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

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Joint Institute for the Study of the Atmosphere and Ocean
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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.

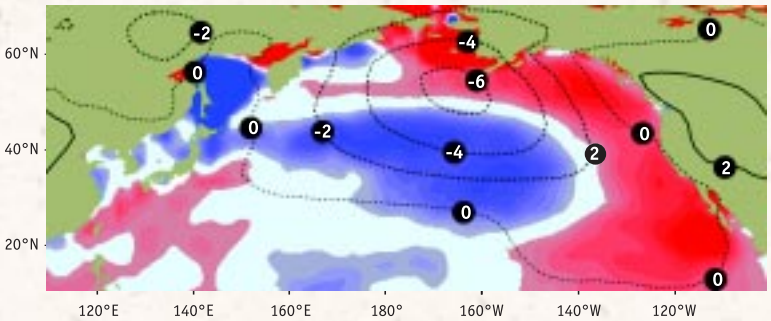


figure 8.1

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.

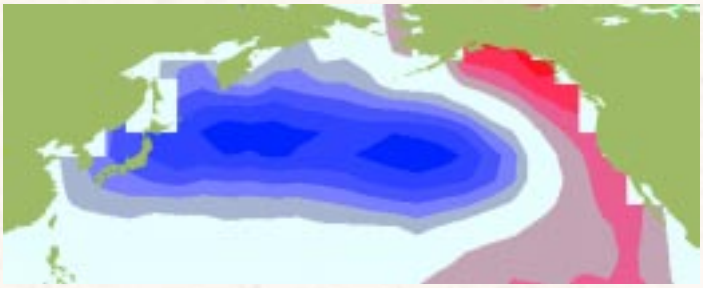


figure 8.2

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.

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

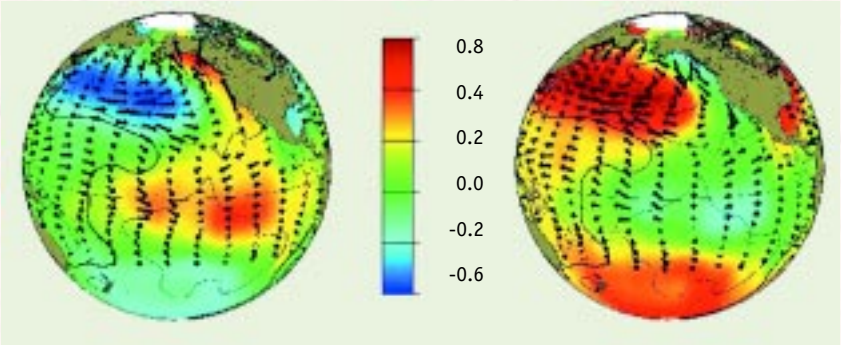


figure 8.3

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.

