recent observed interdecadal climate changes in the northern hemisphere. Bulletin of the American Meteorological Society, 71, 988-993.

Trenberth, K.E. and J.W. Hurrell. 1994. Decadal atmosphere-ocean variations in the Pacific. Climate Dynamics 9: 303-319.

U.S. GLOBEC. 1996. Report on climate change and carrying capacity of the North Pacific ecosystem. U.S. Global Ocean Ecosystem Dynamics Rep. No. 15, Univ. California, Berkeley. 95 p.

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

Walters, G.E. and T.K. Wilderbuer. 2000. Decreasing length at age in a rapidly expanding population of northern rock sole in the eastern Bering Sea and its effect on management advice. Journal of Sea Research 44: 17-26.

Welch, D.W., A.I. Chigirinsky, and Y. Ishida. 1995. Upper thermal limits on the oceanic distribution of Pacific salmon (*Oncorhynchus spp.*) in the spring. Canadian Journal of Fisheries and Aquatic Science 52: 489-503.

Wyllie-Echevarria, T. and W. S. Wooster. 1998. Year-to-year variations in Bering Sea ice cover and some consequences for fish distributions. Fisheries Oceanography 7: 159-170.

Zhang, Y., J. M. Wallace, and D. S. Battisti. 1997. ENSO-like interdecadal variability: 1900-93. Journal of Climate 10: 1004-1020.

Zheng, J. and G.H. Kruse. 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES Journal of Marine Science 57:438-451.

Literature Cited

Large Scale Climate Variability and the Carrying Capacity of Alaska's Oceans and Watersheds



9. Status and Trends of Alaska's Marine Resources: Fish, Birds and Mammals

Douglas P. DeMaster, Alaska Fisheries Science Center
Alan M. Springer, University of Alaska Fairbanks

Introduction

In this paper we propose that abundance trends of marine mammal, bird and fish species can be used as proxies to indicate the health of two key marine ecosystems in Alaska: the Gulf of Alaska and the Bering Sea. Around the world top predators have been monitored as indicators of ecosystem health. The scientific underpinning of this approach is relatively simple: top-level predators are dependent on reliable sources of food that will be available only in ecosystems with intact trophic relationships.

Summarizing available literature on trends in abundance of certain species, our objective is to infer the dominant factors driving dynamics at upper trophic levels in the Gulf of Alaska and Bering Sea. We know that factors such as environmental regime shifts (e.g., the Pacific Decadal Oscillation and El Niño events), pollution, fishing, whaling, competition with invasive species, and global climate change can lead to severe changes in the species composition of marine environments. Managers must now develop good tools to decipher whether patterns of change in indicator species, such as top-level predators, are caused by naturally occurring phenomenon or anthropogenic effects. This task is made more difficult by synergistic effects among two or more factors. In addition, in ecosystems with long-lived species or complex trophic relationships, the effects of natural or anthropogenic influences may take decades to be expressed and detected (see Jackson et al. 2001).

(above)
Sea otters.
Kittiwakes.
Harbor seal.

Status and Trends of Selected Species of Marine Mammals

There are 36 recognized populations (often referred to as stocks) of marine mammals that occur primarily in Alaska (Angliss et al. 2001). Information on trends in abundance is available for only 11 of these populations: five stocks are known to be increasing, five are known to be stable, and one is known to be decreasing. Most populations of large whales for which population data exist appear to be either recovered (e.g., eastern North Pacific gray whale) or recovering from over-exploitation by commercial whalers (e.g., central and eastern North Pacific humpback whale, western Arctic bowhead whale). One notable exception is the eastern North Pacific right whale. Legal and illegal commercial harvests have caused this population to decline to such low levels that some scientists are concerned that, even without additional human-related removals, it will not recover. For many populations of marine mammals, the information necessary to determine trends in abundance is not available. The following subset of marine mammal populations are important indicators of whether the marine environment is suitably healthy to either allow recovery from past over-exploitation or allow populations to remain at carrying capacity.

Cook Inlet beluga whale

The Cook Inlet population of beluga whales, approximately 400 animals, is the smallest of five populations in Alaska (Angliss et al. 2001, Moore and DeMaster 2000, and Hobbs et al. 2001). Reliable historic abundance figures are not available, but the best scientific information indicates that at least 1,000 animals were year-round residents in Cook Inlet. Between 1994 and 1998 the population was estimated to have declined approximately 15 percent per year (*figure 9. 1*). Many factors might have been related to this decline—subsistence harvest, pollution, lack of forage, disturbance by commercial vessel traffic—but annual subsistence harvests of 20 percent of the estimated population were considered unsustainable. Since 1999, the harvest has been reduced to fewer than two animals per year on average, thanks to cooperative efforts between Alaska Native subsistence hunters living in the vicinity of Cook Inlet and National Oceanic and Atmospheric Administration Fisheries (see Angliss et al. 2001).

Although preliminary results from the last four surveys since 1998 indicate that the population is no longer declining and may be increasing, it will take another four to six years to accurately determine trends in abundance. Cook Inlet belugas forage primarily on salmon, eulachon, cod, and other species of fish that aggregate during some portion of the year as part of their normal life history (e.g., to spawn). Therefore, assuming future anthropogenic effects are negligible, this population should be a good health indicator of several major Cook Inlet region fish populations and the environment needed to support them.

Western Arctic bowhead whale

The western Arctic bowhead whales are one of five bowhead populations in the Arctic (Shelden and Rugh 1995), all of which were over-harvested by commercial whalers in 19th or 20th centuries. This population is the only one of the five to show any signs of recovery.

Estimated abundance is at approximately 10,000 animals (IWC 2002: p. 35). Since monitoring by the Alaska Eskimo Whaling Commission (AEWC) began in the late 1970s, the population has maintained an average growth rate of slightly more than 3 percent per year. Given the life history of this species—delayed maturity, three to five years between births, long lives—a growth rate of this magnitude is indicative of a population increasing at near the maximum rate, despite annual removals by Alaska Native subsistence hunters. Over the last five years, the annual harvest has averaged 54 whales (Angliss et al. 2001).

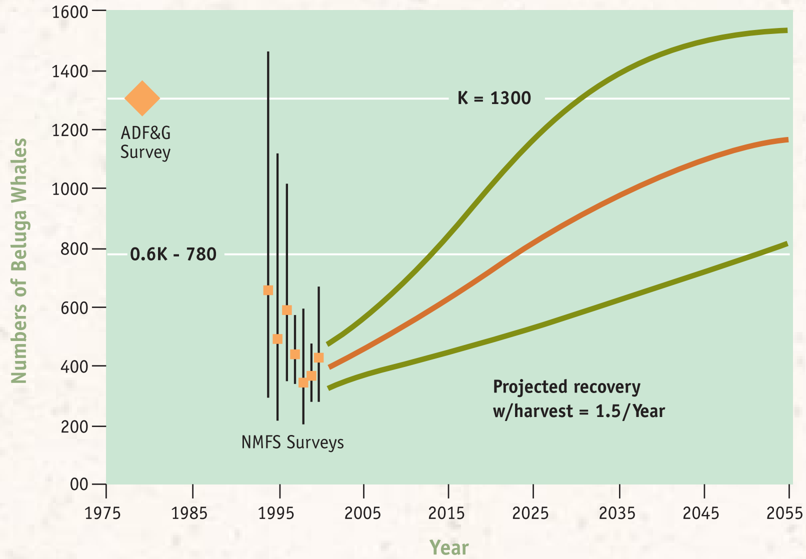


figure 9.1

Summary of Trends in Abundance of Cook Inlet Beluga

The Cook Inlet beluga population declined approximately 15 percent between 1994 and 1998. Surveys since 1998 indicate that the population may be increasing. This chart shows three possible scenarios for population recovery if the population continues to increase.

Credit: DeMaster and Springer. 2002. Oceans and Watersheds Symposium. Anchorage, AK.

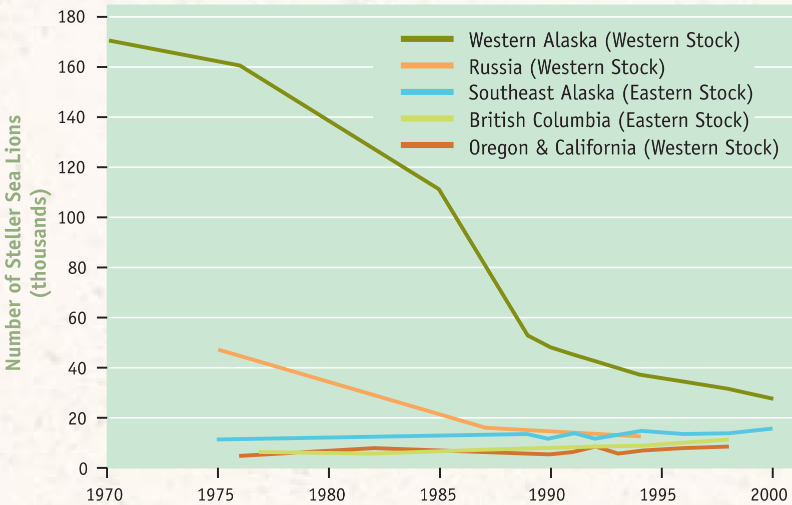


figure 9.2

Summary of Trends in Abundance of Steller Sea Lion Stocks.

Regional counts of adult and juvenile (non-pup) Steller sea lions. The population's overall rate of decline throughout the 1990s has been estimated at five percent per year.

Credit: DeMaster and Springer. 2002. Oceans and Watersheds Symposium. Anchorage, AK.

AEWC's current research plan requires surveys to determine abundance at least once every 10 years with a minimum survey interval of five years. In addition, AEWC also rigorously monitors harvest by collecting data on size, gender, reproductive status, age, food habits, general health condition, and contaminant levels from each landed whale.

Bowhead whales are plankton feeders. The western Arctic population migrates out of the Bering Sea in the spring along coastal leads in sea ice, spending their summers in the Beaufort Sea, where juveniles feed. In the fall, they migrate, ahead of forming winter sea ice, to the western Chukchi Sea and then south through the Bering Strait to the Bering Sea (Moore and DeMaster 1997). The recovery of this population is good evidence that the lower trophic levels in the Bering, Chukchi, and Beaufort seas are relatively healthy. However, contaminant levels in these animals indicate that a variety of pollutants are entering the food chain that will require close monitoring over the next several decades.

Western Steller sea lion

Much has been written about the status and demise of the western population of Steller sea lions (see Angliss et al. 2001, Alaska SeaGrant 1993, DeMaster and Atkinson 2002, Ferrero and Fritz 2002, Loughlin et al. 1992, and Trites and Larkin 1996). The Steller sea lion was listed as threatened under the U.S. Endangered Species Act (ESA) in 1990 after over a decade of declines exceeding 10 percent per year. In 1997, the western population was listed as endangered under the ESA, while the eastern population was listed as threatened. The current size of the western population is in excess of 30,000 animals, compared to approximately 250,000 in the 1960s. The population's overall rate of decline throughout the 1990s has been estimated at five percent per year (Sease et al. 2001) (*figure 9.2*).

Steller sea lions forage on a wide variety of prey species, but seem to depend on adequate aggregations of prey in the nearshore environment. The three most important prey items in the diet of western Steller sea lions are pollock, Pacific cod, and Atka mackerel (Sinclair and Zepplin 2002). These same species are important to the commercial groundfish fishery in the Bering Sea and Gulf of Alaska. Ongoing litigation has yet to resolve whether the conservation measures introduced by the North Pacific Fishery Management Council and the National Marine Fisheries Service are consistent with requirements under the ESA to avoid jeopardy and adverse modification of critical habitat.

Northern fur seal

Northern fur seals occur on both St. Paul and St. George Islands in the Pribilofs, and on Bogoslof Island in the eastern Aleutians. They are classified as depleted under the Marine Mammal Protection Act. This population includes approximately 900,000 animals (Angliss et al. 2001). Pup production for northern fur seals that breed and pup on the Pribilof Islands is approximately 50 percent of its historic maximum. The northern fur seal is one of three pinniped populations that sharply declined in Alaska in the late 1970s. Some authors associate the decline with a regime shift in the North Pacific, while others speculate that it may be related to a switch in killer whale prey following the demise of several species of large whales in the 1960s and 1970s (J. Estes, unpublished data). The abundance of fur seals at St. Paul Island and St. George Island leveled off briefly in the mid-1980s, but has continued to decline since about 1995.

Although the reason for the decline in fur seal abundance on the Pribilof Islands is unknown, it does contrast sharply with a spectacular increase of northern fur seals on Bogoslof Island in the eastern Aleutians in the past 15 years. The number of fur seals at Bogoslof Island is much smaller than on the Pribilofs. Therefore, the increase there does not offset the declines on the Pribilofs.

The contrasting trends in abundance of fur seals on the Pribilofs and Bogoslof Islands indicate differing food web or environmental conditions in the two regions of the Bering Sea.

Northern fur seals are pelagic feeders that eat squid, juvenile pollock, juvenile rockfish, and other species of forage fish that aggregate (Sinclair et al. 1996). Therefore, trends in abundance could serve as a valuable complement to trends in abundance of harbor seals and Steller sea lions in determining the health of the forage fish community in the Bering Sea and Gulf of Alaska.

Harbor seal

The National Marine Fisheries Service and the Alaska Native Harbor Seal Commission currently recognize three distinct populations of harbor seals in Alaska (southeast, central, and western Alaska populations). Considerable uncertainty exists, however, regarding the population structure and ongoing studies using genetics, tagging, morphometrics, and other biological markers are underway. In the interim, biologists have established a suite of haulouts, where time series of maximum counts during the pupping season or during the period when animals are molting have been developed. These data have been used to infer the dynamics of the local subpopulation of harbor seals (Angliss et al. 2001).

Like Steller sea lions and northern fur seals, harbor seal numbers in Alaska, where counts were taken, declined sharply in the late 1970s. This pattern of sharp decline, with a period of relative stability at a low abundance level, followed by a period of slow increase in many areas suggests that whatever factors caused or were associated with the decline have ceased to affect large segments of the population.

The dynamics of harbor seals in other parts of Alaska, however, are quite different. For example, counts of animals at several haulouts in southeast Alaska have increased over the last decade, as they have for sea lions, while total counts of harbor seals in Prince William Sound have declined over this time period. Further, counts of harbor seals on Otter Island (in Pribilof Islands group) have declined 80 percent from the mid-1970s to the mid-1990s (A. Springer, unpublished data).

Diets of harbor seals in the Gulf of Alaska are dominated by octopus and common forage species, particularly pollock, capelin, herring, eulachon, and Atka mackerel (Kenyon 1965, Pitcher 1980). Harbor seals also are an important source of meat and fur for Alaska Native subsistence hunters in the Gulf of Alaska and southeast Alaska. Trends in abundance of this species are an important signal in understanding the influence of regime shifts and fisheries on the marine ecosystem, as well as the effects of subsistence hunting on specific populations of harbor seals.

Sea otter

Sea otters in Alaska were severely over-harvested in the 1700s and 1800s. Around the Aleutian Islands, very few otters survived by the turn of the 20th century. However, after protection was imposed and harvesting stopped, sea otters in Alaska started to recover. By the late 1980s, the population along the Aleutian Islands was in excess of 80,000 animals. In some areas, annual rates of increase exceeded 20 percent per year (Estes 1990). However, in the early 1990s, scientists noticed a decline that has resulted in an approximate reduction of 90 percent of the otters found around the Aleutian Islands to only slightly over 13,000 animals (Estes et al. 1998). Estes et al. (1998) suggest that the decline was caused by a change in the diet of killer whales from Steller sea lions and harbor seals to sea otters following the decline in abundance of sea lions and seals. Studies are underway to test this hypothesis.

At present, the U.S. Fish and Wildlife Service recognizes three distinct populations of sea otters in Alaska (Angliss et al. 2001), although research on population structure continues. Sea otters are a very important predator in the marine environment; their presence or absence significantly influences the composition of the nearshore community in most areas where they occur (Estes and Palmisano 1974). Therefore, monitoring trends in abundance of this species is important in understanding factors causing changes in the species composition of the nearshore marine environment.

Sea otter research.
EVOS photo library.

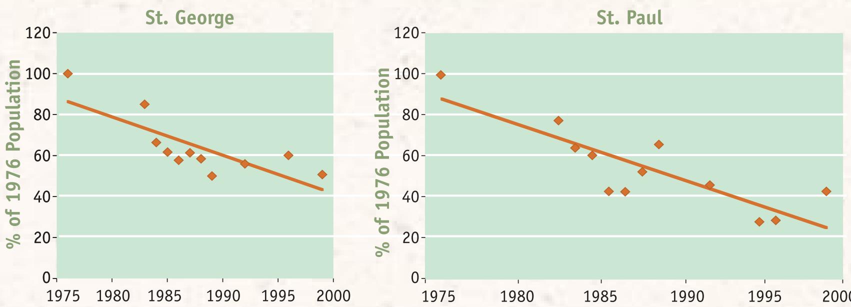


figure 9.3

Population Trends of Red-legged Kittiwakes at Index Sites on St. George and St. Paul Islands.

Populations have decreased by 50 to 70 percent since the 1970s.

Credit: Dragoo et al. 2001.

Status and Trends of Selected Species of Seabirds

Sixty-three species of marine birds are found along Alaska's mainland coast and on its hundreds of islands, numbering nearly 30 million individuals and nesting at nearly 1,700 locations. Roughly 30 million more migrate north each summer from nesting areas in the Southern Hemisphere to feed in the rich waters of the Gulf of Alaska, Bering Sea and Chukchi Sea.

Populations of most species of seabirds, sea ducks and sea geese at several important nesting and wintering locations throughout the state are monitored regularly by the U.S. Fish and Wildlife Service. Data on abundance, productivity, and diet provide valuable information on the status of the various species, as well as on the status of their ecosystems and supporting food webs.

In general, Alaska's seabird populations are healthy, despite local decreases at some locations (Dragoo et al. 2000). For most species, such as the abundant and wide-spread common murres, thick-billed murres and black-legged kittiwakes, decreases at one location are offset by increases elsewhere. Less is known about certain other species that are difficult to study because they nest underground or are nocturnal, such as storm-petrels and auklets, yet presently there is little cause for concern. Two species do merit concern, however: red-legged kittiwakes and Kittlitz's murrelets.

In addition, several sea duck populations apparently are less stable, with two species now at very low levels of abundance: Steller's eiders and spectacled eiders, (www.seaduckjv.org/littoc.html; Kertell 1991, Stehn et al. 1993). Likewise, one of the two species of sea geese in Alaska, the emperor goose, also has experienced a large decline in recent years.

Red-legged kittiwake

Red-legged kittiwakes are endemic to the Bering Sea, nesting at only eight locations with over 95 percent of all birds on St. George Island in the Pribilofs. Since counts were first made on the Pribilofs, numbers on both St. George and St. Paul Islands, the next largest colony, have fallen by 50 percent to 70 percent. No one is certain of when the decline began or what has driven it (*figure 9.3*).

Productivity has varied over the years, but a population model suggests that the decline cannot be explained by changing productivity alone, thus implicating excessive adult mortality that likely occurs in winter (J. Schmutz and V. Byrd, unpublished data). Low productivity and adult mortality are probably the result of inadequate prey resources.

Still, there is reason for optimism for red-legged kittiwakes. The rate of decline on St. George Island has decreased in recent years, while they increased greatly on Buldir Island and Bogoslof Island in the Aleutians. As with the northern fur seal, the contrasting trends in abundance at the Pribilofs compared to the Aleutians indicate different ecosystem states in the two regions.

Kittlitz's murrelet

Climate change on a century time scale is of concern for at least one species of Alaskan seabird, the Kittlitz's murrelet (Van Vliet 1993). This enigmatic seabird, broadly distributed from Southeast Alaska through the Aleutians and as far north as the Chukchi Sea, is one of the least known and least abundant of Alaska's many species of seabirds, numbering perhaps 20,000 total. It occurs in very low abundance everywhere except in Glacier Bay and Prince William Sound, where it is associated with waters influenced by tidewater glaciers.

Numbers have declined by as much as 80 percent in Glacier Bay in the past decade (J. Piatt and A. Springer, unpublished data) and perhaps by a similar amount in Prince William Sound (U.S. Fish and Wildlife Service, unpublished data). The chief concern for the future of these birds, under consideration for listing under the ESA, is the loss of critical habitat if global warming continues and glaciers recede.

Spectacled and Steller's eider

Spectacled eiders on the Yukon-Kuskokwim Delta in southwestern Alaska, the core of their Alaska nesting range, began a long steady decline also in the 1960s from some 100,000 to the present population of about 8,000.

Steller's eiders, once also abundant on the Yukon-Kuskokwim Delta, formerly the core of their range, essentially disappeared during the 1960s-1980s. The cause is not precisely known for either of these cases, but a high incidence of lead pellets in adult female spectacled eiders and common observations of lead poisoning point to this as an important factor in their decline. Lead shot from waterfowl hunters accumulates in ponds where eiders feed, exposing them to its toxic effects. Both species are listed as threatened under the Endangered Species Act.

Emperor goose

Emperor geese nest in greatest density on the Yukon-Kuskokwim Delta. Their abundance fell from about 140,000 in the 1960s to 40,000 over the following two decades. The cause is unknown, but high winter mortality has been suggested as an important contributing factor. Recent increasing numbers, to about 60,000 today, may lead to a recovery of the species.