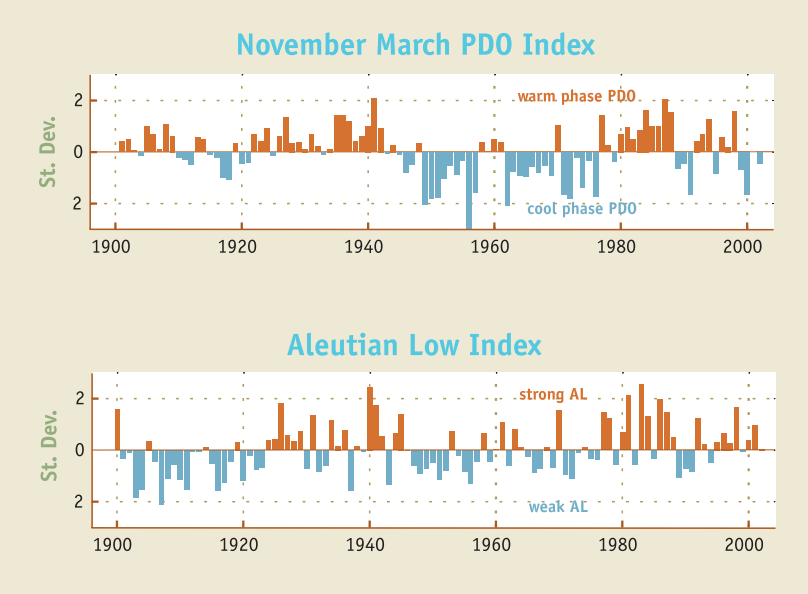


figure 8.4

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

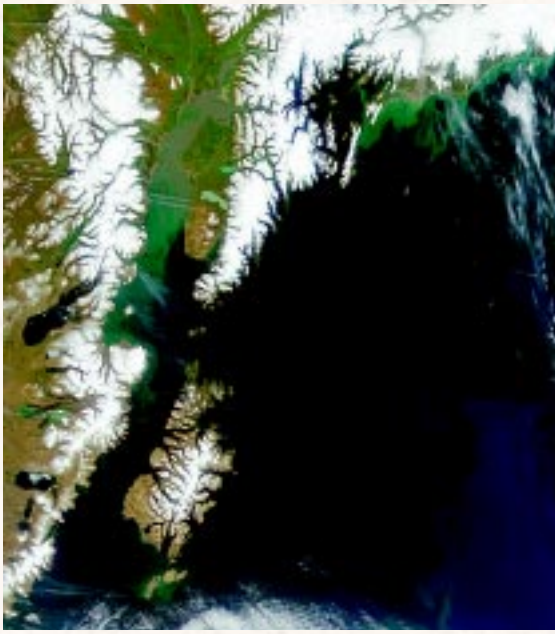
nutrient-rich water into the euphotic zone, where it sparked the doubling in phytoplankton biomass.

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.



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

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

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).

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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.

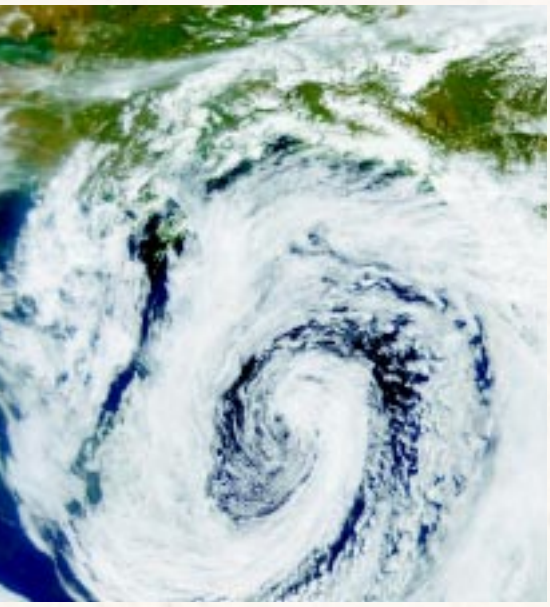
species did not show the same pattern of decline, indicating that carrying capacity differs among these species, likely due to a difference in preferred prey, local environmental dynamics or life history strategies.

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.

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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

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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).

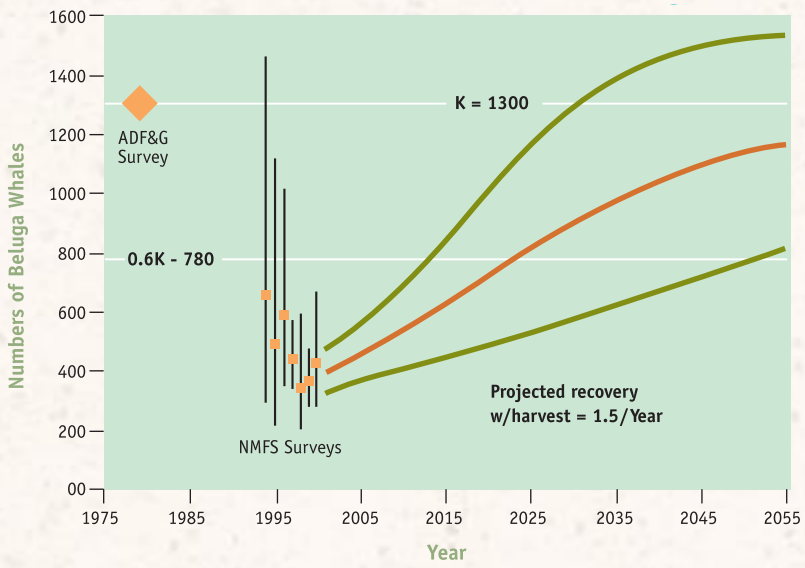


figure 9.1

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.