Status and Trends of Selected Species of Marine Fish

Time series of marine fishes serve as one of the best examples of how important environmental factors are in influencing the species composition of marine communities. For example, prior to the shift from a warm water period in nearshore waters off Alaska to a cold water period, the female spawning biomass of groundfish in the Bering Sea was approximately two million metric tons. Within a decade, the spawning biomass had tripled. Spawning biomass has remained at levels two-to-three times what it was in 1978 throughout the 1990s and into the 2000s. A similar increase in the five commercially important species of salmon in Alaska was observed following the regime shift in the late 1970s.

On the other hand, Anderson and Piatt (1999) reported that the shift resulted in a dramatic reduction in several key forage species in the western Gulf of Alaska, including shrimp and capelin. This same pattern, a reduction in forage fish abundance, apparently occurred in the Bering Sea as well. Recent time series on sea surface temperature in the Bering Sea indicate that we are possibly entering another period of cold surface water, similar to that observed prior to the mid-1970s. Our understanding of ecosystem behavior will be greatly improved by monitoring changes in the species composition of Alaska's commercial and forage fish over the next decade.

Of course, the Bering Sea and Gulf of Alaska are also extremely important fishing grounds to Alaska and the nation. The groundfish fishery in Alaska alone produces approximately 50 percent of all the landings of fish in the U.S. At present, the female spawning biomass of groundfish in Alaska is approximately 40 percent less than it would be absent a fishery, a level used by fishery managers to reduce the likelihood of recruitment overfishing. The resulting biomass and the associated increase in net production of the species is what fishery managers count on for sustainability in fishery management. However, the removal of up to two million tons of groundfish annually and the associated reduction in the standing stock (the biomass remaining after harvesting) have unknown and unaccounted for effects on the marine ecosystem.

The impacts of fishing on the marine ecosystem, including indirect effects related to modification of the benthos, bycatch, and ghost fishing, occur simultaneously with the impacts of short and long term regime shifts (e.g., El Niño/Southern Oscillation events and Pacific Decadal Oscillations) and global climate change. One of the most difficult jobs of marine scientists is to evaluate the extent to which species of concern are being affected by each of these different processes.

Kittiwake research.
EVOS photo library.

Pollock

Pollock has remained the most important commercial species in the Bering Sea in terms of landings from the early 1980s to the present. Harvest levels have remained relatively constant—over one million metric tons—over the last 20 years. The size of the pollock stock, like that of other cods, is dependent on periodic episodes of strong recruitment by single year classes. Spawning biomass of Bering Sea pollock increased dramatically in the late 1970s and early 1980s, and has remained relatively constant at high levels for the past 20 years. In the Bering Sea, the last two strong year classes were from the cohorts spawned in 1992 and 1996.

As in the Bering Sea, pollock biomass in the Gulf of Alaska rose dramatically in the late 1970s and the early 1980s after a record series of strong year classes between 1975-1979. However, a combination of removals by the commercial fishery and a lack of strong year classes since 1979 have resulted in a steady decline that continues to the present. The current spawning biomass of pollock in the Gulf of Alaska is the lowest on record.

Typically, healthy populations of gadid species are harvested at levels approaching 30 percent per year. In Alaska, pollock in the Gulf of Alaska and Bering Sea are harvested at rates between 10-15 percent of exploitable biomass. Pollock is one of the better-studied species of marine fish in Alaska. Fishery-independent surveys using trawls and acoustics are done to assess distribution and abundance. For more information on the assessment of pollock in Alaska (and other groundfish species), the reader is referred to the Stock Assessment Fishery Evaluation (SAFE) Reports (NMFS 2001) on the North Pacific Fisheries Management Council's website: http://www.fakr.noaa.gov/npfunc/safes/safe.htm.

North Pacific cod

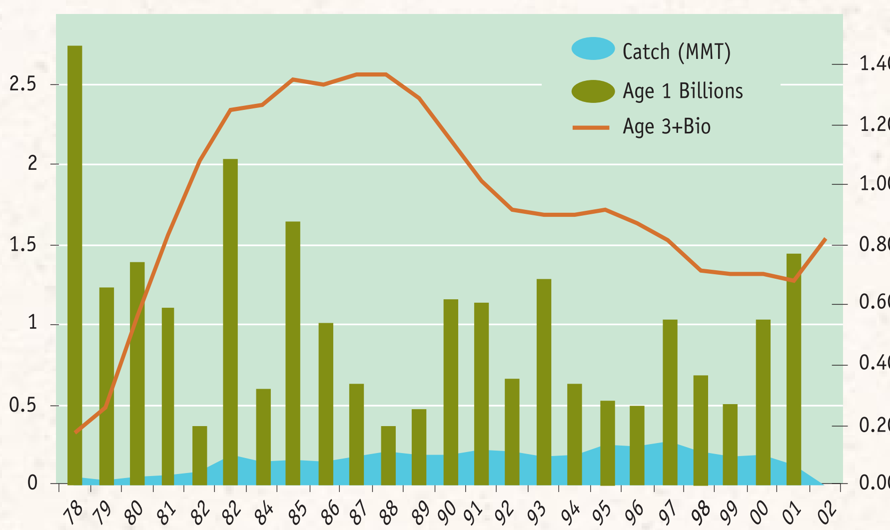
Pacific cod are another important species to fisheries in Alaska. Cod biomass is estimated at approximately 1.54 million metric tons in the eastern Bering Sea and 600,000 metric tons in the Gulf of Alaska. In the Bering Sea, year class strength since 1992 has been below average, although a relatively strong year class was detected in 2000. Current levels of allowable biological catch (ABC) of cod in the Bering Sea and Gulf of Alaska are 223,000 metric tons and 57,600 metric tons, respectively. Cod biomass in both the Bering Sea and Gulf of Alaska peaked in the mid-1980s and has continued a slow decline (*figure 9.4*) Details regarding the status of cod in the Bering Sea and Gulf of Alaska can be found in SAFE Reports (NMFS 2001).

figure 9.4

Trends in Abundance and Catch of Pacific Cod in the Bering Sea

Cod biomass in the Bering Sea peaked in the mid-1980s and has been in slow decline since.

Credit: DeMaster and Springer. 2002. Oceans and Watersheds Symposium. Anchorage, AK.



Atka mackerel

Atka mackerel, not a true mackerel but a member of the greenling family, is both a valuable commercial species and a key forage species in the Aleutian Islands and Gulf of Alaska ecosystems. Despite its importance to commercial fisheries and to marine mammals, many aspects of the life history of Atka mackerel are poorly understood. Based on tagging studies, however, it appears that older juveniles and adults remain within an area and do not move great distances, a life history trait that could make them vulnerable to depletion within portions of their range by locally intense fisheries.

The commercial harvest of Atka mackerel currently takes place only in the waters around the Aleutian Islands. However, there was a significant fishery for Atka mackerel in the Gulf of Alaska as far east as Kodiak Island up until the early 1980s. It is unclear why the population of Atka mackerel in the Gulf of Alaska has not returned, particularly since there has not been a fishery in most of the area since the mid-1980s. The Aleutian Islands population is currently estimated to be at about 450,000 metric tons, but it has declined over 60 percent since 1991. Harvest rates for the species have ranged from 2-14 percent between 1972 and 2000. Details regarding the status of Atka mackerel in the Aleutian Islands can be found in SAFE Reports (NMFS 2001).

Salmon species in Alaska

Salmon fisheries are some of the most important fisheries in Alaska. Commercial catches of Chinook, sockeye, coho, pink, and chum salmon are reported on the Alaska Department of Fish and Game website: http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/salmhome.htm.

SUMMARY OF TRENDS IN ABUNDANCE

Unclear	Decline	Stable	Increase
Harbor seal	Western Steller sea lion	Eastern No. Pacific gray whale	Western Arctic bowhead whale
Cook Inlet beluga	Northern fur seal	Eastern Bering Sea pollock	Central No. Pacific humpback whale
Killer whale	Red-legged kittiwake	Yellow fin sole	Gulf of Alaska flounder
Capelin	Kittlitz's murrelet	Arrowtooth flounder	Pink salmon
Sandlance	Spectacled eider	Pacific ocean perch	
Shrimp	Steller's eider	Gulf of Alaska thornyhead	
Herring	Gulf of Alaska pollock		
	BS Aleutian Islands and GoA northern cod		
	Atka mackerel		
	Chinook, coho, chum, and sockeye salmon		

table 9.1

Summary of trends in abundance for selected species of marine mammals, birds and fish found in the Bering Sea and Gulf of Alaska. Trends in abundance information from the last 10-15 years was used for classification.

Credit: DeMaster and Springer. 2002.

In evaluating the time series of salmon catch data it is important to keep in mind the potential impact of salmon hatcheries and complex management strategies for salmon in Alaska and elsewhere. Clearly, the regime shift in 1977 and the possible regime shift in the late 1990s is of critical importance to salmon dynamics in Alaska.

Catches of Chinook salmon in Alaska jumped over 30 percent between the mid-1970s and the 1980s. However, catches slowly declined after 1985 until 1997, after which the catch levels dropped dramatically. Catches of sockeye salmon in Alaska show a different pattern over time. For this species, catches slowly increased from the early 1970s through 1995, after which they dropped off sharply. A similar pattern is seen for catches of coho and chum salmon in Alaska. Catches of pink salmon show considerable variability between years, but on average have increased from very low levels in 1975 to peak levels in the late 1990s. Understanding the regional dynamics of salmon species in Alaska will be very important in understanding the impact of climate change and fisheries on the species composition in the Bering Sea and Gulf of Alaska.

Forage fish species in Alaska

Many authors have reported profound changes in the marine ecosystem off Alaska after the regime shift in 1977. While the details of this change remain unclear, there is general agreement that a significant reduction in forage species (e.g., capelin, herring, sand lance, shrimp, and eulachon) occurred. As these forage species were important prey to many fish, bird, and mammal predators, their absence likely had severe effects on predators dependent upon them (Merrick 1995, NRC 1996). Unfortunately, forage species are not monitored systematically in Alaska. Surveys to estimate an index of abundance for suite of one forage fish species—herring stocks are reported by the Alaska Department of Fish and Game (www.cf.adfg.state.ak.us/geninfo/finfish/herring/herrhome.htm).

Based on 30 years of small-mesh trawl surveys in one bay in the Gulf of Alaska, Anderson and Piatt (1999) reported a shift in the prey base from one dominated by shrimp to one dominated by pollock, cod and flatfish, a change highly correlated with an increase in sea surface temperature in the Gulf of Alaska. In 2000, with increased funding from Congress to evaluate the extent to which groundfish fisheries were adversely affecting the western stock of Steller sea lions, several research institutions in Alaska, including the National Marine Fisheries Service and the Alaska SeaLife Center, implemented research to monitor changes in the abundance of key forage species in Alaska. The studies will help scientists understand the influence of and importance of "bottom-up" processes in causing changes in the marine community structure in waters off Alaska.

Regional Concerns

In addition to the species-specific concerns described above, there are notable regional concerns at two spatial scales. Two areas stand out at the smaller scale, the Pribilof Islands and the Yukon-Kuskokwim Delta. On the Pribilofs, red-legged kittiwakes are not the only species of seabird to

Without systematic monitoring of key indicator species (including important species of forage fish), determining the influence of fisheries and other anthropogenic effects will not be possible.

have declined—closely related black-legged kittiwakes on both islands and thick-billed murres and common murres on St. Paul Island have seen their populations fall by 30 percent to 75 percent, respectively, since the mid-1970s. These changes, coupled with the large declines of fur seals on both St. Paul and St. George Islands, the decline of harbor seals on Otter Island, the complete loss of walruses and virtually all sea otters by the end of the 1800s, and the loss of most of the sea lions in recent years, make the Pribilofs clearly a place of special concern.

The other smaller region is the Yukon-Kuskokwim Delta, where, in addition to Steller's and spectacled eiders and emperor geese, common eiders have experienced an alarming decline in the past 30 years. Common eiders nest widely in the state, yet have declined only on the Yukon-Kuskokwim Delta.

Elsewhere, murre and black-legged kittiwake numbers also are down at St. Matthew Island and at Cape Pierce on the mainland coast at the southern edge of the Yukon-Kuskokwim Delta. In aggregate, the declines of seabirds and marine mammals on the Pribilofs, of seabirds at St. Matthew Island and Cape Pierce, of eiders and emperor geese on the Yukon-Kuskokwim Delta make the southeastern Bering Sea one of two larger regions of special concern in Alaska.

The other larger region is the Aleutian Islands, where populations of sea lions, harbor seals and sea otters are extremely depressed. Sperm whales, fin whales and sei whales, although apparently recovering from the devastation of the whaling era, remain far below their historic highs. Introduced rats, voles and ground squirrels still infest many islands and likely always will. They take a great toll on seabirds and may continue to reduce the diversity and abundance of avifauna on the Aleutians for years to come.

Implications and Conclusions

- The information needed to characterize trends in abundance is lacking for many populations that are either very important to the ecosystem, possible keystone species, or may be adversely affected by direct or indirect interactions with humans. Additional effort and resources are needed to monitor these populations.
- The marine environments in the Gulf of Alaska and the Bering Sea are healthy for some species, but unhealthy for others. At present, the pattern in trends in abundance is not consistent with any one factor leading to the demise of a large number of top-level predators. There is no longer any doubt that large-scale environmental regime shifts, precipitated by abrupt changes in climate, have a dramatic influence on productivity of marine food webs and subsequent community structure.
- Certain areas seem to be associated with a relatively large number of declines in abundance of top-level predators. In particular, several species of seabirds and marine mammals are declining around the Pribilof Islands; several species of seabirds are declining around the Yukon-Kuskokwim Delta; and several species of marine mammals are decreasing or remain depressed in the Aleutian Islands. Special attention should be given to monitoring the marine environment in these areas.
- The use of indicator species has considerable potential, but it is important to understand the population structure of a species to properly interpret trend data. Where trend data from discrete populations are pooled, it is likely that erroneous conclusions will be made. Therefore, it is very important to expand tagging, genetic, morphometric, and other such studies to better understand the population structure of key indicator species. This is particularly needed to evaluate trends in abundance of seabird and harbor seals populations.
- The next decade appears to be one in which the marine environment will shift back to conditions dominated by relatively cold water, as was the case prior to the shift in 1977. Therefore, it is critically important that efforts be made to understand the influence of this environmental feature on the species composition of the marine community in the Bering Sea and Gulf of Alaska. Without systematic monitoring of key indicator species (including important species of forage fish), determining the influence of fisheries and other anthropogenic effects will not be possible.

Alaska Sea Grant. 1993. Is it food? Addressing marine mammal and seabird declines. Workshop summary, Alaska Sea Grant Report 93-01. University of Alaska, Fairbanks, AK.

Anderson, P.J. and J.F. Piatt. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series 189, 117-123.

Angliss, R.P., D.P. DeMaster, and A.L. Lopez. 2001. Alaska Marine Mammal Stock Assessments, 2001 U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-124, 203 pp.

DeMaster, D.P. and Atkinson, S. Editors. 2002. Steller sea lion decline: Is it food II? University of Alaska, Sea Grant College Program AK-SG-02-02. 78 pp.

Dragoo, D.E., G.V. Byrd, and D.B. Irons. 2001. Breeding status, population trends and diets of seabirds in Alaska, 2000. U.S. Fish and Wildlife Service Report AMNWR 01/07.

Estes, J. A. 1990. Growth and equilibrium in sea otter populations. Journal of Animal Ecology 59:385-401.

Estes, J.A. and J.F. Palmisano. 1974. Sea otters: their role in structuring nearshore communities. Science 185:1058-1060.

Estes, J.A., M.T. Tinker, T.M. Williams, and D.F. Doak. 1998. Killer whale predation on sea otters linking oceanic and nearshore ecosystems. Science 282: 473-476.

Ferrero, R.C. and L.W. Fritz. 2002. Steller sea lion research and coordination: a brief history and summary of recent progress. NOAA Technical Memorandum NMFS-AFSC-129. 34 pp.

Hobbs, R.C., D.J. Rugh, and D.P. DeMaster. 2001. Abundance of beluga whales, *Delphinapterus leucas*, in Cook Inlet, Alaska 1994-2000.

International Whaling Commission. 2002. Report of the Scientific Committee IWC/54/4. 109 pp.

Jackson, J.B. et al. 2001 Historical overfishing and the recent collapse of coastal ecosystems. Science 293, 629-638.

Kenyon, K.W. 1965. Food of harbor seals at Amchitka Island, Alaska. Journal of Mammalogy 46: 103-104.

Kertell, K. 1991. Disappearance of the Steller's Eider from the Yukon-Kuskokwim Delta, Alaska. Arctic 44: 177-187.

Loughlin, T.R., A.S. Perlov, and V.A. Vladimirov. 1992. Range-wide survey and estimation of total numbers of Steller sea lions in 1989. Marine Mammal Science 8:220-239.

Merrick, R. 1995. The relationship of the foraging ecology of Steller sea lions (*Eumetopias jubatus*) to their population decline in Alaska. Ph.D., University of Washington, 1995. 172 pp. THESIS M-32.

Moore, S.E. and D.P. DeMaster. 1997. Cetacean habitats in the Alaskan Arctic. Journal of Northwest Atlantic Fishery Science 22:55-69.

Moore, S.E. and D.P. DeMaster. 2000. Cook Inlet belugas, *Delphinapterus leucas*: status and overview. Marine Fisheries Review 62(3): 1-5.

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

National Marine Fisheries Service. 2001. North Pacific groundfish stock assessment and fishery evaluation (SAFE) reports. Resource Ecology and Fisheries Management, Alaska Fisheries Science Center, National Marine Fisheries Service, U.S. Department of Commerce.

Pitcher, K.W. 1980. Food of the harbor seal, *Phoca richardsi*, in the Gulf of Alaska. Fisheries Bulletin 78: 544-549.

Sease, J.L., W.P. Taylor, T.R. Loughlin, and K.W. Pitcher. 2001 Aerial and land-based surveys of Steller sea lions (*Eumetopias jubatus*) in Alaska, June and July 1999 and 2000. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-122. 52 pp.

Sheldon, K.E.W. and D.J. Rugh. 1995. The bowhead whale, *Balena mysticetus*: its historic and current status. Marine Fisheries Review 57:1-20.

Sinclair, E.H., G.A. Antonelis, B.W. Robson, R.R. Ream, and T.R. Loughlin. 1996 Northern fur seal, *Callorhinus ursinus*, predation on juvenile walleye pollock, *Theragra chalcogramma*. NOAA Technical Report NNFS 126, 167-178.

Sinclair, E. and T. Zeppelin. 2002. Seasonal diet trends among the western stock of Steller sea lions (*Eumetopias jubatus*). Pages 53-55. *in* DeMaster, D.P. and S. Atkinson, Editors. 2002. Steller sea lion decline: Is it food II? University of Alaska, Sea Grant College Program. AK-SG-02-02. 78 pp.

Stehn, R.A., C.P. Dau, B. Conant, and W.I. Butler, Jr. 1993. Decline of Spectacled Eiders nesting in western Alaska. Arctic 46: 264-277.

Trites, A.W. and P.A. Larkin. 1996. Changes in the abundance of Steller sea lions, *Eumetopias jubatus*, in Alaska from 1956 to 1992: How many were there? Aquatic Mammals 22:153-166.

Van Vliet, G.B. 1993. Status concerns for the 'global' population of Kittilitz's murrelet: is the 'glacier murrelet' receding? Pacific Seabirds 21: 5-6.

Literature Cited

©Art Sutch

Status and Trends of Alaska's Marine Resources: Fish, Birds and Mammals



10. Persistent Organic Pollutants in the Alaska Environment

Michael Smolen, World Wildlife Fund

Introduction

When considering chemical contaminants in Alaska, most attention has focused on the Persistent Organic Pollutants (POPs). The currently recognized POPs are 12 chemicals: pesticides (aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, and toxaphene), polychlorinated biphenyls (PCBs), and industrial and incineration by-products (dioxins and furans). In addition, there are other chemicals that have been proposed to be added to the list of POPs because they have similar properties to the known POPs and pose serious health risks to humans and wildlife. Like the POPs, many of these chemicals are settling into the soils and waters of Alaska and are moving into the food webs of both freshwater and marine systems.

The focused research conducted over the past decades on the POPs has prompted changes in the way society views hazards to the environment and human health and has prompted governments to take action to remove egregious chemicals from the environment. Classical toxicological methods are often limited to gross effects from exposure to these chemicals. These studies were conducted using high doses of chemicals, often a million times higher than actual exposure, and evaluated effects including mortality, obvious birth and reproductive effects, cancers, skin and eye irritation, and mutations. Unfortunately, this approach to assessing toxicological risk does not incorporate the results of thousands of peer reviewed papers revealing that a large number of chemicals in use today potentially have other less obvious but serious health effects on both humans and wildlife.

(above)
Flaring off. *(ADF&G)*
Oil drums. *(ADF&G)*
Tanker ballast. *(ADC&BD)*

What are the POPs?

The POPs differ in chemical structures; however, they share four attributes that are used by the United Nations Environment Program (UNEP) Stockholm Convention on POPs to describe Persistent Organic Pollutants: 1) a POP is persistent, with a half-life greater than two months in water, or six months in soil or sediment; 2) a POP also bioaccumulates with values in aquatic systems greater than 5,000 or with an octanol/water partition coefficient (log K_{ow}) greater than 5; 3) a POP has the potential for long-range transport, which can be seen as the presence a long distance from sources, or through documentation in fate models, or detection in monitoring programs; and 4) and probably the most important quality of a POP is the fact that these chemicals adversely affect the environment and/or human health.