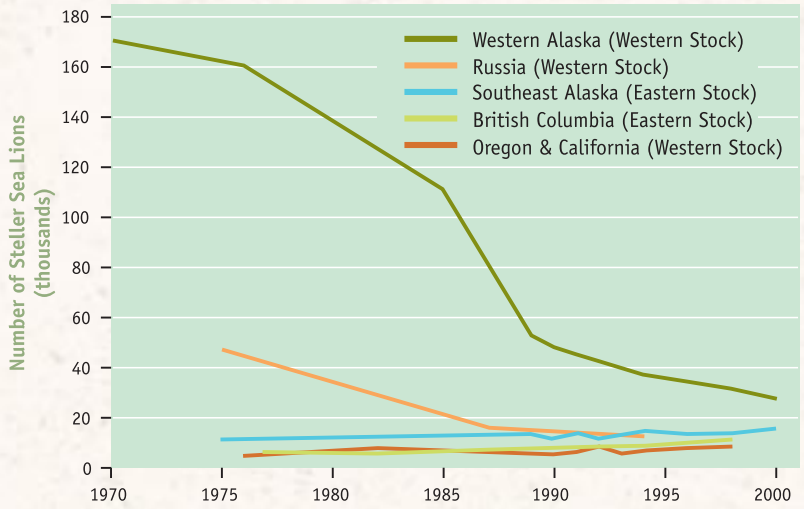


figure 9.2

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.

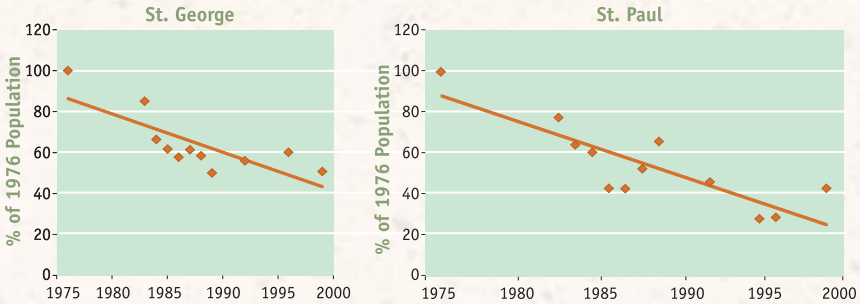


figure 9.3

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.

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.

Kittiwake research.
EVOS photo library.

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

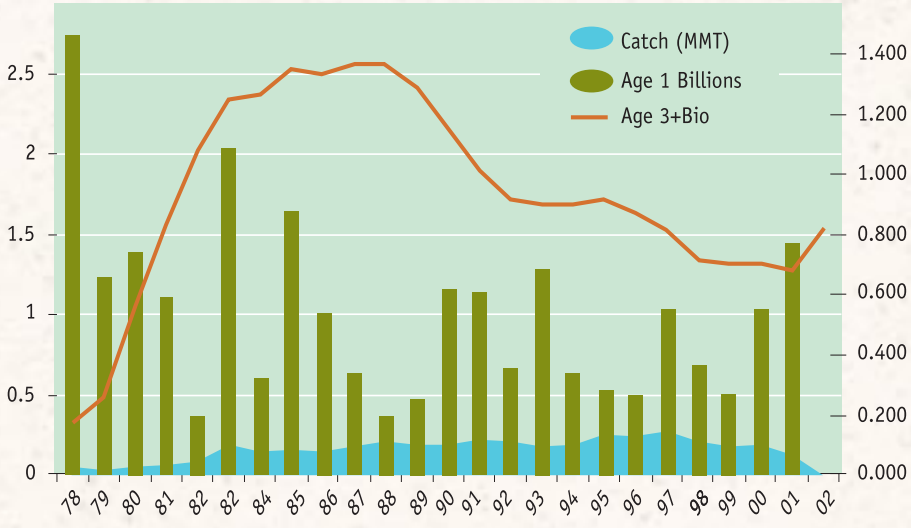
Pacific cod are another important species to fisheries in Alaska. Cod biomass is estimated at approximately 1.54 million metric tons in the eastern Bering Sea and 600,000 metric tons in the Gulf of Alaska. In the Bering Sea, year class strength since 1992 has been below average, although a relatively 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

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.

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.

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

10. Persistent Organic Pollutants in the Alaska Environment

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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), perfluorooctanesulfonyl 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.

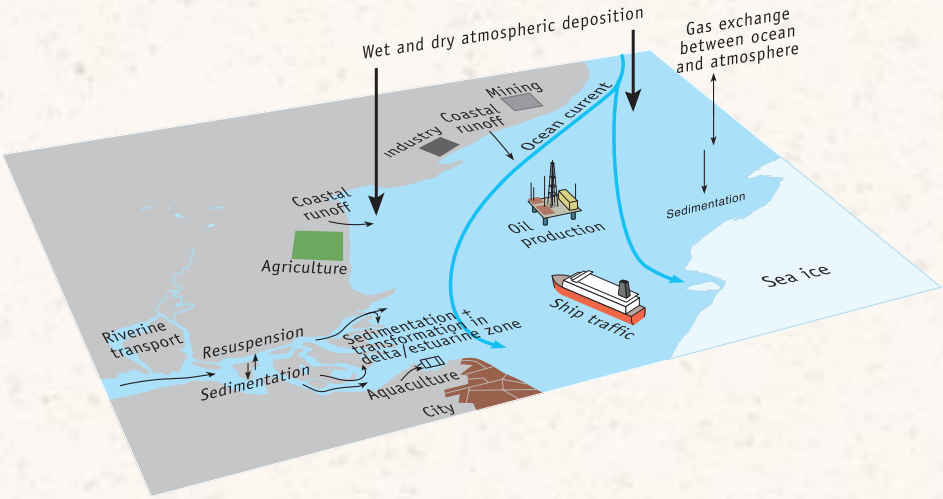

figure 10.1

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).

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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.

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.

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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.

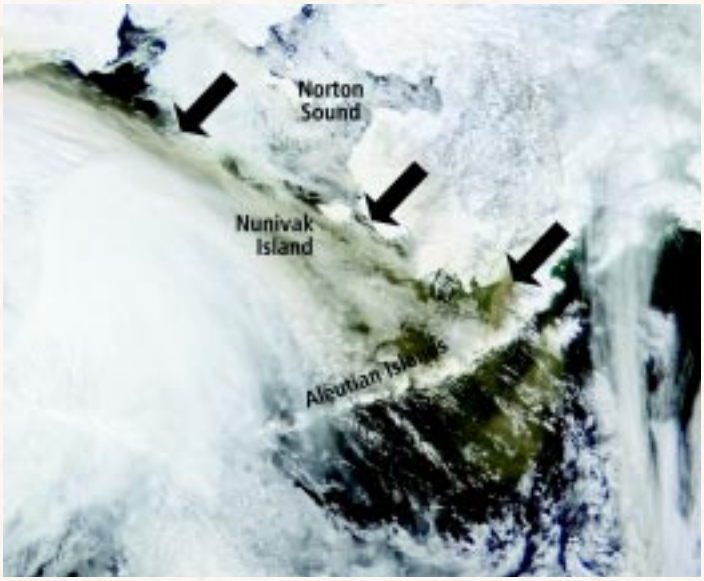

figure 10.3
Asian Dust Storm Over Alaska

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.

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.

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.

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.

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.

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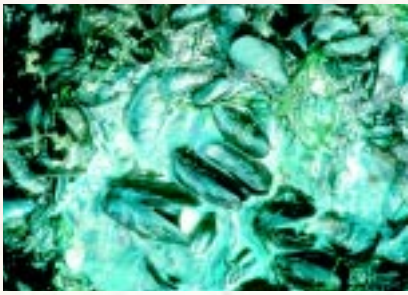

11. Contaminants in Alaska: Is America's Arctic at Risk?

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"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.