Other chemicals share the four properties of POPs, and are, therefore, of concern (AMAP 1998). Some of the chemicals that are being considered as candidates for future global POPs regulations are chlordecone, hexachlorocyclohexane, hexabromodiphenyl, pentachlorophenol, short-chained chlorinated paraffins (SCCPs), penta-brominated diphenyl ether (penta-PBDE), octachlorostyrene, polychlorinated naphthalenes (PCNs), perfluoro-octanesulfonyl fluoride (POSF), perfluorooctanyl sulfonate (PFOS), endosulfan, tetrachlorobenzene (tetra-CB), hexachlorobutadiene (HCBD), and pentachlorobenzene (penta-CB).

A great deal is known about some of these chemicals, such as chlordecone, hexachlorocyclohexane, pentachlorophenol, and endosulfan. These have been detected in the Arctic and are common in tissue samples of Alaskan wildlife and fish. However, other chemicals on the list are not well known but are currently receiving attention in several parts of the world. From preliminary reports, they appear to be persistent, bioaccumulate, move long distances, and have potentially serious health effects. From this list of less well-known chemicals, there are two that draw special concern: perfluorinated carbons and brominated diphenyl ethers.

In June 1998, nearly 100 nations met in Montreal to begin a long process of negotiations which has led to a treaty to phase out POPs chemicals. The result of subsequent meetings in Nairobi, Geneva and Bonn led to the signing of the POPs Treaty in Johannesburg in 2000. This treaty now requires ratification by the governments of 50 countries before it will come into force.

The U.S. Environmental Protection Agency estimates that there are over 87,000 man-made chemicals in use today. Some are released intentionally into the environment while others migrate from commercial products and dumpsites or are released during manufacturing processes. Except for a few of these chemicals, little is known about their release, fate and transport. Much of what is known of chemicals in the environment is limited to products derived from petroleum such as: organic solvents, many pesticides and the common, high volume industrial chemicals, many of which are used in consumer products.

The POPs are especially well known because of their physical, chemical and health-related properties. The 12 chemicals currently on the list drew the attention of nations because they accumulated in wildlife and human tissue, moved long distances across continents, and there was a growing awareness of their insidious health effects associated with exposure (*table 10.1*).

Hundreds of researchers in universities and government agencies published thousands of research papers and reports, meticulously identifying the pattern of entrapment and concentrations in sediment, aquatic systems and biota around the world. Most startling were the discoveries concerning bioaccumulation and biomagnification of the POPs in food webs around the world. Additional impetus and motivation for banning these chemicals on a global scale was the desire to support nationwide efforts to control their production and the ultimate exposure by wildlife and humans. Unfortunately, some countries, such as Russia, India and China, still produce well known hazardous chemicals such as PCBs and DDT.

Attention was first drawn to the 12 POPs when scientists discovered high concentrations in wildlife tissue. This was particularly troubling because some of the animals from the Arctic had the highest recorded levels in the world of the chemicals in their tissue, and these chemicals were not used in the Arctic. Each of the 12 POPs has its own story for why there is an urgent need to ban its use.

table 10.1

THE 12 POPs REGULATED BY THE POPs TREATY

Pesticides
aldrin
chlordane
DDT
dieldrin
endrin
heptachlor
hexachlorobenzene
mirex
toxaphene

Polychorinated biphenyls (PCBs)

Industrial and Incineration by-products
dioxins
furans

Other chemicals have been proposed to join the list because they share similar properties with known POPs and pose serious health risks to humans and wildlife.

The 12 chemicals currently on the list drew the attention of nations because ... there was a growing awareness of their insidious health effects associated with exposure.

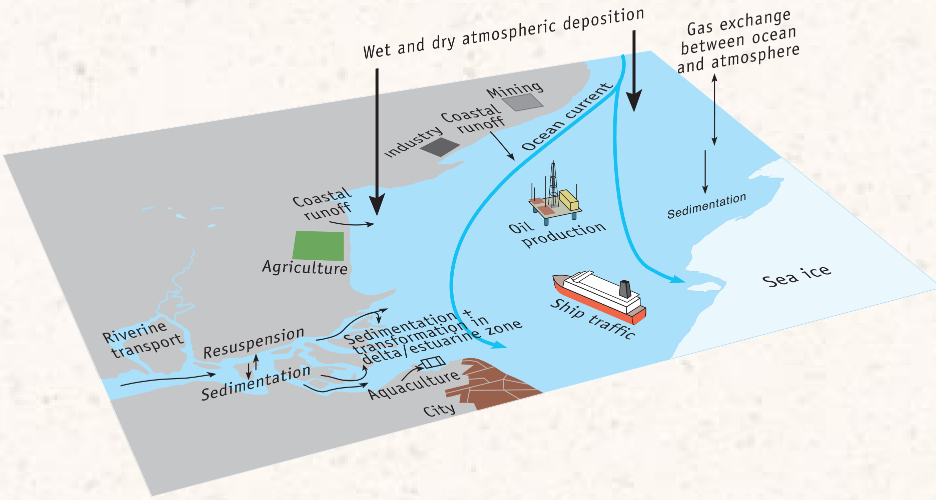


figure 10.1

Arctic Pollution Issues: Coastal and Marine Environments

This conceptual model of the coastal zone and marine environment shows the main subcompartments and contaminant transfers and exchanges with the atmosphere.

Credit: Arctic Monitoring and Assessment Programme, AMAP Assessment Report, Arctic Pollution Issues, Fig.3.17. 1998.

What these chemicals share however, is that they do not stay in one place, and, for some, the volumes produced can be enormous.

Chemicals in Alaska

It is imperative to try to understand better how chemical contaminants get to or move in Alaska. There are four common routes: 1) actual uses and/or release in Alaska; 2) atmospheric transport; 3) aerosols; and 4) coastal ocean currents. Historic interest in how chemical contaminants reach Alaska has been restricted primarily to either contaminants transported into the state in commerce or contaminants generated or released in extractive processes, such as oil or mining.

Chemicals are brought to Alaska for a wide range of reasons: in electronic equipment; to support aviation activities; as pesticides for mosquito control; and as fuels, to name a few. In addition, the release of chemicals from military installations is a widely recognized point source in Alaska. Whether the base is a small White Alice radar site like King Salmon or a large facility like Elmendorf Air Force Base, a wide variety of chemicals are brought into Alaska to maintain these facilities.

Mineral and oil exploration and their transport are other sources of chemical contaminants. The *Exxon Valdez* oil spill is an example of a large-scale unintentional release of crude oil. However, there are also countless other examples of smaller scale releases from leaky pipelines, acts of vandalism to the Alaska Pipeline, and spills from home heating oil tanks or storage tank pipelines. Mineral extraction also can lead to releases of inorganic chemicals, such as arsenic and mercury. Chemicals also enter the environment when mineral ores are refined and concentrated.

Hydrocarbons are probably the most commonly found contaminants in the Alaska environment, with the family of polyaromatic hydrocarbons (PAHs) one of the most informative about contaminant sources and movements in the coastal currents of Alaska. Crude oil and petroleum products contain a wide array of PAHs with the proportions distinctive to the source. The compounds differ when the crude oil is refined by fractionation to get gasoline, diesel fuels and other refined petroleum products. A similar array of chemicals in crude oil can be found together in compounds released from exposed coal deposits or natural seeps of petroleum.

Most studies of sediments in Alaska waters are focused on understanding the sources, patterns, and weathering of man-made and released petroleum hydrocarbons from spilled oil from transport tankers and onshore leaks. The 1989 grounding of the crude oil transport tanker, *Exxon Valdez*, on Bligh Reef in Prince William Sound set in motion a series of studies that are providing a better understanding of hydrocarbons in the natural environment. In order to observe the dynamics associated with the release of 11 million gallons of North Slope crude oil, a variety of studies were done to develop methods to fingerprint petroleum hydrocarbons (Bence and Burns 1995, Short and Heintz 1997). In the process, much was learned about oil from the tanker, and much about the historical presence of natural and man-made hydrocarbons. The *Exxon Valdez* crude contributed a large volume of petroleum. The fingerprinting methods, however, also identified possibly three other sources that contribute to a background that is found mainly in the subtidal sediments in Prince William Sound. Remnant *Exxon Valdez* oil is the overwhelmingly dominant source of petrogenic hydrocarbons in the intertidal (Short et al. 2002) followed by tarballs from the 1964 earthquake (Kvenvolden et al. 1995).

Other sources of hydrocarbon contaminants in sediment are natural oil seeps (Page et al. 1995), organic-rich shales that are precursors to formation of petroleum deposits (Van Kooten et al 2002), and exposed terrestrial coal deposits (Short et al. 1999, Van Kooten et al. 2002). The relative contributions of hydrocarbons from these sources is presently unresolved. Resolving these is important because hydrocarbons from seep oils are readily bioavailable, but hydrocarbons sequestered in shales or coals are not. Sediment core analysis in Prince William Sound and the Gulf of Alaska have found that these natural occurrences have been going on for at least the 160 year age of the cored samples.

Rivers are also important sources of contaminants in coastal waters. Studies on the Mackenzie River and its influence on deposition of hydrocarbons on the Mackenzie Shelf in the Beaufort Sea identify both anthropogenic and natural sources (Yunker et al. 1993). In order to positively identify chemicals common to sources, it is necessary to conduct rather sophisticated methodologies since man-made and natural source hydrocarbons share numerous chemical components. In this study of a major river system flowing into the Arctic, Yunker and coworkers identified a significant component originating from decaying plant material. Another source that is thought to be petrogenic are local oil seeps or bitumen deposits exposed along the river. Anthropogenic sources contribute a minor amount. These are believed to be limited to atmospheric transport with a portion, including pyrogenic residues, originating from forest and tundra fires.

Atmospheric Transport

Global fractionation

As researchers discovered that Arctic animals had astonishingly high concentrations of chemicals that were not known to be used in the Arctic, attention turned to the pathways and sources for these chemicals. Global fractionation has become a commonly accepted model (Wania and Mackay 1993, 1996) for tracking chemicals. It is based on the natural properties of chemicals and climatic processes.

Each chemical has distinct properties that make it unique, such as molecular weight, melting point, boiling point, Henry's Law constant, vapor pressure, solubility in water, air-water partition coefficient, and octanol/water partition coefficient. Temperature plays an important role in how some of these variables affect the potential mobility of a chemical (Wania and Mackay 1993). As temperatures change toward the poles, or with the seasons, climatic conditions may encourage evaporation and gaseous movement of chemicals in the air. Colder climatic conditions encourage condensation or deposition. Some of the chemicals of concern, when released into the environment at warm temperatures, have the potential for long-range movement and eventual deposition in the polar climates.

The natural process for chemical transport is unpredictable since airflow patterns, the amount of solar radiation, local and regional ambient temperatures, moisture, and other physical factors vary greatly across the hemisphere. The subtle differences in properties of each chemical cause each to perform differently. Chemicals with lower volatility may evaporate during hotter seasons of the year or warmer parts of a day. Likewise, these borderline chemicals would condense out in cooler latitudes, seasons or times of the day. Chemicals with evaporative properties closest to the lower limits for evaporation and condensation seem to move stepwise, a grasshopper-like effect, hopping along on air currents dependent upon local conditions. There are numerous examples of the movement of chemicals in air currents around the world. Pesticides banned in Europe are routinely detected in air samples. DDT, long banned in the United States and Canada, pulses in the St. Lawrence River each year during the spring snowmelt (Pham et al. 1993, 1996).

As researchers discovered that Arctic animals had astonishingly high concentrations of chemicals that were not known to be used in the Arctic, attention turned to the pathways and sources for these chemicals.

figure 10.2

Arctic Pollution Issues: Source Regions for HCH, Chlordane,Toxaphene and PCBs in Arctic Air

Contaminants are moved from source areas into the Arctic by air currents.

Credit: Arctic Monitoring and Assessment Programme. AMAP Assessment Report, Arctic Pollution Issues, Fig.6.6. 1998.

First, the extreme cold climate of the polar region increases the persistence of chemicals. Second, the reduced solar radiation in the polar region retards the photodegradation of pesticides, and other contaminants.

A study by Chernyak and coworkers (1996) provides additional information about the long-range transport of chemicals that are thought to be short-lived. Many of the newer pesticides used in agriculture were designed to have relatively short half-lives and rely on the energy in sunlight to photodegrade. Chernyak et al. analyzed subsurface water, the surface microlayer water, ice, and fog at numerous sites in the Bering and Chukchi Seas for 18 pesticides. They discovered a number of agrochemicals in each sample. Those with the highest concentrations in the water and surface microlayer were associated with the ice edge. The authors propose that the pesticides are deposited on the ice and, as it melts, the chemicals concentrate at the ice edge. The pesticides detected in water samples were the insecticides chlorpyrifos, endosulphan I and II, and fenvalerate, and the fungicide chlorothalonil. Samples of surface microlayer from Bristol Bay had two pesticides, the fungicide chlorothalonil and the herbicide trifluralin.

The authors believe that these pesticides were deposited from fog, which recently swept over the sampling area. Fog samples had the herbicide metolachor, and the insecticides terbufos and chlorothalonil. Air samples lacked appreciable concentrations of pesticides, and it is proposed that fog may be the primary carrier of these pesticides. Deposition in Alaska seems to rely on fog and ice. Samples of ice contained atrazine (herbicide) and chlorpyrifos (insecticide), two pesticides that are being phased out by the EPA.

Two important concepts can be drawn from this study. First, the extreme cold climate of the polar region increases the persistence of chemicals. Second, the reduced solar radiation in the polar region retards the photodegradation of pesticides, and other contaminants. Coupled together, conditions in the Arctic favor the long distant transport of agrochemicals. Very little research has been done to specifically identify pesticides in water, fog and ice. Thus, the magnitude of agrochemicals and other chemicals wafting into Alaska is not fully understood.

Hexachlorocyclohexane

HCH is a well-studied example of global fractionation in the Arctic. HCH was first synthesized in 1825, but its insecticidal properties were not discovered until the early 1940s. By 1942 HCH was becoming widely used in agriculture in developing countries (Li 1999). It is a broad-spectrum pesticide and has been applied to a very wide variety of crops, to protect seed and to remove ectoparasites from livestock and poultry. Li estimates that 10 million tons of HCH were used worldwide between 1948 and 1997. It is now banned in many countries. Canada banned technical grade HCH in 1971. This was followed by the United States (1976), China (1982), and the former Soviet Union (1990).

It is difficult to determine which countries are still using technical grade HCH, but Li (1999) believes that India, Pakistan, Brazil, Malaysia, Israel, and some African countries are still using it in vector control programs and, to a limited extent, in agriculture. Gamma-HCH is still used today and is marketed as lindane in the United States and many other countries around the world. You can find lindane in treatments for head lice in your local pharmacy. EPA is taking steps to remove such pharmaceuticals.

Technical grade HCH is a mixture of eight isomers with four accounting for most of the volume. These are alpha (55-80 percent), beta (5-14 percent), gamma (8-15 percent), and delta (2-16 percent). Alpha and gamma are the most volatile and are involved in long-range transport. Studies conducted in the Arctic identify HCH as one of the most abundant pesticides in water, snow and some wildlife. The Arctic Ocean is a sink for HCH and is probably the main source of HCH entry into the Arctic food webs (Li 1999).

Technical grade HCH is highly volatile. Takeoka and coworkers (1991) studied the movement of HCH in a coastal area of eastern India. They estimated that 99.6 percent of the HCH applied to the ground moved into the air within one week of application. The remaining 0.4 percent moved to a local estuary; however, 75 percent of that HCH also volatilized into the air. Alpha and gamma isomers were most active in these movements, with the degree of movement related to the temperature.

The use of HCH has a very interesting historical pattern. The developed countries used technical grade HCH first and were also first to restrict and ultimately ban its use. The use then proceeded to developing countries in a wave starting with larger countries and over the years to

smaller countries. A wave of bans followed. China started production of technical grade HCH in 1952 and used it extensively until it was banned in 1983. During that interval, Li estimates that they produced four million tons, almost one-half of the entire volume produced worldwide.

India, another major user of technical grade HCH, imported the insecticide shortly after World War II, and began domestic production in 1952. It was widely used in agriculture and in vector control programs, accounting for about 70 percent of all insecticide usage in India in the 1980s. Use was severely restricted in 1990. India currently has the highest concentrations of HCH in its soil, sediment and air.

Technical grade HCH is still used in many small countries in the tropical and subtropical regions of the globe. Many of these countries are using higher volumes as they make a transition from small family farms to larger, mechanized farms. These later farms have become dependent on high volume use of pesticides and fertilizers. This pattern of new uses in small countries will become even more prevalent as developing countries develop agricultural export strategies in a quest for income in the global marketplace.

Technical grade HCH is not used in the Arctic, but appears in astonishing concentrations throughout the region. Wania and Mackay (1999) and Wania et al. (1999) propose a rather thought-provoking mechanism and pathway for this long-range transport. Using existing data on concentrations in soil, sediment, water, and air, they developed a model that describes the transfer rates among compartments. They then take this model and alter the input values to determine the kinds of changes that can be expected if there were bans against use.

Keeping in mind that as much as 99.6 percent of the HCH used in India is airborne within one week, the expectation was that these chemicals from India, Malaysia and China become airborne and flow north to the Arctic region. The Wania/Mackay model, however, demonstrates that alpha HCH more or less remains in the climate zone where it was applied. They propose that only 0.6 percent of the global use reaches the Arctic, and that most of this comes from the temperate and subarctic zones. Eurasia is suspected as providing most of the alpha HCH to the Arctic. Wania/Mackay also point out that the polar regions are much smaller in size from the other regions. Therefore, contaminants that move from the other larger regions pollute a much smaller region.

Wania and Mackay further propose that the Arctic becomes a sink not so much because great volumes of contaminants waft in and condense there, but because the cold climate increases their persistence. They estimate that the half-life of alpha HCH in the Arctic atmosphere is four years, and in the Arctic Ocean it increases to 11.5 years, creating a sink gradually building up with time. Wania and Mackay believe that as much as 95 percent of alpha HCH is now in Arctic waters, and it is from these waters that HCH enters the food webs of the region. In 1995 the concentrations recorded in the air in the Arctic was lower than previously recorded, primarily due to the global bans. The concentration in the Arctic waters is also declining as more alpha HCH is being mixed into the deeper waters.

Aerosols

Chemicals with properties that resist long-range movement, such as low volatility, can move on particulate matter in the air and travel as aerosols. Chemicals traveling in a gaseous state can bind to particulate matter in the air. Once bound, the particle with chemical together can travel long distances. There are two pathways for aerosols in Alaska. The first is a phenomenon peculiar to the Arctic, "Arctic Haze," and the other is regional intrusion of particulates associated with dust storms.

Arctic haze was first described in 1957 when Mitchell described haze bands that he attributed to submicron sized particles. Optical transparency measurements confirmed the nature of the haze. Shaw (unpublished manuscript) estimated that the intensity of sunlight was reduced by the haze, ranging from 10 to 30 percent, which was two to three times the annual mean for localities in the lower 48 states. Furthermore, the haze only occurred during late winter and early spring.

Identification of the cause of Arctic Haze was problematic, since the belief at the time was that the pollution was from local sources. Since there were no known sources of local pollution in far northern Alaska, it was difficult to explain the origin of the particulate matter that made up the haze. Extensive research was conducted through the 1970s which focused on identifying particulates in the haze from specific sources. Using vanadium, sulfates and carbon black as trace indicators of combustion from petroleum and coal, the patterns of these chemicals in the haze indicated that the primary sources were in northern Europe and Asia. Shaw found that the dirtiest air comes into Alaska with northerly winds.

Organochlorine chemicals do not appear to match the travel patterns as seen by the submicron particulate driving the Arctic Haze phenomenon (Fellin et al. 1996). However, polyaromatic hydrocarbons did show a pattern of buildup over the winter months that was very similar to the pattern of particulates, and the authors propose that these contaminants are physically bound to the particulates. Likewise, the POPs chemicals dioxins and furans were identified in winter samples in Arctic air by Hung and coworkers (2002). These contaminants were isolated from filtered particles, indicating that these chemicals were hitchhiking and contributing to the pool of contaminants in Arctic Haze.

The global implications of the phenomenon of Arctic Haze require further research.

Shaw provides a hypothesis on the conditions promoting the formation of Arctic Haze (Shaw, unpublished manuscript). The formation of Arctic Haze is driven in part by cold temperatures. The lack of sunlight in winter, coupled with the higher reflectance of snow and ice cover, contributes to extremely cold temperatures from November to March. The air masses also become more uniform and stable over the region, leading to less movement of contaminants through convection. Another result of the extreme cold temperatures is that the atmosphere has much less water, and thus reduces the chances of contaminants in the air being washed out. Therefore, the physical conditions associated with winter in the Arctic create ideal conditions to keep submicron particles suspended in the atmosphere, and these concentrations build over the winter as more contaminants flow northward.

The size of the air mass of the Arctic Haze follows the changing shape of the Arctic Front, a climatic zone delimited by a mean winter temperature. This front is also seasonal in nature and can be absent in summer, but grows to approximately the size of the continent of Africa by late winter-early spring (Shaw, unpublished manuscript, Crane and Galasso 1999, Crane et al. 2001).

The global implications of the phenomenon of Arctic Haze require further research. Contaminants move to the poles and accumulate over a six-month period. At the onset of spring, these chemicals literally precipitate out onto land or onto the surface of the ice and oceans of the Arctic regions. Sulfur dioxide, vanadium and carbon black particles that scientists use to measure Arctic Haze may not pose as serious a threat as do other chemical contaminants that are also hitchhiking along in the air masses. Hung and coworkers document dioxins and furans traveling on particulate matter in Arctic Haze, with the source being northern Eurasia. These point to the other potential contaminants associated with stack emissions as probably hitchhiking and becoming a part of the Arctic Haze. Polyaromatic hydrocarbons common to petroleum products have also been found to move along into the Arctic Haze (Jaffrezo et al. 1994). The research documenting the movement of chemicals toward the poles is not complete, since attention is focused on detection of only a few chemicals. There have been no comprehensive analyses of the air and precipitates of Arctic Haze in Alaska.

Dust storms

Dust storms are treated separately here even though this form of long-range transport also depends on air currents and aerosols. Aerosols are usually restricted to small particles, whereas the particulates in a dust storms can be two to three millimeters in size. Dust storms are not new phenomena, though they appear to be more frequent due to the global pattern of increasing desertification.

Dust storms can be identified from the ground as hazy skies, dust particles reaching the ground, or by air samples as part of monitoring programs. Satellite images are providing a better understanding of the dynamics of dust storms. For example, unusual weather conditions in early April, 2001 in eastern Asia led to high winds that swept an estimated million tons of soil and dirt into the air. The SeaWiFS satellite of the Goddard Space Flight Center of the National Oceanic and Atmospheric

Administration captured images between the 5th and 6th of April that highlighted the process of long-range transport of the dust. Cyclonic winds moved the dust storm from the central regions of China and Mongolia to as far away as western Washington state. The plume ranged between 7,000 and 23,000 feet with concentrations varying among the layers. The dust plume crossed the western coast of the United States on April 12th and passed over Boston on the 14th. The cloud dissipated over the Atlantic after traversing about two thirds of the way to Europe.

The SeaWiFs Program also documented another Asian dust storm over Alaska. In April 2002, a dust storm front was observed passing over the Aleutians on a path for Nunivak Island, Bristol Bay, and ultimately, the Alaska heartland. Residents in Mekoryuk and Hooper Bay reported "black snow" following this event (*figure 10.3*).

Other similar cases have been documented by satellites. These storms carried arsenic, copper, lead, and zinc from the industrial centers in Asia into the United States. The concentrations of dust particles averaged from 20 to 50 mg/m^3 with peaks detectable at over 100 mg/m^3 (Huser et al. 2001). The dust storms are an obvious indication that large size particles can move long distances under the right conditions. Such transport occurs annually in Eastern Asia when it is common for high winds and airflow shifts to an eastward direction to occur.

Monitoring along the west coast of the United States has detected radical shifts in carbon monoxide, sulfur dioxide and other contaminants associated with industrial activities. When backtracking analysis is done on these contaminants, eastern Asia is identified as the source. Despite the vivid satellite imagery, very little is known of the content of these dust events. Millions of tons of soil can be expected to provide the vehicle on which a wide range of contaminants, such as organochlorine pesticides, PCBs, dioxins, and furans, can bind and move with the dust particles.

Another concern about long-range transport of large size particulates is that biological materials are also picked up and move in the plume. In a recent dust storm that originated in sub-Saharan Africa in 2000, fungi, viruses and bacteria were identified in the dust cloud. The main plume emerged from Africa and moved westward, ultimately reaching the Caribbean Islands and northern South America. The fungus, *Aspergillus*, is believed to have traveled to the Caribbean and is proposed to be a source of the *Aspergillus* that is damaging the coral reefs. Dust storms originating in Asia may also carry pathogens and consequently, there needs to be increased diligence in watching for disease outbreaks in Alaska.

To date there has been insufficient monitoring in the United States to assess the composition of the particles and contaminants in both the Arctic Haze and dust storm events. A growing program in Canada is being supported by Canada's commitment to AMAP (Arctic Monitoring and Assessment Program) and the Northern Contaminants Program. Air sampling stations are reporting on the dynamics of contaminant transport across the Arctic region of Canada, and concentrations of POPs and other newer chemicals. The United States needs to fill the gap in Alaska with a similar monitoring program.

Coastal Ocean Currents

Chemical contaminants have two distinct compartments in offshore coastal waters. Water itself can sequester and transport water-soluble chemicals, while offshore sediment can sequester both soluble and insoluble contaminants. Concentrations of all the detected pesticides indicate that levels seem to be higher at the ice/water interface than in the water column with the explanation that wave action dilutes the contaminants.

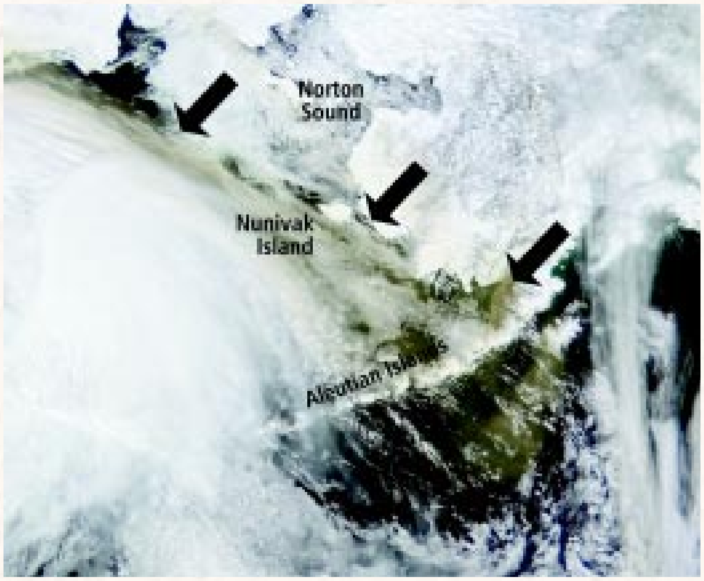


figure 10.3
Asian Dust Storm Over Alaska

The SeaWiFs Program documented an Asian dust storm over Alaska. In April 2002, a dust storm front was observed passing over the Aleutians on a path for Nunivak Island, Bristol Bay, and ultimately, the Alaska heartland.

Credit: SeaWiFS Project, NASA/ Goddard Space Flight Center and ORBIMAGE, 2002.

Ice as it melts has long been suspected of depositing chemical contaminants into the water, especially floating ice in the far northern waters (Pfirman et al. 1995). Studies of POPs and pesticides in the Bering and Chukchi Seas support the view that dissolved concentrations in open water are present (Strachan et al. 2001, Zi-wei et al. 2002). However, the water columns, whether in the open ocean or in the current flows along the coast, appear to have uniform concentrations and there does not appear to be a natural conveyer of contaminants from more distant regions to Alaska's waters.

Chemical contaminants in the offshore sediments, no matter what the source of deposition, are a potential pathway of exposure to the local fauna. This has been documented for the western Beaufort Sea in Alaska waters (Valette-Silver et al. 1999) where PAHs and arsenic appear in the invertebrate and vertebrate nodes of the food web.

Need for Monitoring Programs in Alaska

The monitoring of contaminants in Alaska has been mostly non-existent. Two programs run by the National Oceanic and Atmospheric Administration have attempted to determine the levels of select anthropogenic chemicals in fish and shellfish. National Status & Trends (NST) administered the National Benthic Surveillance Project (NBSP) from 1984 through 1993 monitored chemical concentrations in the livers of bottom-dwelling fish and in sediments at the sites where the fish were collected. Fifteen sites around Alaska were sampled. However, no new data have been added since the end of the program and there are now no trend studies.

A monitoring program needs to be the frontline in determining the ebb and flow of chemical contaminants in Alaska by providing baseline information on all potentially important man-made chemicals as they arrive by commerce, air, dust, or water.

The second program administered by NST is the Mussel Watch Program. This was begun in 1986 and continues today. Bivalves (mussels and oysters) are collected every other year at over 250 U.S. coastal and estuarine sites. Sediment samples are also collected. Samples are analyzed for 24 PAHs, 18 PCB congeners, DDT, DDD, DDE, 16 other chlorinated pesticides, and tributyl-tin. There are 11 sites sampled in Alaska waters. Two sites are in the southeastern panhandle and nine in the Gulf of Alaska/Cook Inlet/Prince William Sound regions of the state. Both of these programs provide some trend and pattern data; however, additional effort is needed to develop a comprehensive chemical monitoring program for the state.

A meeting of the eight Arctic rim countries (Canada, Denmark/Greenland, Iceland, Norway, Sweden, the Russian Federation, and the United States) led to the establishment of the Arctic Environmental Protection Strategy (AEPS) in 1991. Part of the goal of AEPS was to protect the Arctic ecosystems from man-made chemicals, to begin identifying the contaminants of concern, and to determine ways to reduce or eliminate the pollution. The Arctic Monitoring and Assessment Program (AMAP) was created to implement this strategy.

One of AMAP's first activities was to design and implement a harmonized monitoring program of data from the Arctic rim countries that would provide a comparable picture of the pattern of contaminants across the Arctic. Without such a program, comparisons could only be made using a wide variety of independent studies that produced data using different techniques and species. Part of the AMAP strategy is also to look at all the compartments in which contaminants flow and accumulate: air, water, sediment, plants, invertebrates, and vertebrates, including humans. AMAP focuses on the Arctic, and fortunately, its scope includes all of Alaska.

In 1989, AMAP published the AMAP Assessment Report: Arctic Pollution Issues, in which Chapter 6 presents the monitoring data and conclusions. Unfortunately, very little data for this report was contributed by the U.S. from harmonized studies in Alaska. It is imperative that the U.S. participate actively in the AMAP program, and that it institute programs to monitor air, sediment, water, and key species in the food web. A monitoring program needs to be the frontline in determining the ebb and flow of chemical contaminants in Alaska by providing baseline information on all potentially important man-made chemicals as they arrive by commerce, air, dust, or water.

Today, important decisions evaluating the risks of chemical exposure must rely on data generated outside the region and with little knowledge of the status and trends of these chemicals in the environment. The potential threats to fish, wildlife and the people of the state only can be prevented, and the sources of chemicals from outside the state only can be halted, with accurate knowledge and diligent monitoring.

AMAP. 1998. Persistent organic pollutants, in AMAP Assessment Report: Arctic Pollution Issues, Chapter 6. (B.G.E. de March, C.A. de Wit, D.C.G. Muir, eds.). Pp. xii + 183-371.

Bence, A. E. and W. A. Burns. 1995. Fingerprinting hydrocarbons in the biological resources of the Exxon Valdez spill area. ASTM STP 1219, P.G. Wells, J.N. Butler, and J.S. Hughes, eds., American Society for Testing and Materials, Philadelphia pp. 84-140.

Chernyak, S.M., C.P. Rice, and L.L. McConnell. 1996. Evidence of currently-used pesticides in air, ice, fog, seawater and surface microlayer in the Bering and Chukchi Seas. Marine Pollution Bulletin, 32(5):410-419.

Crane, K. and J.L. Galasso. 1999. The Arctic Environmental Atlas. Office of Naval Research/Naval Research Lab/Hunter College, 164 pp.

Crane, K., J. Galasso, C. Brown, G. Cherkashov, G. Ivanov, V. Petrova, and B. Vanstayan. 2001. Northern ocean inventories of organochlorine and heavy metal contamination. Marine Pollution Bulletin, 43(1-6):28-60.

Fellin, P., L.A. Barrie, D. Dougherty, D. Toom, D. Muir, N. Grift, L. Lockhart, and B. Billeck. 1996. Air monitoring in the Arctic: Results for selected persistent organic pollutants for 1992. Environmental Toxicology and Chemistry, 15(3):253-261.

Hung, H., P. Blanchard, G. Poole, B. Thibert, and C.H. Chiu. 2002. Measurement of particle-bound polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) in Arctic air at Alert, Nunavut, Canada. Atmospheric Environment, 36:1041-1050.

Husar, R.B., D.M. Tratt, B.A. Schichtell, S.R. Falke, F. Li, D. Jaffe, S. Grasso, T. Gill, N.S. Laulainen, F. Lu, M.C. Reheis, Y. Chun, D. Westphal, B.N. Holben, C. Gueymard, I. McKendry, N. Kuring, G.C. Feldman, C. McClain, R.J. Frouin, J. Merrill, D. DuBois, F. Vignola, T. Murayama, S. Nickovic, W.E. Wilson, K. Sassen, N. Sugimoto, and W.C. Malm. 2001. The Asian dust events of April 1998. Journal of Geophysical Research - Atmospheres, 106(D16):18317-18330.

Jaffrezo, J.L., M.P. Clain, and P. Masclet. 1994. Polycyclic aromatic hydrocarbons in the polar ice of Greenland — Geochemical use of these atmospheric tracers. Atmospheric Environment, 28(6):1139-1145.

Kvenvolden, K.A., F.D. Hostettler, P.R. Carlson, J.B. Rapp, C.N. Threlkeld, and A. Warden. 1995. Ubiquitous tar balls with California-source signature on the shorelines of Prince William Sound, Alaska. Environmental Science and Technology, 29(10):2684-2694.

Li, Y.F. 1999. Global technical hexachlorocyclohexane usage and its contamination consequences in the environment: from 1948 to 1997. The Science of the Total Environment, 232:121-158.

Page, D.S., P.D. Boehm, G.S. Douglas, and A.E. Bence. 1995. Identification of hydrocarbon sources in the benthic sediments of Prince William Sound and the Gulf of Alaska following the *Exxon Valdez* oil spill. ASTM STP 1219, P.G.Wells, J.N. Butler, and J.S. Hughes, eds., American Society for Testing and Materials, Philadelphia.

Pfirman, S.L., H. Eicken, D. Bauch, and W.F. Weeks. 1995. The potential transport of pollutants by Arctic sea ice. The Science of the Total Environment, 159:129-146.

Pham, T., K. Lum, and C. Lemieux. 1993. The occurrence, distribution and sources of DDT in the St. Lawrence River, Quebec (Canada). Chemosphere, 26(9):1595-1606.

Pham, T., K. Lum, and C. Lemieux. 1996. Seasonal variation of DDT and its metabolites in the St. Lawrence River (Canada) and four of its tributaries. The Science of the Total Environment, 179:17-26.

Short, J. W., and R. A. Heintz. 1997. Identification of Exxon Valdez oil in sediments and tissues from Prince William Sound and the northwestern Gulf of Alaska based on a PAH weathering model. Environ. Sci. Technol. 31:2375-2384.

Short, J. W., K. A. Kvenvolden, Pl r. Carlson, F. D. Hostettler, R. J. Rosenbauer and B. A. Wright. 1999. Natural hydrocarbon background in benthic sediments of Prince William Sound, Alaska: Oil vs Coal. Environ. Sci. Technol. 33:34-42

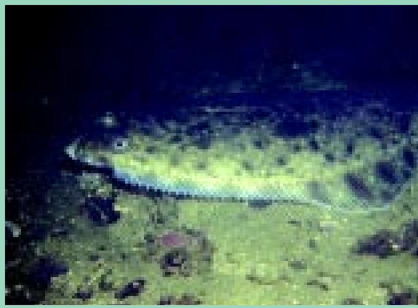
Short, J. W., M. R. Lindeberg, P. M. Harris, J. Maselko and S. D. Rice. 2002. Vertical oil distribution within the intertidal zone 12 years after the Exxon Valdez oil spill in Prince William Sound. In Proceedings of the 25th Arctic & Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, Canada, pp. 57-72.

Strachan, W.M.J., D.A. Burniston, M. Williamson, and H. Bohdanowicz. 2001. Spatial differences in persistent organochlorine pollutant concentrations between the Bering and Chukchi Seas (1993). Marine Pollution Bulletin, 43(1-6):132-142.

Takeoka, H., A. Ramesh, H. Iwata, S. Tanabe, A.N. Subramanian, D. Mohan, A. Magendran, and R. Tatsukawa. 1991. Fate of the insecticide HCH in the tropical coastal area of South India. Marine Pollution Bulletin, 22(6):290-297.

Van Kooten, G. K., Short, J. W. and J. J. Kolak. 2002. Low-maturity Kulthieth formation coal: a possible source of polycyclic aromatic hydrocarbons in benthic sediment of the northern Gulf of Alaska. Environmental Forensics (in press).

Literature Cited



©Art Sutch

Persistent Organic Pollutants in the Alaska Environment

Valette-Silver, N., M.J. Hameed, D.W. Efurd, and A. Robertson. 1999. Status of the contamination in sediments and biota from the western Beaufort Sea (Alaska). Marine Pollution Bulletin, 38(8):702-722.

Wania, F. and D. Mackay. 1993. Global fractionation and cold condensation of low volatility organochlorine compounds in polar regions. Ambio, 22(1):10-18.

Wania, F. and D. Mackay. 1996. Tracking the distribution of persistent organic pollutants. Environmental Science and Technology, 30(9):390A-396A.

Wania, F., D. Mackay, Y-F. Li, T.F. Bidleman, and A. Strand. 1999. Global chemical fate of a-hexachlorocyclohexane.1. Evaluation of a global distribution model. Environmental Toxicology and Chemistry, 18(7):1390-1399.

Wania, F. and D. Mackay. 1999. Global chemical fate of a-hexachlorocyclohexane. 2. Use of a global distribution model for mass balancing, source apportionment, and trend prediction. Environmental Toxicology and Chemistry, 18(7):1400-1407.

Yunker, M.B., R.W. Macdonald, W.J. Cretney, B.R. Fowler, and F.A. McLaughlin. 1993. Alkane, terpene, and polycyclic aromatic hydrocarbon geochemistry of the Mackenzie River and Mackenzie shelf: Riverine contributions to Beaufort Sea coastal sediment. Geochimica et Cosmochimica Acta, 57:3041-3061.

Zi-wei, Y., J. Gui-bin, and X. Heng-shen. 2002. Distribution of organochlorine pesticides in seawater of the Bering and Chukchi Sea. Environmental Pollution, 116:49-56.

Literature Cited



11. Contaminants in Alaska: Is America's Arctic at Risk?

Carl M. Hild, University of Alaska Anchorage

"To find a diet free from DDT and related chemicals, it seems one must go to a remote and primitive land still lacking in the amenities of civilization. Such a land appears to exist, at least marginally, on the far Arctic shores of Alaska — although even there one may see the approaching shadow . . . ."

– RACHEL CARSON, 1962 –

Risks posed by persistent organic pollutants (POPs) to Arctic ecosystems and human populations were central to the genesis of the Stockholm Convention and remain a primary concern when evaluating potential POPs impacts. For the United States, "Arctic ecosystems" means Alaska. Once, not too long ago and within the living memory of Native Alaskans, the Arctic was a pristine wilderness where POPs were never used and could not be detected in wildlife or humans. But the face of Alaska is changing, with increasing urbanization, industrialization, extractive resource activity, and commercial and social contacts with the global community. Accompanying these changes are concerns that the physical, climatic and social aspects that make Alaska unique—particularly for the indigenous population—also make this region peculiarly prone to risks from global pollutants. Although exposures to POPs are being noted at this time, their impact will be more evident in the future unless pollution issues are addressed now.

As the data to follow demonstrate, wildlife and human residents are experiencing POPs contamination from local, regional and international sources. The levels in most environmental media typically remain substantially below those found in highly polluted areas of

(above)
Eggs.
Frost.
Mussels.

When people perceive that they are one with the environment, and the environment is contaminated, then they also are contaminated.

the lower 48 United States. However, in high-trophic-level feeding species—including killer whales and humans—some POPs levels have been recorded that are comparable to those found in the general United States population and similar marine mammal species.

POPs contamination of the Great Lakes started as a predominantly regional and local phenomenon, and the initial management successes from domestic and binational strategies with Canada reflected this scale. For Alaska, however, the intervention options mandate a much more global approach. From a polar perspective, "close" to Alaska and its surrounding waters means the huge and growing industrial and population centers in Asia, less regulated neighbors just a few miles distant in Russia, and sources across the Arctic Ocean in Europe that are all closer than Washington, D.C.

This review of POPs in Alaska links the assessment of human health with the state of the environment and ecosystems. For Alaska Natives, there is a deep connection with the air, the water, the animals, and humans. When people perceive that they are one with the environment, and the environment is contaminated, then they also are contaminated. This integrated world view differs from traditional "Western" practice, which has, in the past, tended to separate humanity from its supporting ecosystems. The many similarities in POPs toxicities between humans and other mammalian species suggest that it would be unwise to hold to the belief that humanity is somehow impervious to and distinct from impacts on the supporting ecosystems.

Why is Alaska at Special Risk?

For a variety of reasons, the Arctic ends up as an ultimate receptor and "sink" for POPs. The persistence and potential effects of these deposited POPs may also be more pronounced in polar climates. Factors in evaluating POPs risks to Alaska include:

Location: The large expanse of the State of Alaska, accentuated by its island chains (Aleutians, Pribilofs), means that its neighbors are not limited to the great ocean expanses or to Canada and Mexico/Caribbean, as is the situation for the other United States. In addition to Canada, China, Korea, and other upwind Asian countries, Russia is the nearest trans-Pacific neighbor, only a short kayak excursion away. Human and wildlife populations regularly traverse these artificial national boundaries.

Physical climate: Needless to say, winter is cold in Alaska, but spring and summer are times of relative warmth and rapid biological activity. The cycle of prolonged winter darkness and cold, followed by warmth and 24-hour light, places peculiar stresses on ecosystems. Through the winter, mammals rely on fat stores, thereby releasing lipid-soluble POPs within their bodies as the fat is metabolized. In the spring melt, POPs that have accumulated in the ice are released to the food chain during the limited time of peak productive and reproductive activity. And, throughout all of this, the predominantly cold temperatures and permafrost reduce or eliminate the microbial activity necessary to degrade POPs.