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.

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

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

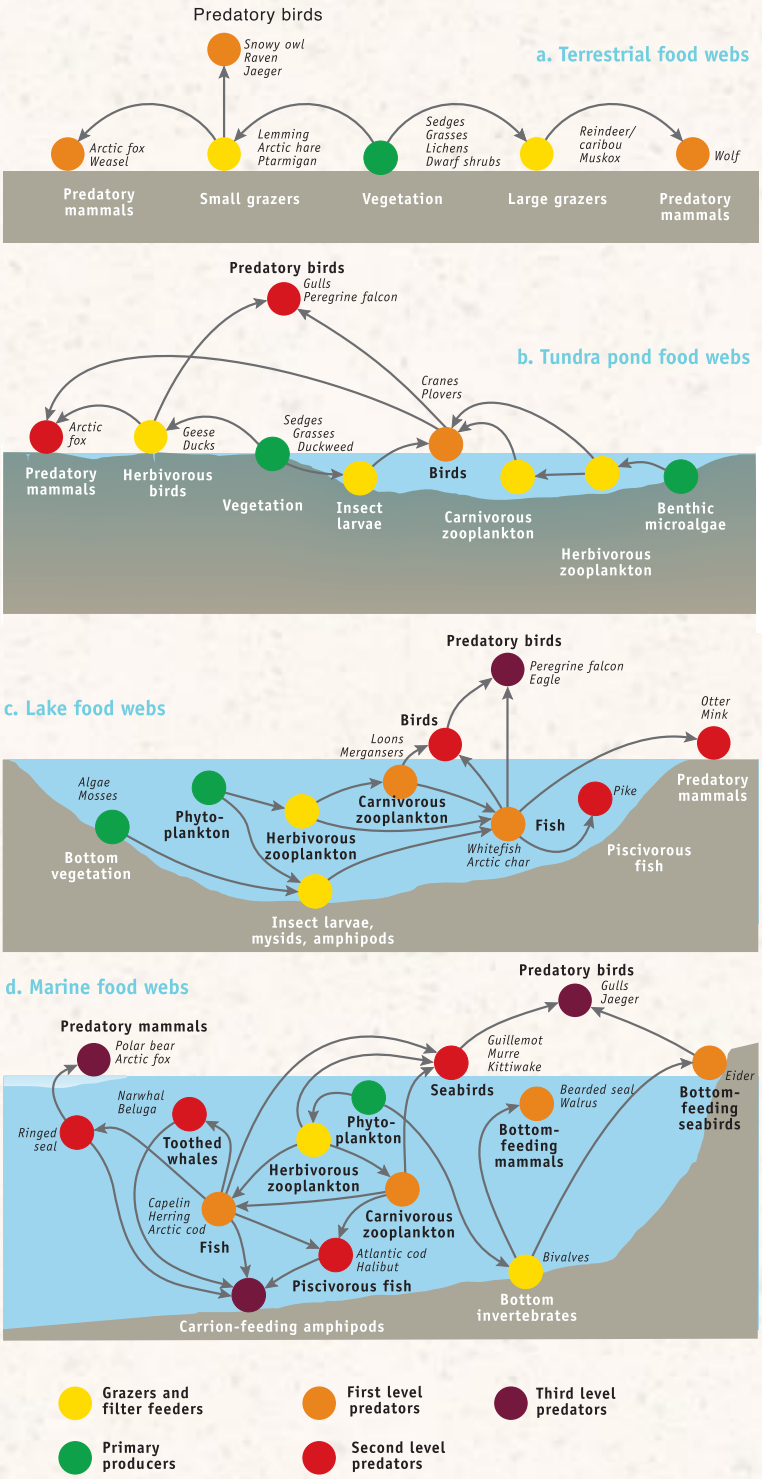

figure 11.2

Examples of Arctic Food Webs

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

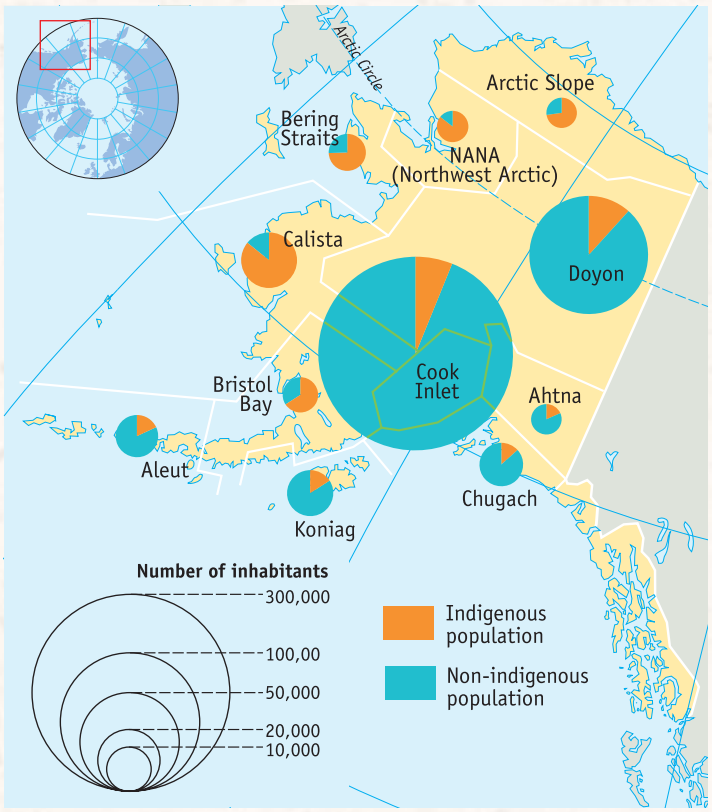

figure 11.3

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