Ecological sensitivity: Cold temperatures and long periods of darkness are associated in the Arctic with slow growth, low productivity and low diversity in terrestrial ecosystems. Anthropogenic damage to such ecosystems can require a long period of recovery.

Fat as the currency of life: Survival for all species in polar climates rests on securing and maintaining energy levels. Some animals have round bodies to conserve energy, while another strategy is to secure a regular supply of high-energy food. Fat is high-energy food. POPs are lipophilic, and so as fat is consumed, these contaminants are passed efficiently up the food chain to the top predators, including humans.

Hydrologic Transport

The very low water solubility of most POPs—counterbalancing their high lipid solubility—leads to water transport predominantly attached to fine particles. However, some organic pollutants, such as the hexachloro-cyclohexanes (e.g., lindane) are more soluble in water and can be transported through a combination of prolonged persistence in cold waters and large volumes of oceanic water movement. Hydrologic pathways are also interconnected with atmospheric transport through the semi-volatile nature of POPs, where contaminants can exchange between environmental media.

For Alaska, a combination of riverine and oceanic transport can bring POPs from long distances (*figure 11.1*). The major rivers draining the agricultural and industrial areas of Russia flow into the Arctic Ocean. A number of Russian rivers are known to have readily detectable levels of various pesticides, including DDT, that do not appear to be decreasing over time (Zhulidov et al. 1998). These rivers release POPs to the Arctic Ocean, after which contaminants can be transported by the prevailing currents generally westward from the contaminated Ob and Yenisey Rivers, and eastward from the less contaminated Lena River.

Oceanic currents in the Pacific also provide a transport pathway for contaminants. After contaminants have traveled down rivers and into the ocean from agricultural fields and industrial areas of Southeast and Central Asia, the western Pacific currents can carry these contaminants to other parts of the world. The currents move along Japan, Korea and Russia, and finally flow through the Bering Sea and into the Arctic Ocean (AMAP 1998) (*figure 11.1*). Surface water studies of PCBs have identified this movement and the accumulation of materials within the Bering Sea (Yao et al. 2001). Work from Japan on the "Squid Watch Program" is tracking the movements of POPs in the North Pacific driven by the prevailing west wind and the Kuroshio warm current (Hashimoto et al. 1998).

Migratory Species

Waterfowl

Transport of contaminants from other regions of the globe to the food supply of Alaska Natives and other Americans can also occur through the movement and harvesting of migratory species. The springtime return of waterfowl is the first fresh meat many Alaska Natives have after a long winter of eating dried meat and stored foods. In addition to adult birds, eggs are also collected and consumed. Some of these birds have wintered in Asia and Central America. In those regions, feeding areas (such as fallow fields) may have been sprayed with organochlorine insecticides. The bodies of birds can carry pollutants that may be banned in the American communities that consume them.

figure 11.1

Predominant Currents in the Arctic Ocean

Figures are estimated inflows or outflows in Sverdrups (million m³ per second).

Atlantic water + Intermediate layer, 200- 1700 m

Pacific water, 50-200m

Surface water circulation

River inflow

Ocean currents provide transport pathway for contaminants.

Credit: Arctic Monitoring and Assessment Programme, AMAP Assessment Report, Arctic Pollution Issues, Fig.3.27. 1998.

Salmon

Migratory fish do not travel as far as migratory birds, but the mechanism for accumulation of contaminants is similar. Recently, it was shown that the very low concentrations of HCB, s-DDT and a number of PCB congeners detected in sockeye (red) salmon returning to interior Alaska lakes can contribute more POPs to the lake ecosystem than the amount contributed by atmospheric deposition (Ewald et al. 1998).

Eagles

In Alaska, bald eagle populations have remained robust, with DDT/DDE levels generally well below the potential effect level of ~3.6 μg/g DDE (Anthony et al. 1999, Wiemeyer et al. 1993). Eagles nesting along the Tanana River in the interior of Alaska in 1990-91 had DDE levels below concentrations known to result in sublethal or lethal effects, and most organochlorine concentrations were an order of magnitude lower than concentrations in bald eagle eggs from elsewhere in the United States (Richie and Ambrose 1996).

However, even in the presence of this apparent success there are warning signs. Eagles in the western Aleutian Islands have been found to have ratios of DDT/DDE that indicate new DDT sources, and DDE levels in some eggs on one island (Kiska) may be depressing reproductive success (Anthony et al. 1999, Estes et al. 1997). Although the sources are not yet known, the prey species, especially migratory birds from Asia where DDT is still used, need to be assessed further. It also should be noted that although DDE is suspected as the causative agent in the above-mentioned studies, DDE concentrations in eagle eggs were positively correlated with other organochlorines, including oxychlordane, beta-HCH, dieldrin, and hexachlorobenzene.

Peregrine falcon

Historic declines in peregrine falcon populations at several locations, including Alaska, have been correlated with DDE concentrations in their eggs causing eggshell thinning and hatching failure (Ambrose et al. 1988, 2000, White et al. 1988). Threshold concentrations of ~15-20 ppm are associated with a 20 percent eggshell thinning in peregrine falcons (Peakall et al. 1990). Populations are expected to decrease if eggshells are at least 17 percent thinner than pre-DDT measurements (Kiff 1988). Peregrine falcons in interior and northern Alaska declined during the 1960s, stabilized in the mid-1970s, began to increase in the late 1970s, and have since stabilized or continued to increase.

Eggs from two subspecies of peregrine falcons were collected from interior and northern Alaska between 1979 and 1995 and analyzed for organochlorine compounds and metals (Ambrose et al. 2000). This study represents one of the few relatively long-term data sets from Alaskan biota and can offer some insight into POPs residue trends with time. In general, organochlorines declined over time, although the trend was not as strong for PCBs, which declined more slowly.

These results agree with trends observed in other peregrine falcon populations, which show that PCB concentrations have not decreased as clearly as other organochlorine compounds (Peakall et al. 1990, Newton et al. 1989, Johnstone et al. 1996). Although organochlorine levels have decreased over time, evidence for cumulative and single-contaminant reproductive effects was found in remote locations (Ambrose et al. 2000). Contaminant monitoring remains a necessary management tool for this species, which is recovering from near extinction caused largely by environmental contaminants and continues to remain vulnerable to persistent and bioaccumulative compounds.

Sea otter research.
EVOS photo library.

Killer whale

Certain populations of killer whales (*Orcinus orca*) have been extensively studied over the past 30 years, including populations in Puget Sound, Washington, the inside waters of British Columbia, Southeastern Alaska, and Kenai Fjords/Prince William Sound, Alaska. The POPs concentrations found in some populations of Alaska killer whales are similar to those recently reported in pinnipeds and cetaceans that occur in more contaminated waters (Ylitalo et al. 2001). Levels of total PCBs in blubber ranged up to 500 ppm, and total DDTs ranged up to 860 ppm, while median levels and some group levels were significantly lower.

Concentrations of POPs in transient killer whale populations (marine mammal-eating) were much higher than those found in resident animals (fish-eating), apparently because of differences in diets (amounts and types of fat consumed) and feeding locations (localized or broad-ranging) (Ylitalo et al. 2001). Both resident and transient whale groups described in the report reside in Alaska waters, although the transient pods may move hundreds of miles up and down the coast beyond Alaska and through international waters.

Life-history parameters such as sex, age and reproductive status also influence the concentrations of POPs in Alaska's killer whales. Reproductive female whales contain much lower levels of POPs than sexually immature whales or mature male animals in the same age class. This is likely due to the transfer of POPs from the female to her offspring during gestation and lactation. Birth order also influences the concentrations of POPs. Adult male, resident, first-born whales contain much higher POPs concentrations than are measured in subsequent offspring to resident animals in the same age group (Ylitalo et al. 2001). There is also some evidence of decreased survival of the first-born transients that have the highest POPs levels (Matkin et al. 1998, 1999).

Reports of POPs levels in killer whales have been associated with decreases in reproductive success (Matkin et al. 1998, 1999). The causal factors for low reproduction and population decline of certain transient groups of killer whales from Prince William Sound/Kenai Fjords are not known. The low reproduction and population decline may be a natural cycle, related to human factors (e.g., oil spill), exposure to natural toxins (e.g., biotoxins), decline in the primary prey species (harbor seal), or a combination of environmental and anthropogenic factors. Exposure to toxic POPs may also be a contributing factor (Ylitalo et al. 2001).

Sea otter

Sea otters have declined precipitously throughout the Aleutian Islands over the past decade (Estes et al. 1998). Although investigations to date suggest predation may be the primary cause of the decline, contributing factors such as contaminants have not been completely ruled out. Sea otters at several isolated sites in the Aleutians (Adak, Shemya) have been recorded with elevated levels of certain POPs, particularly PCBs (Giger and Trust 1997). PCB levels in sea otters from the Western Aleutian Islands (Adak and Amchitka Islands) were somewhat higher than levels found in California sea otters, and were significantly elevated relative to PCB concentrations in sea otters from southeast Alaska (Bacon et al. 1999).

The relative contribution to PCB levels in Aleutian sea otters from long-range sources compared to local contamination from old defense sites cannot be ascertained using currently available data (Bacon et al. 1999, Estes et al. 1997). Sum-DDT levels in Aleutian otters, although much higher than the very low values found in Southeast Alaska, remain substantially lower than in California otters. These sum-DDT concentrations were not in the range that causes reproductive impairment in captive mink, a related species and commonly used comparison. However, there is little information that can help evaluate whether there may be interactive effects among POPs and other stressors affecting Aleutian sea otters.

Species Consumed by Humans

Beluga

Beluga whales (*Delphinapterus lucas*) are a preferred food for many Alaska Natives. The muktuk (the skin and outer layer of fat) is considered a choice item for consumption. This outer layer of fat contains the highest levels of POPs in the animal (Wade et al. 1997). The blubber of beluga whales from Alaska contains POPs in concentration ranges similar to those found in beluga whales from the Canadian Arctic (Muir and Norstrom 2000) but much lower than levels in whales from the highly contaminated St. Lawrence River in eastern Canada (Krahn et al. 1999). Within Alaska, the low levels in the Cook Inlet stock are noteworthy, as these animals reside in one of the most "urban" areas of Alaska, where anthropogenic contamination could be expected to result from the relatively higher density of human residents and commercial activities (Krahn et al. 1999).

Photo courtesy Alaska Division of Tourism.

Gender is an important factor to consider when interpreting differences in POPs concentrations among beluga whale stocks (Krahn et al. 1999). For example, the adult males of each stock had higher mean concentrations of all contaminant groups than did the adult females of the same stock. This is considered to be an effect of POPs transfer from the mother to the calf during gestation and lactation. This theory is supported by the finding that upon reaching sexual maturity, the levels of toxaphene, PCBs, DDTs, and chlordane steadily go down in females as they produce calves and lactate (Wade et al. 1997).

Bowhead whale

The bowhead whale stock (*Balaena mysticetus*) migrates through the Bering, Beaufort and Chukchi Seas and is listed as an endangered species. Alaska Natives are the only U.S. citizens permitted to harvest the bowhead whale for food. Studies have shown relatively low levels of PCBs in bowhead whale blubber, but these levels tend to increase with age (McFall et al. 1986, O'Hara et al. 1999). Previous reports support the view that these large filter-feeding whales, consuming at a lower level on the food chain, have lower concentrations of POPs in their blubber. Toothed whales, eating higher up the food chain, may have one or two orders of magnitude more POPs than the filter-feeding whales (O'Hara and Rice 1996, O'Shea and Brownell 1994, Borell 1993).

These PCB levels in Steller sea lions generated concern among local subsistence populations, who requested an evaluation of potential human health impacts.

Seals

The various seal species in Alaska constitute a substantial portion of the marine mammal diet of numerous predator species, including humans. Blubber samples from four Alaska seal species (Bearded seal, *Erignathus barbatus*; harbor seal, *Phoca vitulina*; northern fur seal, *Callorhinus ursinus*; and ringed seal, *P. hispida*) have been collected and analyzed for POPs contaminants (e.g., total PCBs, total DDTs, total chlordanes, HCB, and dieldrin) (Krahn et al. 1997). Harbor seals, frequently consumed by Alaska Natives, were found to have low but measurable levels of several of these POPs. The concentrations of POPs in harbor seals from Prince William Sound were generally much lower (e.g., total PCBs up to 100-fold and total DDTs up to 30-fold lower) than those recently reported for harbor seals from the northwestern U.S. mainland, including animals involved in mass mortality events (Krahn et al. 1997). For Alaska, however, in contrast to other parts of the United States, the potential for POPs biomagnification continues, through the consumption of harbor seals by humans, an additional one or more trophic levels higher.

Notable among the multiple studies of seal species is the finding that POPs concentrations in male subadult northern fur seals sampled in 1990 at St. Paul Island in the Bering Sea were higher than concentrations in the ringed and bearded seals from the Bering Sea or in the harbor seals from Prince William Sound. Fur seals feed mainly on oceanic species such as squid and pollock. Female and juvenile fur seals migrate long distances into the open ocean of the northern Pacific, far south of Alaska, and even to the shores of Japan, as well as California. The higher POPs concentrations in fur seals are consistent with exposures occurring during these long oceanic migrations. Harbor seals feed on different species of fish that tend to be very coastal, like perch. Harbor seals do not migrate, but stay close to their coastal feeding and haul-out areas.

Steller sea lion

Studies show that PCBs are the predominant POPs in sea lion blubber, followed by levels of DDT/ DDE. Levels of chlordane compounds were an order of magnitude lower. Higher concentrations of PCBs and DDTs were found in Steller sea lions from Alaska compared to those from the Bering Sea, indicating that the populations have different sources of exposure (Lee et al. 1996). Like beluga whales, as Steller sea lion females become sexually mature they show a dramatic decline in POPs levels. It has been calculated that they may lose 80 percent of their PCBs and 79 percent of DDT/DDE through lactation while nursing the first pup (Lee et al. 1996). Two studies of PCBs in Steller sea lion blubber found an average of 23 ppm (Varanasi et al. 1993) and 12 ppm in males (Lee et al. 1996).

These PCB levels in Steller sea lions generated concern among local subsistence populations, who requested an evaluation of potential human health impacts (Middaugh et al. 2000a, b, see the following Levels in Alaska Natives section).

Salmon

Salmon species are key to commercial and recreational fisheries and to the well-being of many subsistence communities. For the Alaskan fishing industry, salmon is a billion-dollar business. For subsistence communities, fish by weight make up about 59 percent of the total subsistence harvest for Alaska Natives, with salmon being the most important species (AMAP 1998). In western Alaska, the fish harvest can approach 220 kg (485 lb) per person per year and make up more than 73 percent of all locally harvested food (Wolfe 1996). The U.S. Fish and Wildlife Service and Alaska state government are currently assessing contaminant levels and evaluating fish health in salmon from selected Alaska rivers.

The migratory and reproductive patterns of sockeye salmon (*Oncorhynchus nerka*) are known to provide a means of transport for very low levels of chemicals such as PCBs and DDT to waters used by other species of Alaska freshwater fish, such as grayling (*Thymallus arcticus*) (Ewald et al. 1998). Migrating salmon carry these low but measurable levels of POPs to spawning areas where, after spawning, they die and decay. The POPs then become bioavailable to other local species. The levels of POPs delivered by salmon to Alaska interior lakes and rivers have been estimated to be slightly above the levels deposited through atmospheric means, although these levels are far below those found in fish from the Great Lakes region.

Polar bear

Polar bears are at the top of the Arctic marine food web. Norstrom et al. (1998) investigated chlorinated hydrocarbon compounds in polar bears from much of the circumpolar Arctic. They found strong relationships among contaminant concentrations and sex. Individual dietary preferences, regional differences in species availability and food-chain structure also contributed to variability within the data. For example, baleen whale and walrus carcasses may be seasonally important food sources for polar bears in the Bering Sea and Chukchi Sea region, supplementing their primary diet of ringed and bearded seals.

Walrus (except when eating seals) and baleen whales feed at lower trophic levels than other Arctic marine mammal species. Conversely, polar bears feeding on beluga carcasses in eastern Canada exhibit higher POPs levels. Thus, prey selection can affect the pattern of chlorinated hydrocarbon uptake in these different polar bear populations. Total chlordanes (sum of 11 chlordane-related compounds) were the most uniformly distributed POPs in this study, reflecting a similar pattern found in air and seawater sampling (Norstrom et al. 1998).

Although sample sizes were small, concentrations of total PCBs, total chlordanes, DDE, and dieldrin in polar bears from the Bering, Chukchi and western Beaufort Seas tended to be among the lowest in the study area. The atmospheric circulation of this area is dominated by eastward airflow from Asia and the North Pacific Ocean. Sources of POPs in the Bering, Chukchi and western Beaufort Seas are, therefore, more likely to have originated in eastern Asia. PCBs were generally used less often in Asia, except Japan, than in North America and Europe (Norstrom et al. 1998). The U.S. Fish and Wildlife Service, Office of Marine Mammal Management, continues to work with Alaska Native hunters to collect samples for analysis of environmental contaminants.

Native Peoples of Alaska

A large proportion of Alaskans are indigenous peoples — 16 percent by the 2000 census *(figure 11.3)*. Food is central to culture. Alaska Natives, although sharing different cultural heritages, are linked to their environment through the foods that they gather locally and consume. The

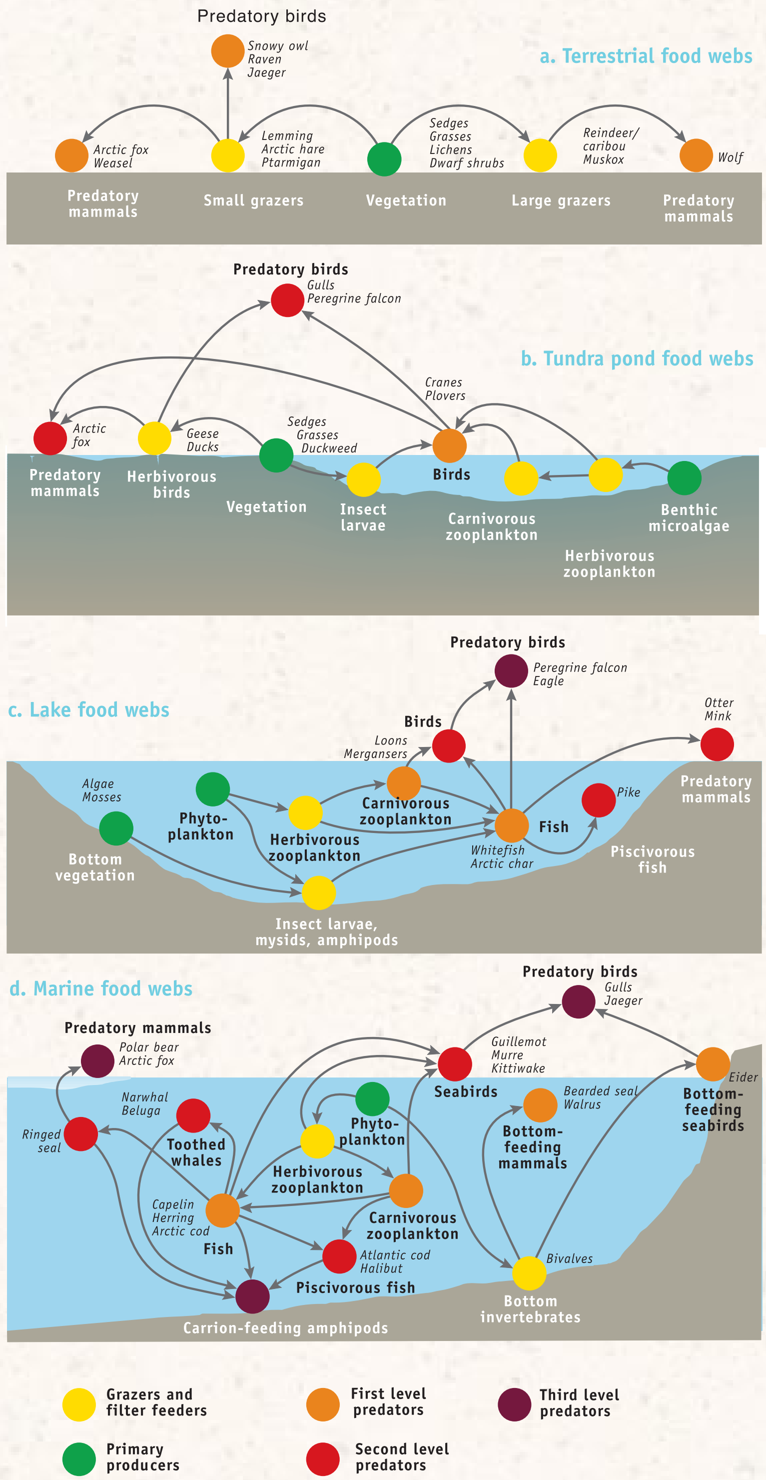


figure 11.2

Examples of Arctic Food Webs

Credit: Arctic Monitoring and Assessment Programme, AMAP Assessment Report, Arctic Pollution Issues, Fig.4.2. 1998.

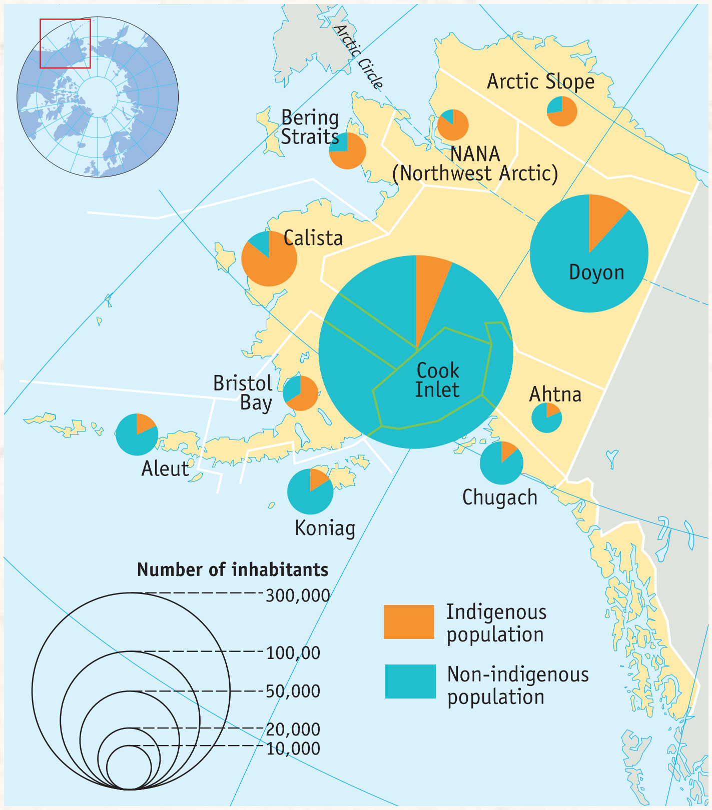


figure 11.3

Indigenous Population Comparisons

Total and indigenous population of Arctic Alaska by Native Regional Corporations.

Credit: Arctic Monitoring and Assessment Programme, AMAP Assessment Report, Arctic Pollution Issues, Fig.5.3. 1998.

social structures that define behavior in the sharing of subsistence harvests and through feasts are the traditions of Alaska Natives—the cultural values of the people. Children and youth are taught about their environment and about their relationship to the community through hunting, fishing, gathering, and sharing. The survival knowledge of the group is passed down from generation to generation, ensuring the transmission of language and values. The work of obtaining one's own food is rigorous and promotes self-reliance and self-esteem. For all of these factors, continued confidence in the quality of locally obtained foods is essential (Egeland et al. 1998).

Alaska Natives eat 6.5 times more fish than other Americans (Nobmann et al. 1992). Under the Marine Mammal Protection Act, Alaska Natives are the only people in the United States allowed to hunt marine mammals, which they then eat. By doing so, Alaska Natives consume predator species (seals, sea lions, bears, and toothed whales) at the very top of the food chain.

Many Alaskans have wide seasonal variation in their dependence on locally available foods. Their diet shifts in response to short intense summers and the migration of wild birds, fish and mammals. Alaska Natives eat more fat, albeit different types, than most U.S. citizens. Marine mammal fats and fish oils differ significantly from pork and beef fats in their ability to provide health benefits (Jensen and Nobmann 1994, Nobmann et al. 1992, Scott and Heller 1968).

In regions where employment opportunities are scarce or seasonal, locally obtained foods remain an economic necessity. Shifting food consumption in remote Alaska communities is not beneficial for several reasons. Food that is purchased is expensive and rarely fresh owing to the long distances it must be shipped and the number of times it must be handled as it goes into smaller and smaller stores. Many people in these remote communities have very limited food budgets because of the scarcity of jobs and high costs of heating and other costs associated with life in a remote and challenging environment (Egeland et al. 1998).

Store-bought foods in remote Alaska communities need to have a long shelf life. Therefore, the foods have been frozen, canned or chemically preserved. Many of these foods do not have the nutritional value of fresh foods from the local area. Store-bought foods are much higher in processed sugars, saturated fats, sodium, and simple carbohydrates, contributors to such conditions as obesity, diabetes, heart disease, and dental caries. These conditions are growing at alarming rates in Alaska (APHA 1984, Ebbesson et al. 1996, Lanier et al. 2000, Nobmann et al. 1992, Nobmann et al. 1998, Nutting 1993, Schraer et al. 1996). Health surveys have also indicated that, in some communities, the individuals who are most concerned about environmental pollution are the same people who most frequently consume less traditional foods and are shifting to buying food from the store (Dewailly et al. 1996, Egeland et al. 1998, Hild 1998).

Adding to concerns about contaminants in local foods, Alaska Natives have reported changes in the subsistence species they hunt. These changes include seals with diseases they have not seen before, no hair, yellow fat, fat and meat that does not taste as it should, and seals with abnormal growths and abnormal sex organs. Similar concerns have been raised about other subsistence species. These observations, collected now by the Alaska Native Science Commission (www.nativeknowledge.org), may contribute to an understanding of what is occurring in the changing Arctic. In the absence of key information to answer specific questions, and in response to media reports about contamination of the Arctic, the conclusion being reached by many Alaska Natives is that the animals may not be healthy, and the health of their children may be at risk.

POPs Levels in Alaska Natives

Most of the POPs under the Stockholm Convention were never used in or near Alaska. For the other POPs (e.g., PCBs, DDT, polychlorinated dioxins/furans), local use in Alaska and emissions to the environment are much less than have occurred in the lower 48 states. Yet there is considerable concern among residents—particularly Alaska Natives—that they may have become contaminated through consuming traditional foods. The most expeditious way to assess the extent to which Alaskans have been exposed to these persistent toxic substances is to measure levels in human tissue (Hild 1995). Unfortunately, there is no statistically based survey of POPs levels in Alaskans. Indeed, there is no national statistically based survey of POPs levels in the U.S. population, although serum has been collected under the NHANES IV study and is being analyzed at the Centers for Disease Control and Prevention (CDC).

POPs levels have been measured in small studies of selected Alaska Natives, lower 48 background comparison groups and Great Lakes fishers, providing valuable indicative and comparative information on POPs levels (*figure 11.4*). These data can help inform hypotheses and conclusions regarding sources of human exposure to POPs and the resulting concentrations and trends. For example, as with marine mammal exposures, high trophic level feeding is generally more problematic than lower on the food chain. Thus, it can be hypothesized that Alaska Native diets based on plants and plant-eating animals are of less concern than those relying on the consumption of marine mammal predator species.

The importance of location and proximity to emission sources and transport pathways can also be evaluated, as the western Aleutians represent a quite different locale from the Beaufort Sea off northeastern Alaska. Likewise, the subject's age may be a major determinant of many POPs levels. As has been evident in lower 48 studies, POPs levels tend to increase with age because of the fundamental persistent and bioaccumulative nature of the contaminants, especially in males where there is no excretion through lactation. Age is also an important consideration in evaluating Alaska Native levels, as dietary practices and the proportion of traditional foods in many diets have changed over recent years.

In response to citizen concerns, the State of Alaska, Department of Health and Social Services, conducted a targeted study of POPs in five Aleutian communities (Middaugh et al. 2000a, b 2001). These communities had become concerned because some Alaska Steller sea lion blubber had been reported to contain relatively high levels of PCBs (23 ppm, Varanasi et al. 1993, 12 ppm in males, Lee et al. 1996), potentially impacting their use of sea lions as a source of meat and oil. Total PCB, dioxin and furan toxicity equivalence concentrations (TEC) levels in the Aleutian volunteers (Middaugh et al. 2001) were similar to those in the background U.S. population (Arkansas) and considerably below fisher exposures on the Great Lakes (Anderson et al. 1998).

Middaugh et al. (2000a) also analyzed the age relationship to concentration levels, demonstrating increased POPs levels with age. Similar age-related

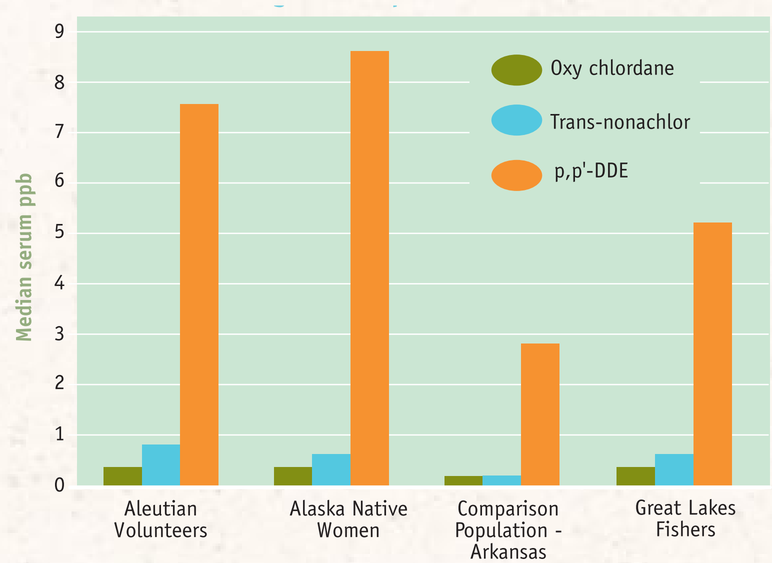


figure 11.4
POP levels in Alaska in Comparison with US Populations

Credit: Middaugh et al. 2000. pers comm C. Rubin 2002 for median levels in Alaska Native Women.

Mussel research.
EVOS photo library.

findings are evident in other studies from lower 48 populations and cannot necessarily be ascribed to dietary pattern changes. Because the Aleutian sample sizes were very low and from volunteer populations in isolated, select communities, few conclusions can be drawn. A broader surveillance is needed to answer key questions and address community concerns.

A small group of Aleut women of childbearing age—not pregnant at the time—was identified in the Middaugh et al. (2001) study. If their levels were compared with the maternal plasma study data of the Arctic Monitoring and Assessment Programme (AMAP 1998), the Aleut women would have the highest levels of p,p'-DDE (geometric mean 0.503 ppm lipid) so far found in the circumpolar region. They were second highest among the other Arctic nations for trans-nonachlor (g. mean 0.0498 ppm lipid) and oxychlordane (g. mean 0.0285 ppm lipid) (Middaugh et al. 2001). Note, again, that the Aleutian studies are only preliminary and cannot be considered statistically representative of this population. The relative elevations of DDT and chlordane derivatives are, however, consistent with the location of the Aleutians near continuing use regions for these POPs in Asia.

From the other side of Alaska, Arctic Slope mothers have POPs levels (DDT, DDE, mirex, transnonachlor, oxychlordane, and PCBs) that are lower than those in the Aleutian/Pribilof Islands women of childbearing age (Simonetti et al. 2001). These levels are comparable with levels in the lower 48 states for background populations (Anderson et al. 1998).

At this time, POPs movement and deposition trends to the north are unknown. An ongoing national surveillance program has not been in place to clearly indicate whether the 12 POPs under the Stockholm Convention are increasing, stable, or decreasing. There is an indication that in other Arctic nations some forms of PCBs are declining, whereas no trends are apparent for the more chlorinated forms (Hung et al. 2001).

Ongoing POPs Research in Alaska

Human health and ecological research on POPs levels and effects in Alaska is increasing, linking the domestic and transpolar efforts of the Arctic Monitoring and Assessment Program (AMAP), Arctic Council, U.S. Federal agencies, Alaska state government, and tribal groups. These research efforts cover a spectrum from expanding work on environmental levels through measurements of body burdens and effects along the food chain to wildlife and humans. Emphasis is placed on community involvement in the planning, decision-making and communication of this work.

Among these research efforts, measurements are underway of POPs levels transported in the air to Alaska and of levels in water and sediments of the Yukon River. Studies have been conducted on POPs levels in a wide range of species including Chinook and chum salmon, Steller's eiders, black-capped chickadees, red-throated loons, and wood frogs. This research is accompanied by expansion of data collection on marine mammals and other high-trophic predators, notably bald eagles and polar bears. With Alaska Natives, traditional food practices are being documented and analyzed to assess not only the contaminant loads, but also the nutritional benefits of the diet. POPs levels in mothers and the umbilical cord blood of their offspring are being measured to assess the body burden of contaminants. These data serve as an essential link in studies of potential effects (e.g., developmental, immunological) on the children. Research data have also been published as part of ongoing studies assessing the link between POPs levels and breast cancer (Rubin et al. 1997) and on the effect of HCB and DDE in human cell cultures (Simonetti et al. 2001).

These research efforts in Alaska parallel the POPs reduction and elimination activities under the Stockholm Convention. While the current Alaska data outlined herein serve to inform U.S. consideration of the Stockholm Convention, the ongoing work will further help to:

- monitor increases or declines in POPs levels in Alaska and detect any wildlife or human hotspots of POPs contamination;
- identify potential domestic and international sources of ongoing POPs contamination;
- guide communities on the risks and benefits of traditional practices; and

- increase the general scientific knowledge of the effects of these toxic substances and the levels at which these effects occur.

Conclusion

POPs can now be measured in all environmental media and species in Alaska. POPs levels in Alaska are generally low, however, when compared to the lower 48 United States. Accompanying these comparatively low levels are isolated examples of elevations that portend a cautionary warning in the absence of international action. DDT/DDE and PCB levels in transient Alaska killer whales are as high as those found in highly contaminated east coast dolphins, reaching to the hundreds of parts per million in lipid.

On Kiska Island in the Aleutians, DDE concentrations in bald eagle eggs approach effect levels seen in the Great Lakes. And Aleuts have some of the highest average DDE and chlordane levels measured in Arctic human populations, highlighting their proximity to continuing emission sources in Asia. Indeed, Alaska's location—geopolitically and climatically—suggests that POPs pollution could be exacerbated in future years in the absence of international controls.

The hunting and dietary practices essential to survival in the Arctic make indigenous humans and wildlife especially vulnerable to POPs. Where animal fat is the currency of life, this intensifies the unique combination of POPs properties to migrate north, associate with fat, persist, bioaccumulate, and biomagnify.

For Alaska Natives, current POPs levels vary with location and diet. In the human populations measured (Aleutian, Pribilof, North Slope), POPs levels are similar to those experienced by the background U.S. population, and generally below those of fisher communities around the Great Lakes. It is, therefore, important to emphasize that there are no known POPs levels at this time in Alaska that should cause anyone to stop consuming locally obtained, traditional foods or to stop breastfeeding their children. Current information indicates that the risks associated with a subsistence diet in Alaska are low, whereas in contrast, the benefits of this diet and breastfeeding children are well documented (Bulkow et al. 2002, Ebbesson et al. 1996, Jensen and Nobmann 1994, Nobmann et al. 1992, Scott and Heller 1968).

Further investigation and assessment are needed for specific species and foods in traditional diets and to broaden the database across Alaska communities. The international AMAP (1998) report came to the same conclusion for the entire Arctic, and Alaska levels of most of the POPs are generally lower than for other polar nations. The international community has also moved to further reduce POPs contamination through negotiation of the Stockholm Convention on POPs, implementation of which should help minimize future increases in levels of the listed POPs.

The full-text of this abridged report can be found as Chapter 5 of the EPA 2002 report "The Foundation for Global Action on Persistent Organic Pollutants: A United States Perspective."

"We are as one with our ancestors and children. We are as one with the land and animals."

Alaska Native anthropologist, Rosita Worl

Literature Cited

©Art Sutch

Contaminants in Alaska: Is America's Arctic at Risk?

Ambrose R.E., R.J. Ritchie, C.M. White, P.F. Schempf, T. Swem, and R. Dittrick. 1988. Changes in the status of peregrine falcon populations in Alaska. In: Cade T.J., J.H. Enderson, C.G. Thelander, and C.M. White, eds. Peregrine Falcon Populations: Their Management and Recovery. Proceedings of the 1985 International Peregrine Conference. The Peregrine Fund, Inc. Boise, ID. pp. 73-82

Ambrose R.E., A. Matz, T. Swem, and P. Bente. 2000. Environmental Contaminants in American and Arctic Peregrine Falcon Eggs in Alaska, 1979-95. U.S. Fish and Wildlife Service, U.S. Department of the Interior. Technical Report NAES-TR-00-02. 67pp.

American Public Health Association (APHA). 1984. The National Arctic Health Science Policy. Washington, DC: American Public Health Association Report Series.

Anthony R.G., A.K. Miles, J.A. Estes, and F.B. Isaacs. 1999. Productivity, diets, and environmental contaminants in nesting bald eagles from the Aleutian Archipelago. Environmental Toxicology and Chemistry 18:2054-2062.

Arctic Monitoring and Assessment Programme (AMAP). 1998. AMAP Assessment Report: Arctic Pollution Issues. Oslo, Norway.

Bacon C.E., W.M. Jarman, J.A. Estes, M. Simon, and R.J. Norstrom. 1999. Comparison of organochlorine contaminants among sea otter (*Enhydra lutris*) populations in California and Alaska. Environmental Toxicology and Chemistry 18(3):452-458.

Borell, A. 1993. PCB and DDTs in blubber of cetaceans from the northeastern North Atlantic. Marine Pollution Bulletin 26:146-151.

Bulkow, L.R., R.J. Singleton, R.A. Kapron, L.E. Harrison, and the Alaska RSV Group. 2002. Risk factors for severe respiratory syncytial virus infection in Alaska Native children. Pediatrics 109(2):210-216.

Carson, R. 1962. Silent Spring. Chapter 11, paragraphs 19, 20. New York: Houghton Mifflin.

Dewailly, E., P. Ayotte, C. Blanchet, J. Grondin, S. Bruneau, B. Holub, and G. Carrier. 1996. Weighing contaminant risks and nutrient benefits of country food in Nunavik. Arctic Medical Research 55:(Suppl 1):13-19.

Ebbesson, S.O.E., C. Schraer, E.D. Nobmann, and L.O.E. Ebbesson. 1996. Lipoprotein profiles in Alaskan Siberian Yupik Eskimos. Arctic Medical Research 55:165-173.

Egeland, G.M., L.A. Feyk, and J.P. Middaugh. 1998. The use of traditional foods in a healthy diet in Alaska: risks in perspective. State Alaska Epidemiology Bulletin 2(1):15.

Estes, J.A., C.E. Bacon, W.M. Jarman, R.J. Norstrom, and R.J. Anthony. 1997. Organochlorines in sea otters and bald eagles from the Aleutian Archipelago. Marine Pollution Bulletin 34:486-490.

Estes, J.A., M. Tinker, T.M. Williams, and D.F. Doak. 1998. Killer whale predation of sea otters linking oceanic and near shore ecosystems. Science 282:473-476.

Ewald, G., P. Larrsson, H. Linge, L. Okla, and N. Szarzi. 1998. Biotransport of organic pollutants to an inland Alaska lake by migrating sockeye salmon (*Oncorhynchus nerka*). Arctic 51(1):40-47.

Giger, M. and K.A. Trust. 1997. Tissue Concentrations of Elemental and Organochlorine Compounds in Sea Otters from Two Aleutian Islands in Alaska. U.S. Fish and Wildlife Service, Anchorage Field Office, Ecological Services. Technical Report WAES-TR-97-01.

Hashimoto, S., Y. Shibata, H. Tanaka, A. Yatsu, and M. Morita. 1998. PCDDs and PCDFs contamination in the northern Pacific area reflected on squid liver tissues. Organohalogen Compounds 41:413-416.

Hild, C.M. 1995. The next step in assessing arctic human health. Science Total Environment 160/161:559-569.

Hild, C.M. 1998. Cultural concerns regarding contaminants in Alaskan local foods. Circumpolar Health 96. International Journal of Circumpolar Health 57(1):561-566.

Hung, H., C.J. Halsall, P. Blanchard, H.H. Li, P. Fellin, G. Stern, and B. Rosenberg. 2001. Are PCBs in the Canadian Arctic atmosphere declining? Evidence from 5 years of monitoring. Environmental Science and Technology 35:1303-1311.

Jensen, P.G. and E. Nobmann. 1994. Foods. Nutrition Services, Alaska Area Native Health Service, U.S. Department of Health and Human Services, Indian Health Service, Alaska Area Native Health Service. Chart Series.

Johnstone, R.M., G.S. Court, A.C. Fesser, D.M. Bradley, L.W. Oliphant, and J.D. MacNeil. 1996. Long-term trends and sources of organochlorine contamination in Canadian tundra peregrine falcons, Falco peregrinus tundrinus. Environmental Pollution 93:109-120.

Kiff, L.F. 1988. Changes in the status of the peregrine in North America: an overview. In: Cade T.J., Enderson J.H., Thelander C.G., White C.M., eds. Peregrine Falcon Populations: Their Management and Recovery. Proceedings of the 1985 International Peregrine Conference. The Peregrine Fund, Inc. Boise, ID. pp. 123-139.

Krahn, M.M., P.R. Becker, K.L. Tilbury, and J.E. Stein. 1997. Organochlorine contaminants in blubber of four seal species: integrating biomonitoring and specimen banking. Chemosphere 34(9-10):2109-2121.

Krahn, M.M., D.G. Burrows, J.E. Stein, P.R. Becker, M.M. Schantz, and D.C. Muir. 1999. White whales (*Delphinapterus leucas*) from three Alaskan stocks: concentrations and patterns of persistent organochlorine contaminants in blubber. Journal of Cetacean Research Management 1(3):239-249.

Lanier, A.P., J.J. Kelly, P. Holck, B. Smith, and T. McEvoy. 2000. Alaska Native Cancer Update 1985-97. Anchorage, AK: Alaska Native Health Board and Alaska Native Medical Center.

Lee, J.S., S. Tanabe, H. Umino, R. Tatsukawa, T.R. Loughlin, and D.C. Calkins. 1996. Persistent organochlorines in Steller sea lion (*Eumetopias jubatus*) from the bulk of Alaska and the Bering Sea, 1976-1981. Marine Pollution Bulletin 32(7):535-544.