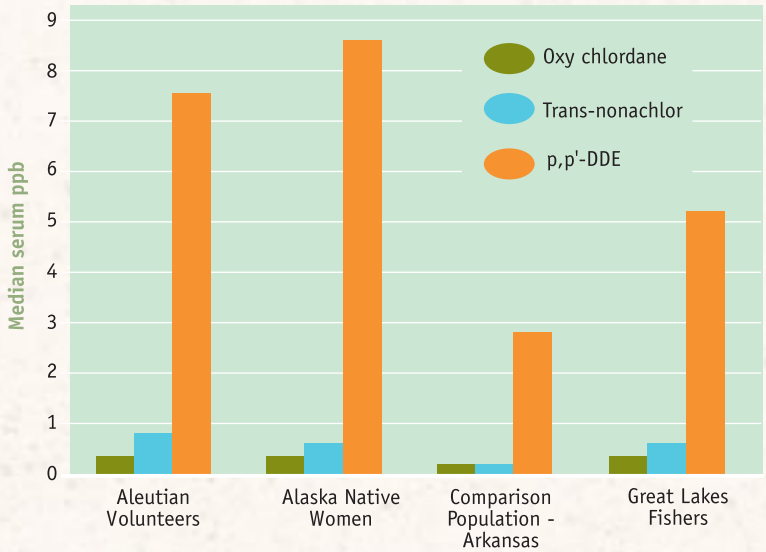

figure 11.4

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

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

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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.

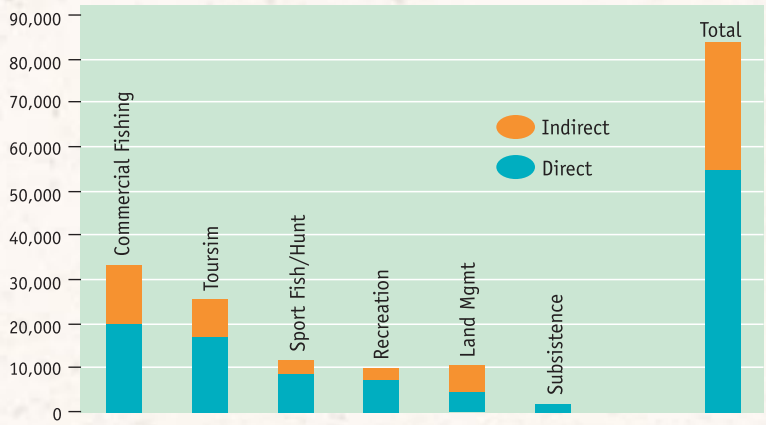

figure 12.1

Direct and Indirect Alaska Jobs in 1998 from Healthy Ecosystems

Credit: Colt. 2001.

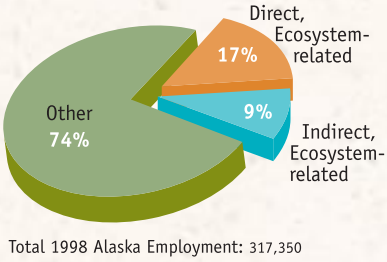

figure 12.2

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 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

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

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.

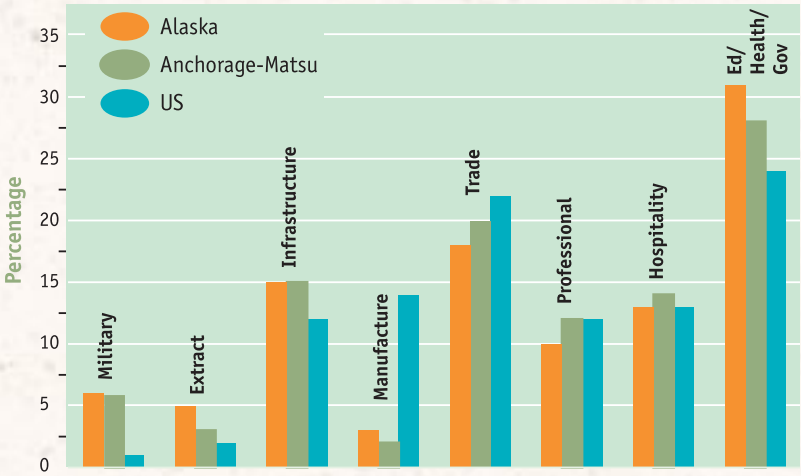

figure 12.3
Year 2000 Shares of Total Employment by Industry Group, Alaska vs. United States

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.

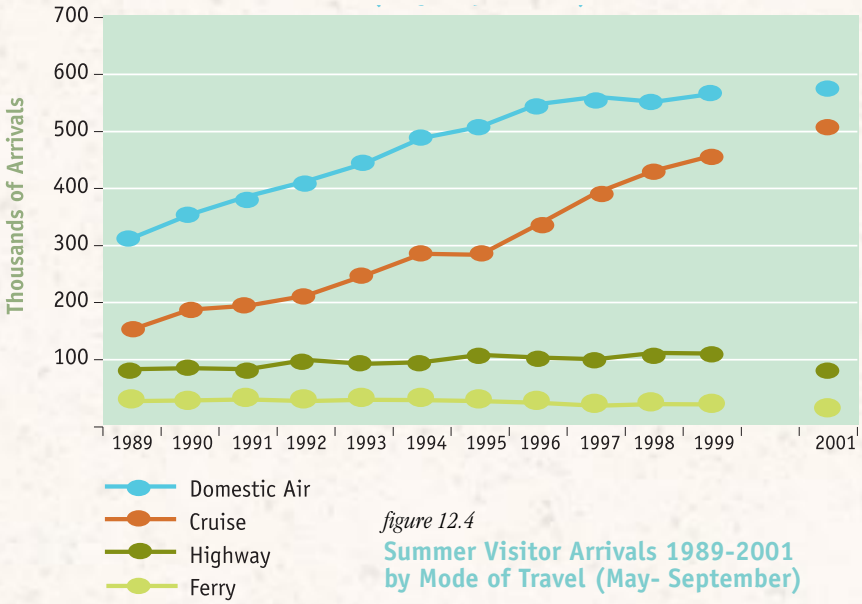

figure 12.4

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.

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