Matkin, C.O., D. Scheel, G. Ellis, L.B. Lennard, H. Jurk, and E. Saulitis. 1998. *Exxon Valdez* Oil Spill Restoration Project Annual Report, Comprehensive Killer Whale Investigation Restoration Project 97012 Annual Report. *Exxon Valdez* Oil Spill Trustee Council, Anchorage, AK.

Matkin, C.O., D. Scheel, G. Ellis, L.B. Lennard, H. Jurk, and E. Saulitis. 1999. *Exxon Valdez* Oil Spill Restoration Project Annual Report, Comprehensive Killer Whale Investigation Restoration Project 98012 Annual Report. *Exxon Valdez* Oil Spill Trustee Council, Anchorage, AK.

McFall, J.A., S.R. Antoine, and E.B. Overton. 1986. Organochlorine Compounds and Polynuclear Aromatic Hydrocarbons in Tissues of Subsistence Harvested Bowhead Whale (*Balaena mysticetus*). Report 20696, North Slope Borough, Department of Wildlife Management, Barrow, AK.

Middaugh, J., L. Verbrugge, M. Haars, M. Schloss, and G. Yett. 2000a. Assessment of exposure to persistent organicTM. pollutants (POPs) in 5 Aleutian and Pribilof villages. State of Alaska Epidemiology Bulletin 4(1).

Middaugh, J., L. Verbrugge, M. Haars, M. Schloss, and G. Yett. 2000b. Assessment of exposure to persistent organic pollutants (POPs) in 5 Aleutian and Pribilof villages -Addendum: pesticide results from St. Paul and St. George. State of Alaska Epidemiology Bulletin 4(6).

Middaugh, J., L. Verbrugge, M. Haars, M. Schloss, and G. Yett. 2001. Assessment of exposure to persistent organic pollutants (POPs) in 5 Aleutian and Pribilof villages. Final Report. State of Alaska Epidemiology Bulletin 5(5). 22 pp.

Muir, D.C.G. and R.J. Norstrom. 2000. Geographical differences and time trends of persistent organic pollutants in the Arctic. Toxicology Letters 112/113:93-101.

Newton, I., J.A. Bogan, and M.B. Haas 1989. Organochlo_rines and mercury in eggs of British peregrines, *Falco peregrinus*. Ibis 131:355-376.

Nobmann, E.D., T. Byers, A.P. Lanier, J.H. Hankin, and M.Y. Jackson. 1992. The diet of Alaska Native adults: 1987-1988. American Journal of Clinical Nutrition 55:1024-1032.

Nobmann, E.D., S.O.E. Ebbesson, R.G. White, C.D. Schraer, A.P. Lanier, and L.R. Bulkow. 1998. Dietary intakes among Siberian Yupiks of Alaska and implications for cardiovascular disease. International Journal of Circumpolar Health 57:4-17.

Norstrom, R.J., S.E. Belikov, E.W. Born, G.W. Garner, B. Malone, S. Lopinski, M.A. Ramsay, S. Schliebe, I. Stirling, M.S. Stishov, J.K. Taylor, and O. Wiig. 1998. Chlorinated hydrocarbon contaminants in polar bears from eastern Russia, North America, Greenland, and Svalbard: biomonitoring of Arctic pollution. Archives of Environmental Contamination and Toxicology 35:354-367.

Nutting, P.A. 1993. Cancer incidence among American Indians and Alaska Natives, 1980 through 1987. American Journal of Public Health 83:1589-1598.

O'Hara, T.M., M.M. Krahn, D. Boyd, P.R. Becker, and L.M. Philo. 1999. Organochlorine contaminant levels in Eskimo harvested bowhead whales of arctic Alaska. Journal of Wildlife Diseases 35:741-752.

O'Hara, T.M. and C. Rice. 1996. Polychlorinated biphenyls. In: Fairbrother, Locke, Hoff, eds. Noninfectious Diseases of Wildlife, 2nd ed. Ames, IA: Iowa State University Press, pp. 71-86.

O'Shea, T.J. and R.L. Brownell, Jr. 1994. Organochlorine and metal contaminants in baleen whales: a review and evaluation of conservation implications. Sci Total Environ 154:179-200.
Peakall, D.B., D.G. Noble, J.E. Elliot, J.D. Somers, and G. Erickson. 1990. Environmental contaminants in Canadian peregrine falcons, Falco peregrinus*: a toxicological assessment. Canadian Field-Naturalist (104):244-254.*

Ritchie, R.J. and S. Ambrose. 1996. Distribution and population status of bald eagles (*Haliaeetus leucocephalus*) in Interior Alaska. Arctic (49):120-126.

Rubin, C.H., A. Lanier, and A. Harpster. 1997. Environmental Chemicals and Health - Report of Pilot Study of Breast Cancer and Organochlorines in Alaska Native Women. Report of the National Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, GA.

Schraer, C.D., S.O.E. Ebbesson, E. Boyko, E. Nobmann, A. Adler, and J. Cohen. 1996. Hypertension and diabetes among Siberian Yupik Eskimos of St. Lawrence Island, Alaska. Public Health Report 111:51-52.

Scott, E.M. and C.A. Heller. 1968. Nutrition in the Arctic. Archives of Environmental Health 17:603-608.

Literature Cited


©Art Sutch

Contaminants in Alaska: Is America's Arctic at Risk?

Literature Cited


©Art Sutch

Contaminants in Alaska: Is America's Arctic at Risk?

Simonetti, J., J. Berner, and K. Williams. 2001. Effects of p,p' relevant to the Alaskan environment. Toxicology in Vitro 15:169-179.

Varanasi, U., J.E. Stein, K.L. Tilbury, D.W. Brown, J.P. Meador, M.M. Krahn, and S.L. Chan. 1993. Contaminant Monitoring for NMFS Marine Mammal Health and Stranding O'Leary Response Program. In: Proceedings of the Eighth Symposium on Coastal and Ocean Management, pp. 2516-2530.

Wade T.L., L. Chambers, P.R. Gardinali, J.L. Sericano, T.J. Jackson, R. J. Tarpley, R. Suydam. 1997. Toxaphene, PCB, DDT, and chlordane analysis of beluga whale blubber. Chemosphere 34 (5-7):1351-1357.

White, C.M., R.E. Ambrose, C.J. Henny, R.E. Hunter, and J.A. Crawford. 1988. Organochlorines in Alaskan peregrine falcon eggs and their current impact on productivity. In: Cade T.J., J.E. Enderson, C.G. Thelander, and C.M. White, eds. Peregrine Falcon Populations: Their Management and Recovery. Proceedings of the 1985 International Peregrine Conference. The Peregrine Fund, Inc. Boise, ID. pp. 385-393.

Wiemeyer, S.N., C.M. Bunck, and C.J. Stafford. 1993. Environmental contaminants in bald eagle eggs-1980-84-and further interpretations of relationships to productivity and shell thickness. Archives of Environmental Contamination and Toxicology 24:213-227.

Wolfe, R.J. 1996. Subsistence Food Harvests in Rural Alaska and Food Safety Issues. Juneau, AK. Alaska Department of Fish and Game, Division of Subsistence.

Yao, Z.W., G.B. Jiang, C.G. Zhou, H. Hi, and H.Z. Xu. 2001. Distribution of polychorinated biphenyls in the Bering and Chukchi Sea. Bulletin of Environmental Contamination and Toxicology 66:508-513.

Ylitalo, G.M., C.O. Matkin, J. Buzitis, M.M. Krahn, L.L. Jones, T. Rowles, and J.E. Stein. 2001. Influence of life-history parameters on organochlorine concentrations in free-ranging killer whales (*Orcinus orca*) from Prince William Sound, AK. The Science of the Total Environment 281(1-3):183-203.

Zhulidov, A.V., J.V. Headley, D.F. Pavlov, R.D. Robarts, L.G. Korotova, V.V. Fadeev, O.V. Zhulidova, Y. Volovik, and V. Khlobystov. 1998. Distribution of organochlorine insecticides in rivers of the Russian Federation. Journal of Environmental Quality 27:1356-1366.

12. Oceans, Watersheds and Humans: Facts, Myths and Realities

Steve Colt, University of Alaska Anchorage
Henry P. Huntington, Huntington Consulting

Introduction

Alaskans expect a great deal from their oceans and watersheds. Commercial fishing, sport fishing, subsistence hunting, recreation, offshore oil and gas development, transportation, and tourism are among the many ways the oceans, coast, watersheds, and their resources are used. These activities, however, can strain or break the capacity of the ecosystem to sustain them and they are not always compatible. Conflicts and controversies between different user groups are increasingly common. The role of societal forces in shaping the human-aquatic relationship is often under-appreciated, but can be critical. Protecting the health of Alaska's oceans and watersheds requires managing the interactions between humans and those ecosystems, based on an understanding of the dynamics of both the natural and the social systems involved.

This paper provides an introductory look at the relationship between humans and the oceans and watersheds of Alaska. We begin by characterizing various aspects of the human interaction with oceans, followed by a critical look at five "myths" concerning oceans and watersheds. Although the evidence to support them may be ambiguous at best, these myths are often accepted as true by many Alaskans. Since perceptions often drive actions at all levels—from individual behavior to agency management to state and federal policy—we believe that our five examples and other similar myths deserve closer scrutiny, as reflected in a final challenge we pose concerning the management of Alaska's oceans.

(above)
Subsistence. *(ADC&BD)*
Sport fishing. *(AK Division of Tourism, R. Montague)*
Commercial fishing.

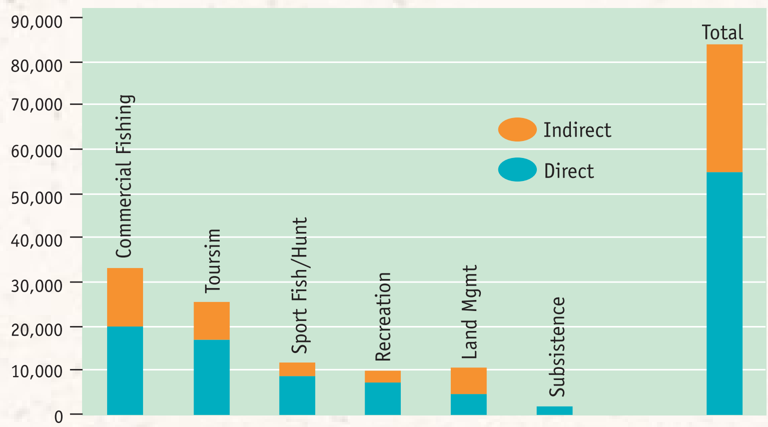


figure 12.1
Direct and Indirect Alaska Jobs in 1998 from Healthy Ecosystems

Credit: Colt. 2001.

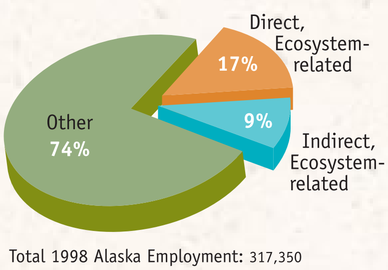


figure 12.2
Percentage of Total Alaska Jobs in 1998 from Healthy Ecosystems

Credit: Colt. 2001.

Characterizing the Human-Ocean Interaction

In examining the various human activities related to the oceans, we found the division of activities to be somewhat artificial, and discovered a considerable overlap, for example between sport fishing, tourism and recreation. Nonetheless, these categories provide useful units of analysis, and tend to correspond to current data collection methods. Where possible, we identify trends in the data where reliable time series are available.

While most residents and visitors probably assume that healthy ecosystems are important to the overall well-being of Alaska and its people (Brown 1998), the economic significance of Alaska's environment is often taken for granted. Some recent studies, however, have tried to quantify some aspects of the importance of a healthy environment. Using 1998 data, Colt (2001) concluded that some 84,000 jobs, or 26 percent of Alaska's total employment, depended directly or indirectly on healthy ecosystems (*figures 12.1 and 12.2*).

Commercial fishing

Commercial fishing in Alaska provides well over half the nation's domestic catch of fish (National Research Council 1996). Between fishing, processing and the provision of services, commercial fishing supports nearly 20,000 direct jobs and over 33,600 total statewide jobs (Colt 2001) and is the mainstay of many coastal communities. For many fishermen, their livelihood is more than a source of income, providing social and cultural benefits as well as money.

Commercial fishing vessels range from small-scale open boat fishermen along the coast, often in remote areas, to large vessels that catch and process fish at sea. Some fisheries are dominated by local boats, whereas some are carried out by fleets based in distant ports. Allocation decisions are based on a variety of factors, including economic efficiency, social impacts, environmental impacts, and historical patterns of use.

The purpose of commercial fishing is to provide food for humans and animals. The size of the Alaska commercial fishing industry and the distribution of its products around the world indicate both the productivity of Alaska's oceans and their importance for global society.

A sustainable fishing industry depends on sustainable fish populations. The management of Alaska's fisheries, in terms of both total harvests and allocation among types of fishermen, is critical. The division of management responsibility between the state and federal governments, in addition to various international treaties and agreements, complicates the process of allocating and managing harvests (National Research Council 1996). In addition, competition between commercial, sport and subsistence fisheries pits different interests against one another. Determining an equitable and efficient distribution of the catch is often a more challenging task than determining the sustainable overall harvest level. And, as we shall argue below, these two management tasks are not as separable as they may appear to be.

Commercial fishing, at the scale it is conducted in Alaska, has the potential for substantial impacts on the environment. Fishermen catch not only the species they are seeking, but often many other fishes as well, known as bycatch. They can also catch seabirds and marine mammals, and some trawling methods disturb the seabed. The magnitude of harvests alters marine food webs, which may have large effects on certain species. Determining these environmental impacts, however, is difficult at best in a complex and ever-shifting marine ecosystem. The persistent uncertainty surrounding the decline of Steller sea lions is a case in point (DeMaster and Springer, this volume).

Sport fishing

Sport fishing, both in nearshore waters and in rivers, is one of the most popular uses of aquatic resources. In each of the last several years, about one in four Alaska residents purchased a sport fishing license. As children under 16 and adults over 60 do not need to purchase an annual license, the total proportion of Alaskans who sport fish is likely to be substantially higher. Sport fishing is equally popular among visitors to Alaska. For over a decade, sales of licenses to non-residents have exceeded sales to residents, and non-resident sales have continued to increase while resident figures have remained the same.

For some participants, sport fishing is an opportunity to get food. Most fishing probably falls in between the enjoyment of the activity and the taste of fresh fish. Sport fishing, however, involves more than having fun. Guides, lodges, suppliers of fishing equipment, and providers of other services all benefit from the money spent by sport fishermen. About 6,600 jobs depend directly on sport fishing, with an additional 2,600 or so indirectly dependent (Colt 2001, Haley et al. 1999). Sport fishing comes into conflict with commercial and subsistence fishing over allocations of the harvest and priority uses of the fish.

In addition to harvesting fish, sport fishermen have the potential to disrupt habitats, particularly along riverbanks. Large numbers of fishermen in one area, as commonly seen on some Kenai Peninsula rivers, can damage the bank leading to erosion, increased turbidity of the water, and other impacts. The use of motorboats on rivers can cause damaging wakes and noise disturbance.

Subsistence

The traditional use of plants, fish, birds, and mammals is the oldest form of resource use in Alaska. For Native communities, subsistence harvests have cultural, spiritual, nutritional, economic, and social significance. For non-Natives engaged in subsistence, many of the same values apply. In the marine environment, subsistence resources include fish and their eggs, marine mammals, seabirds and their eggs, invertebrates, and marine plants. Harvests in many communities total in the hundreds of pounds per person (Schroeder et al. 1987).

The allocation of resources among users is a contentious aspect of law and management practice (Huntington 1992). The definition of subsistence and of subsistence users is similarly controversial. The rural-urban distinction drawn by the Alaska National Interest Lands Conservation Act of 1980 has been attacked both for its premise—that rural residents have priority access to fish and wildlife—and for the way it has been implemented. For example, the issue of whether the Kenai Peninsula should be classified as urban or rural has been particularly contentious (Wolfe 1991).

The allocation of resources among users is a contentious aspect of law and management practice.

The role of subsistence in local and statewide economies is often difficult to identify. As a means of producing food and other products, subsistence is often more economical than purchasing food at the store, plus, subsistence foods are generally healthier. Subsistence harvests can also have a cash element, either as food or for products and artwork made from animal parts such as ivory, skins, fur, teeth, bones, and baleen. The overlap of subsistence and cash economies is a normal practice in Native villages, but blurs any distinction that can be made between traditional and commercial activities. In the Northwest Territories, Canada, estimates of the cash value of foods from subsistence harvests range from $700 per person upwards, for a territorial total in the millions (Weihs et al. 1993). In Alaska, the purchase of supplies and equipment for subsistence activities is estimated to create some 2,000 jobs statewide (Colt 2001).

Subsistence harvests, especially in cases such as marine mammals where restrictions on harvests are largely absent under the Marine Mammal Protection Act of 1972, can have an impact on species or populations, though there are few instances where subsistence harvests have caused a problem by themselves. The use of motorized transport, such as boats and all-terrain vehicles, creates other potential impacts, especially to riverbanks and wetlands.

Tourism

As a generator of employment, tourism ranks third in Alaska's economy behind oil and fishing (Goldsmith 1997). It creates some 16,800 jobs directly and nearly 9,000 more indirectly (Colt 2001). Tourism is largely a coastal activity. About half of all visitors travel through Alaska on

a large cruise ship. Many others take day cruises, charter fishing trips, and rent kayaks. In more rural areas, tourists may fly in for a short visit, but do not often leave shore.

Tour operators and providers of tourist-related services create many jobs and generate a great deal of revenue, often dispersed through many towns and businesses. The benefits of different types of tourism, however, accrue differently. Cruise ship passengers spend most of their money on products and services provided by large, out-of-state corporations. Tourists staying on shore stay in hotels, rent cars or motor homes, eat at restaurants and buy food in grocery stores, and spend money in several places as they travel.

Tourism clearly affects habitat and species. Cruise ships discharge polluted waste into coastal waters and may disturb seabird colonies and interfere with seal pup survival. Foot and small boat traffic can contribute to the erosion of shorelines and riverbanks. The scale of the tourism industry relative to the resident population and infrastructure also makes it inevitable that tourists will compete with local residents for space and access. The presence of tourists can interfere with local activities, such as subsistence practices along popular rivers or coastlines.

...the volume of use that is concentrated in relatively few access points for tourism, recreation and sport fishing may lead to competition for space and services.

Recreation

Recreation refers to outdoor activity by Alaska residents. Many Alaskans enjoy spending time in coastal or nearshore areas, traveling by boat, walking or camping on the shore, digging for clams, and so on. Recreation may be regarded primarily as a quality of life matter, but it has economic and management significance, too. People traveling to enjoy the coast or purchasing equipment spend money, often in considerable sums. One recent estimate suggests that this economic activity is responsible for 7,200 direct jobs and 9,800 total jobs (Colt 2001). The designation of protected areas, including recreation areas, is one government response that supports recreational uses, as is the construction of public use cabins along the coast.

Although recreation is often classified as a nonconsumptive use of coastal resources, it is not always benign. Overuse of popular areas can lead to habitat damage. The presence of visitors in some cases can interfere or conflict with fishing, subsistence and other marine activities. Furthermore, the volume of use that is concentrated in relatively few access points for tourism, recreation and sport fishing may lead to competition for space and services.

Transportation

Shipping is a primary reason that Alaska's large communities and nearly all of its smaller ones are located along the coast or navigable rivers. The modern sites of several other villages were determined in part by barge access. Shipping supplies to communities is, however, just one of many ocean or river transportation activities. Alaska exports its oil, minerals, timber, and other natural resources over water. Most fish that are exported are sent via sea rather than air. People, too, travel by sea on the Alaska Marine Highway, which provides relatively inexpensive access to and from some communities lacking road access.

Shipping and passenger services do more than move goods and people. Accidents, such as the *Exxon Valdez* oil spill, can cause considerable environmental damage. Ports are typically the most polluted sites along the coast, due to the amount of traffic and the concentration of fueling and maintenance services. Cruise ships bring thousands of people at a time to coastal communities precisely because they can move over water with little infrastructure and relatively low cost.

Offshore oil and gas development

Oil and gas development occurs where there is oil and gas, whether on sea or land. Offshore development is hampered rather than facilitated by its location, but it can have a significant impact on the marine environment. The extraction of oil and gas provides revenue for the state or federal government or both, provides jobs and income for workers and providers of oilfield services, and supplies Alaska and the nation with energy.

In the nearshore environment, oil and gas development is often associated with pollution, physical impacts on habitat, noise disturbance, and other impacts to species and habitats. Offshore activities can also interfere with users of living resources, for example by the displacement of people or fish and marine mammals. The 1995 buyback of offshore oil and gas development leases in Bristol

Bay to avoid conflicts with salmon fishermen was a significant political response to these conflicts.

Cumulative impacts and multiple uses

Each of these areas of human activity has benefits and costs. Considered individually, each poses a number of difficult questions concerning rights of access, priority uses, relative economic significance, environmental impacts, and other societal values, but none of them occur in isolation. In fact, two or more often occur at the same time and place. Evaluating the cumulative impacts of all human activities, and the relative impacts that they have on one another, is an especially complex task.

One way to approach the problem is to start, as we have done, with each sector individually. Strong trends upward or downward over time indicate the possibility of impacts on or from other sectors. Plateaus may indicate saturation of the supply (e.g., all the available fish are already being caught, so there is no room for more fishermen) or of demand (e.g., everyone who wants a boat already has one, so boat buying is no longer expanding). Definitive links between most sectors are usually very hard to demonstrate, although there are many conflicts over perceived competition for resources. Nonetheless, evidence of unsustainable use in one sector should lead to an examination of related sectors as well as to other potential contributing factors.

One limitation of this approach is that new uses—such as aquaculture—may emerge. Determining equitable allocations of scarce resources is at best difficult. The concept of "multiple use" works less well than it may have in the past. The relative importance of one activity compared with another and the degree to which one affects another are uncertain and controversial parameters, depending largely on which measure is chosen to evaluate competing claims and perspective.

The competing claims on Alaska's aquatic environments are further complicated by the distinct regulatory regimes that apply to various sectors and activities. The cruise ship industry, for example, must abide by state and federal laws concerning pollution, enforced by the Coast Guard, the Environmental Protection Agency and the Alaska Department of Environmental Conservation. The impacts that cruise ships may have on seals, however, fall under the Marine Mammal Protection Act, enforced in this case by the National Marine Fisheries Service.

Similarly, impacts of offshore oil and gas development are regulated under the National Environmental Policy Act, which mandates environmental impact statements. For federally owned offshore areas, these are prepared under the auspices of the Minerals Management Service. But the fisheries that may be impacted are managed by the National Marine Fisheries Service (itself an agency of the Department of Commerce), which may contribute to the environmental impact statement but does not have a role in making the final decision. The determination of cumulative impacts and the resolution of conflicts is thus often determined by the legislative branch or the judiciary, as advocates of each side compete for priority.

The incremental and cumulative impacts of human activities on one another and on the environment itself are often overlooked as each sector tries to expand. The sustainable health of Alaska's oceans and rivers ultimately depends on understanding and addressing these cumulative benefits and impacts, particularly considering quality of life factors.

Myths and Realities

There are many accepted "truths" about Alaska's economy and environment, its oceans and watersheds not excepted. Such "truths" are based both on facts and on widely shared assumptions, but the simplistic nature of these conceptions often conceals greater complexity and ambiguity. We call these shared but unexamined conceptions "myths." In powerful ways, these myths can shape our perceptions of human interactions with Alaska's oceans and watersheds. Perceptions, in turn, influence analysis and policy. But reliance on myths, whether implicit or explicit, may distort accurate understanding of what is really going on, thus impeding effective management. To illustrate this point, we provide five examples of myths and analyze the basis for each. These five are not necessarily false, but are misleading or poorly understood. There are, of course, far more, and we encourage readers to think critically about simplistic statements of "truth" that may in fact be nothing more than uncritically accepted myths.

Photo courtesy Alaska Division of Tourism, Mike Affleck.

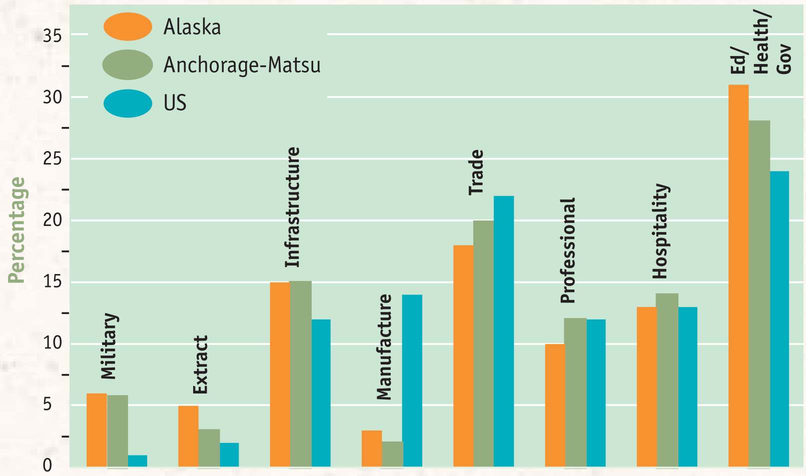


figure 12.3

Year 2000 Shares of Total Employment by Industry Group, Alaska vs. United States

Credit: compiled by authors from U.S. Census 2002.

Myth 1: Alaska's social and economic health closely tracks changes in marine resource availability and world markets.

Over the past decade, there has been great volatility in both Alaska's ecosystems (DeMaster and Springer, this volume) and in world markets for Alaska products such as salmon (Knapp 2001). By contrast, Alaska's demographics and economy are in aggregate far more stable between the 1990 and 2000 censuses. There are two primary reasons for this. First, the two biggest factors currently driving the Alaska economy are the oil industry and federal spending—neither of which is directly tied to the health of marine resources or to world markets for these resources. Second, although for some regions this myth may be substantially true, most people and places have been able to absorb short-term (1–5 year) fluctuations in income, prices, resource availability, and other environmental and economic parameters (*figure 12.3*). Medium-term (5–20 year) and long-term (more than 20 year) changes may be more significant, as people react to marked changes in job opportunities and other factors that determine where and how they live.

Myth 2: Tourism is the "next big thing" for Alaska's economy.

Tourism is a significant source of employment and income for Alaskans, and is often described as a major area of growth, particularly for rural areas with few other economic development opportunities. While tourism may have that potential, recent figures give less cause for optimism. Between 1989 and 1998, summer arrivals increased by seven percent per year. From 1998 to 2001, however, the overall increase had slowed to a mere one percent per year, with arrival modes such as highways showing declines in arrivals (*figure 12.4*). Although marketing appeals tend to emphasize fish, scenery, wildlife, and wilderness, there is little information to evaluate the role of marine ecosystem health in promoting or supporting tourism. Finally, it is unclear how much total economic activity tourism can actually support, or whether eco- and cultural tourism can actually have a significant impact on the economies of rural communities.

Myth 3: Rapidly increasing human use is stressing Alaska's marine ecosystem.

Whether the oceans and watersheds ecosystem is at or near significant thresholds of stress or degradation is a question for ecologists and oceanographers (see Mantua, this volume; DeMaster and Springer, this volume). An examination of trends in human uses, however, belies the assumption that human uses are all increasing rapidly. Coastal populations are relatively stable overall, with modest growth in most regions of the state. In coastal regions, however, there is a large pulse of teenagers who will soon be seeking jobs and otherwise beginning to use the marine system, which may greatly increase the effective human presence without altering the total population.

There have been, of course, shifting patterns of human use. The scale of commercial fishing has not increased. The timber industry is declining. Conversely, the footprint of tourism is expanding, as is the quality of life industry, which includes retirement and second homes in places such as the Kenai Peninsula. Not surprisingly, perhaps, these shifts have created conflicts among uses as various interests compete for the same resources (Little 2002). Uses no longer fall neatly into "consumptive" and "nonconsumptive" categories. For example, there is evidence that recreational uses of beaches and intertidal zones may have a far greater environmental impact than shellfish mariculture (Ralonde 2002, Alessa 2002).

Myth 4: Alaska is different and lessons from elsewhere do not apply.

Alaska is remote, sparsely populated, and in most areas has no obvious signs of human degradation of the environment. These factors are all in contrast to much of the rest of the United States, which is the most common basis for comparison. It is no surprise, then, that a superficial comparison of conditions in Alaska with those elsewhere in the country leads some people to conclude that Alaska need not worry about the types of impacts seen elsewhere. Nonetheless, there are other northern regions, such as Greenland and Nunavut, that are remote and sparsely populated. The experiences of these places cannot be easily ignored.

The collapse of the cod fishery in Newfoundland is one well known example of ecological and economic disaster. It is interesting to note, however, that cod harvests were stable for a decade prior to the collapse of the stock. The Newfoundland experience provides a reminder that commercial fish harvests can change rapidly for reasons that we may not understand, anticipate or be able to control.

Closer to home, recent trends in the salmon industry and in Alaska's economy show the influence of forces outside the state, and a general economic convergence of Alaska and the rest of the United States. While Alaska salmon harvests have remained stable or increased in numbers of fish, the economic value of those fish has declined sharply as a result of competition from farmed salmon. The primary lesson is that traditional extractive industries cannot provide unlimited growth, because they are vulnerable both to exhausting the resource and to competition from substitutes.

Myth 5: Alaska's coastline is protected from, or inaccessible to, development.

This myth is related to the point in the previous myth that Alaska's environment is more than sufficient to provide for its sparse human population. One aspect of this belief is that the harsh northern climate keeps most people away, making it impossible to damage the ecosystems on a large scale (see Nash 1980 for further discussion). An alternative source of complacency is the belief that Alaska's vast protected areas (national parks, wildlife refuges, etc.) are more than adequate to protect the environment. For the coastline in particular, both assumptions overstate the truth. The lure of resources such as gold and oil has repeatedly overcome barriers of climate and distance. In 1900, at the height of the gold rush, Nome was Alaska's largest city. The oil developments on the North Slope have overcome even greater environmental and logistical obstacles.

In other areas, access is improving, allowing more and more recreational and other small-scale users to reach more and more of the coastline. Boat traffic cannot be regulated, with the potential for significant impacts to coastlines in places such as Prince William Sound, where beaches and intertidal zones may suffer the impacts of increasing foot traffic. Uses are also becoming more extensive. "Soft adventure" tourism is growing rapidly, placing increasing numbers of people farther afield (Colt 2002). Mariculture and other economic development is increasing, with the potential for environmental and scenic impacts. Looking at Prince William Sound as an example, the coastline is actually owned or managed by many different agencies, organizations and individuals, with substantial unrealized potential for development within easy access of Anchorage.

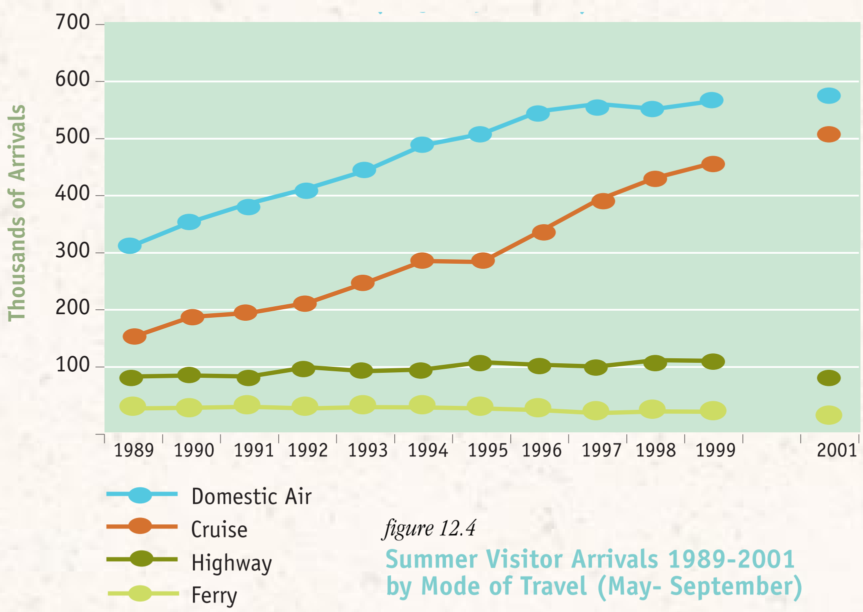


figure 12.4

Summer Visitor Arrivals 1989-2001 by Mode of Travel (May- September)

From 1998 to 2001 overall increase in summer arrivals has slowed to one percent.

Credit: Alaska Visitor Statistics Program. Compiles by Colt. 2002.

How can Alaska manage its oceans and watersheds for a healthy environment and a healthy economy?

A Challenge

Based on the characterization of human uses of oceans and watersheds, and bearing in mind the lessons learned from critically examining myths surrounding those uses, we now pose the challenge central to further debate about the relationship between Alaskans and their aquatic ecosystems—to determine whether the following statement is true:

The current management system for Alaska's oceans and watersheds adequately provides for a healthy environment and a healthy economy.

The foundation for this challenge is threefold: human uses are, on aggregate, growing both in volume and in geographic spread; conflicts over management and allocation are substantial and increasing; and the ecological health of Alaska's oceans and watersheds is important to the state's residents. There is little humans can do to control the large-scale natural processes of climate and ocean circulation, making management of human uses the most direct way for society to influence the biological health and economic productivity of ecosystems. The effectiveness of this management will substantially affect the long-term environmental and economic health of the state.

Answers to this question are not straightforward. Several related questions about both ecosystems and the economy must also be asked. Ecologically, it is not clear, as mentioned earlier, whether we are approaching any significant stress thresholds. With the uncertainties inherent in the natural environment (Mantua, this volume; DeMaster and Springer, this volume), efforts to achieve "maximum sustainable yields" in fisheries extractions are likely to be impossible for most if not all species, raising a question of what alternative goals might actually be achievable.

Bycatch is a quintessential complicating factor: how does the extraction of one species affect the size or sustainability of harvests of another species? Cumulative impacts of various activities are poorly studied and understood, increasing uncertainty and making it more likely that ecological surprises will occur. Because environmental management is greatly fragmented (for example, consider the number of agencies and jurisdictions that have some influence over the life cycle and habitat of salmon in Alaska), can the management system as a whole respond adequately to the threats faced by the ecosystem? These secondary questions on the ecosystem side deserve attention and need to be addressed before the primary challenge can be answered.

Economically, the situation is more contentious and ambiguous. The goal of a "healthy economy" raises the question of *whose* economy. Some fisheries, for example, may be economically efficient (e.g., they may generate maximum value-added), but the benefits may accrue to one group rather than another. Some recent management strategies, such as the community development quota or CDQ, have attempted the dual task of regulating the fishery and promoting economic growth in rural communities. Determining the relative priorities of those goals is not a trivial task. There is also a question of the time period over which effectiveness is to be measured. It may be possible to achieve substantial short-term gains, but these may jeopardize the medium- and long-term health of the environment and/or the economy. Determining which measure to use is not a simple decision.

An underlying consideration for our challenge is the degree to which society is willing to accept that the resources of Alaska's oceans and watersheds are finite. If there were enough for everyone for all uses, no management conflicts would arise, and indeed no management would be necessary. This is clearly not the case. And yet, allocation battles place considerable implicit and explicit pressure on managers to allow greater use, which could push the system to or past the limits of ecosystem productivity. This problem becomes even more severe when a given resource declines in abundance.

We can rephrase our challenge, and ask "How can Alaska manage its oceans and watersheds for a healthy environment and a healthy economy?" A good place to start that discussion is with the recognition that when we make many demands on aquatic resources, either society or the environment will ultimately impose some form of limits on how much we use.

Alessa, L. Assistant Professor of Biology, University of Alaska Anchorage. 2002. Personal Communication.

Brown, G. 1999. Quality of life community profiles. Anchorage: Alaska Pacific University. Available online: http://polar.alaskapacific.edu/gregb/profal13.pdf

Colt, S. 2001. The economic importance of healthy Alaska ecosystems. Anchorage: University of Alaska, Institute of Social and Economic Research. Available online: www.iser.uaa.alaska.edu

Colt, S. 2002. Recreation and Tourism in Southcentral Alaska: Patterns and Prospects. Portland, OR: USDA Forest Service Pacific Northwest Laboratory, General Technical Report Series (forthcoming).

Estes, C.C. 2001. The status of Alaska water export laws and water transfers. Presentation to the American Society of Civil Engineers, World Water and Environmental Resources Congress, Orlando, Florida. May 2001.

Goldsmith, S. 1997. Structural Analysis of the Alaska Economy: A Perspective from 1997. Anchorage: Institute of Social and Economic Research.

Haedrich, R.L. and L.C. Hamilton. 2000. The fall and future of Newfoundland's cod fishery. Society and Natural Resources 13:359–372.

Haley, S., S. Goldsmith, M. Berman, H.J. Kim, and A. Hill. 1999. Economics of Sport Fishing In Alaska. Anchorage: Institute of Social and Economic Research.

Huntington, H.P. 1992. Wildlife management and subsistence hunting in Alaska. London: Belhaven Press. xvii + 177 p.

Knapp, G. 2001. Challenges and Strategies for the Alaska Salmon Industry. Anchorage: Institute of Social and Economic Research. Available online at http://www.iser.uaa.alaska.edu/iser/people/knapp/strategies percent2021.pdf

Little, J. 2002. Oyster farmer looks for home in Kenai fjords. Anchorage Daily News, May 12, 2002, A-1.

Miller, S. and D.W. McCollum. 1999. Less May Mean More: Maximizing the Economic, Environmental, and Social Benefits from Alaska's Visitors Industry. Available online at http://www.dced.state.ak.us/cbd/toubus/lessmay.htm

Nash, R. 1980. Wilderness and the American mind. Third edition. New Haven: Yale University Press. xvii + 425 p.

National Research Council. 1996. The Bering Sea ecosystem. Washington, D.C.: National Academy Press. x + 307 p.
Ralonde, R. Marine Advisory Program, University of Alaska. 2002. Personal Communication.

Schroeder, R.F., D.B. Andersen, R. Bosworth, J.M. Morris, and J.M. Wright. 1987. Subsistence in Alaska: Arctic, Interior, Southcentral, Southwest, and Western regional summaries. Technical Paper 150. Juneau: Alaska Department of Fish and Game, Division of Subsistence. xxxi + 690 p.

U.S. Census Bureau. 2002. Year 2000 Census Summary File 1, Alaska extracts.

Weihs, F.H., R. Higgins, and D. Boult. 1993. A review and assessment of the economic utilizations and potential of country foods in the northern economy, final report. Prepared for the Royal Commission on Aboriginal People, Canada.

Wolfe, R.J. 1991. Subsistence management in Alaska: 1991 update. Juneau: Alaska Department of Fish and Game, Division of Subsistence. 4 p.

Literature Cited

Oceans, Watersheds and Humans: Facts, Myths and Realities

Affiliates

Vera Alexander
School of Fisheries and Ocean Science, UAF
vera@sfos.uaf.edu

Jim Ayers
Oceana, North Pacific Office
jimayers@gci.net

James Balsiger
EVOS TC Member
jim.balsiger@noaa.gov

Dick Beamish
Fisheries and Oceans Canada
beamishr@pac.dfo-mpo.gc.ca

James Berner
Alaska Native Tribal Health Consortium
jberner@anmc.org

VernonByrd
Alaska Maritime NWR
Vernon_Byrd@fws.gov

Maria Adams Carroll
Arctic Slope Native Association
mcarroll@barrow.com

David R. Cline
World Wildlife Fund Alaska Field Office
wwf@acsalaska.net

Patricia Cochran
Alaska Native Science Commission
anpac1@uaa.alaska.edu

Steve Colt
Institute of Social & Economic Research,
University of Alaska Anchorage
afsgc@uaa.alaska.edu

Doug DeMaster
Alaska Fisheries Science Center, NMFS
douglas.demaster@noaa.gov

Craig Dorman
VP, UA Statewide System
craig.dorman@alaska.edu

Doug Eggers
ADF&G
doug_eggers@fishgame.state.ak.us

David Fluharty
School of Marine Affairs,
University of Washington
fluharty@u.washington.edu

Scott Glenn
Rutgers University
Institute of Marine and Coastal Sciences
glenn@imcs.rutgers.edu

Jack Helle
Alaska Fisheries Science Center/Auke Bay Lab
jack.helle@noaa.gov

Carl Hild
Institute of Circumpolar Health Studies, UAF
ancmh@uaa.alaska.edu

George Hunt Jr.
University of California, Irvine
glhunt@uci.edu

Henry Huntington
Huntington Consulting
hph@alaska.net

David Irons
U.S Fish and Wildlife Service
david_irons@fws.gov

Charles Johnson
Alaska Nanuuq Commission
cjohnson@nook.net

Jesus Jurado-Molina
SAFS University of Washington
jesus.jurado-molina@noaa.gov or
jjurado@u.washington.edu

Eric Knudsen
USGS
eric_knudsen@usgs.gov

Gordon Kruse
University of Alaska Fairbanks, SFOS
gordon.kruse@uaf.edu

Carol Ladd
NOAA - Pacific Marine Environmental Lab
Carol.ladd@noaa.gov

Lloyd Lowry
University of Alaska Fairbanks, SFOS
llowry@eagle.ptialaska.net

Nate Mantua
University of Washington, JISAO
mantua@atmos.washington.edu

Oceans U.S.
http://www.ocean.us

Trevor McCabe
At Sea Processors
tmccabe@atsea.org

Marcia McNutt
Monterey Bay Aquarium Research Institute
mcnutt@mbari.org

Lyn McNutt
University of Alaska Fairbanks
lyn@gi.alaska.edu

Phil Mundy
GEM Science Director
phil_mundy@oilspill.state.ak.us

Jennifer Nielsen
USGS
jennifer_nielsen@usgs.gov

Brenda Norcross
University of Alaska Fairbanks
norcross@ims.uaf.edu

Todd O'Hara
Department of Wildlife Management,
North Slope Borough
tohara@co.north-slope.ak.us

Chris Oliver
North Pacific Management Council
Chris.Oliver@noaa.gov

Clarence Pautzke
North Pacific Research Board
cpautzke@nprb.org

John Piatt
Alaska Science Center, USGS
john_piatt@usgs.gov

Caleb Pungowiyi
President Robert Aqqaluk Newlin Sr. Memorial Trust
caleb.pungowiyi@nana-reg.com

Randy Rice
Alaska Seafood Marketing Institute
rrice@alaskaseafood.org

Patrick Simpson
Scientific Fishery System, Inc.
pat@scifish.com

Michael Smolen
World Wildlife Fund
smolen@wwfus.org