Ecosystem Considerations for 2001

Reviewed by
The Plan Teams for the Groundfish Fisheries
of the Bering Sea, Aleutian Islands, and Gulf of Alaska

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INTRODUCTION

Since 1995, the North Pacific Fishery Management Councils (NPFMC) Groundfish Plan Teams have prepared a separate Ecosystem Considerations section to the annual SAFE report. The intent of the Ecosystems Considerations section is to provide the Council with information about the effects of fishing from an ecosystem perspective, and the effects of environmental change on fish stocks. The effects of fishing on ecosystems have not been incorporated into most stock assessments, in part due to data limitations. Most single species models cannot directly incorporate the breadth and complexity of much of this information. ABC recommendations may or may not reflect discussion regarding ecosystem considerations. This information is useful for effective fishery management and maintaining sustainability of marine ecosystems. The Ecosystems Considerations chapter attempts to bridge this gap by identifying specific ecosystem concerns that should be considered by fishery managers, particularly during the annual process of setting catch limits on groundfish.

Each new Ecosystem Considerations report provides updates and new information to supplement the original report. The original 1995 report presented a compendium of general information on the Bering Sea, Aleutian Island, and Gulf of Alaska ecosystems as well as a general discussion of ecosystem-based management. The 1996 Ecosystem Considerations report provided additional information on biological features of the North Pacific, and highlighted the effects of bycatch and discards on the ecosystem. The 1997 Ecosystems Considerations report provided a review of ecosystem –based management literature and ongoing ecosystem research, and provided supplemental information on seabirds and marine mammals. The 1998 edition provided information on the precautionary approach, essential fish habitat, an overview of the effects of fishing gear on habitat, El Nino, collection of local knowledge, and other ecosystem information. The 1999 report again gave updates on new trends in ecosystem-based management, essential fish habitat, research on effect of fishing gear on seafloor habitat, marine protected areas, seabirds and marine mammals, oceanographic changes in 1997/98, and local knowledge. If you wish to obtain a copy of a previous Ecosystem Considerations Chapter, please contact the Council office (907) 271-2809.

In 1999, a proposal came forward to enhance the Ecosystem Considerations Chapter by including more information on ecosystem indicators of ecosystem status and trends and more ecosystem-based management performance measures. This enhancement, which will take several years to fully realize, will accomplish several goals:

1) Track ecosystem-based management efforts and their efficacy
2) Track changes in the ecosystem that are not easily incorporated into single-species assessments
3) Bring results from ecosystem research efforts to the attention of stock assessment scientists and fishery managers, and
4) Provide a stronger link between ecosystem research and fishery management

The 2000 Ecosystem Considerations document included some new contributions in this regard and will be built upon in future years. It is particularly important that we spend more time in the development of ecosystem-based management indices, which are poorly represented in this year's document. Ecosystem-based management indices should be developed that track performance in meeting the stated ecosystem-based management goals of the NPFMC, which are:

1. Maintain biodiversity consistent with natural evolutionary and ecological processes, including dynamic change and variability.
2. Maintain and restore habitats essential for fish and their prey.
3. Maintain system sustainability and sustainable yields for human consumption and non-extractive uses.
4. Maintain the concept that humans are components of the ecosystem.

ECOSYSTEM STATUS INDICATORS

The main purpose of this section on Ecosystem Status Indicators is to provide new information and updates on the status and trends of ecosystem components. This section has two purposes. The first is to bring the results of ecosystem research efforts to the attention of stock assessment scientists and fishery managers, which will provide stronger links between ecosystem research and fishery management. The second purpose, and perhaps the main one, is to spur new understanding of the connections between ecosystem components by bringing together many diverse research efforts into one document. As we learn more about the role that climate, humans, or both may have on the system, we will be able to derive ecosystem indicators that reflects that new understanding.

Physical Environment

Ocean Surface Currents

Contributed by W. James Ingraham, Jr.

Recently, ocean surface current modeling has been used increasingly to understand the year-by-year movements of larval fish in the eastern Bering Sea and Gulf of Alaska, in order to predict such things as survival and spatial overlap with predators (Wespestad et al., 1999). Everything you always wanted to know about surface currents in the North Pacific ocean and Bering Sea is contained in the test computer model "Ocean Surface CURent Simulator" (OSCURS). With this numerical model just pick your own input: 1) a start-point on the graphic chart; 2) any start-day from January, 1980 to July, 1999; and 3) a duration, the number of days to drift. In about 20 seconds up pops a chart showing the vectors of daily movement strung together in a trajectory giving you the net drift from the start-point.

These experiments can now be run by the general public on the World Wide Web by connecting to the REFM Division's home page, **http://www.refm.noaa.gov,** and clicking on "OSCURS" then linking to either the information article "Getting to Know OSCURS" which describes the model and its uses or clicking "Live Access Server". Alternatively, connect directly to **http://shark.pmel.noaa.gov/kobin-las/GenericLAS**.

Development of OSCURS was motivated by the need in fisheries research for indices that describe variability in ocean surface currents. Historical pattern recognition in the time-series data provides some limited forecasting value. These synthetic data, derived through empirical modeling and calibration, provide insights, which far exceeds their accuracy limitations. OSCURS daily surface current vector fields are computed using empirical functions on a 90 km ocean-wide grid based on daily sea level pressures (1946-1997); long-term-mean geostrophic currents (0/2000 db) were added. The model was tuned to reproduce trajectories of satellite-tracked drifters with shallow drogues from the eastern North Pacific.

Output is in 2 forms; 1) a graphic image chart with trajectory in red or 2) ascii data file of daily latitude-longitudes of water movement. Trajectories replicate satellite drifter movements quite well on time-scales of a few months. You can produce trajectories up to one year long, but their absolute accuracy diminishes with time.

By repeating the runs from the same point year-by-year gives the time history of surface current variability from that location, serving one of the main purposes of OSCURS for comparison with fisheries data. See the information article for a summary of such experiments I have already run.

Your e-mail feedback is welcome at **jim.ingraham@noaa.gov**.

A century (1901-2000) of winter climate variability as it effects surface ocean currents in the Gulf of Alaska is shown by the Papa Trajectory Index (PTI) which is calculated using OSCURS (Figure 1).

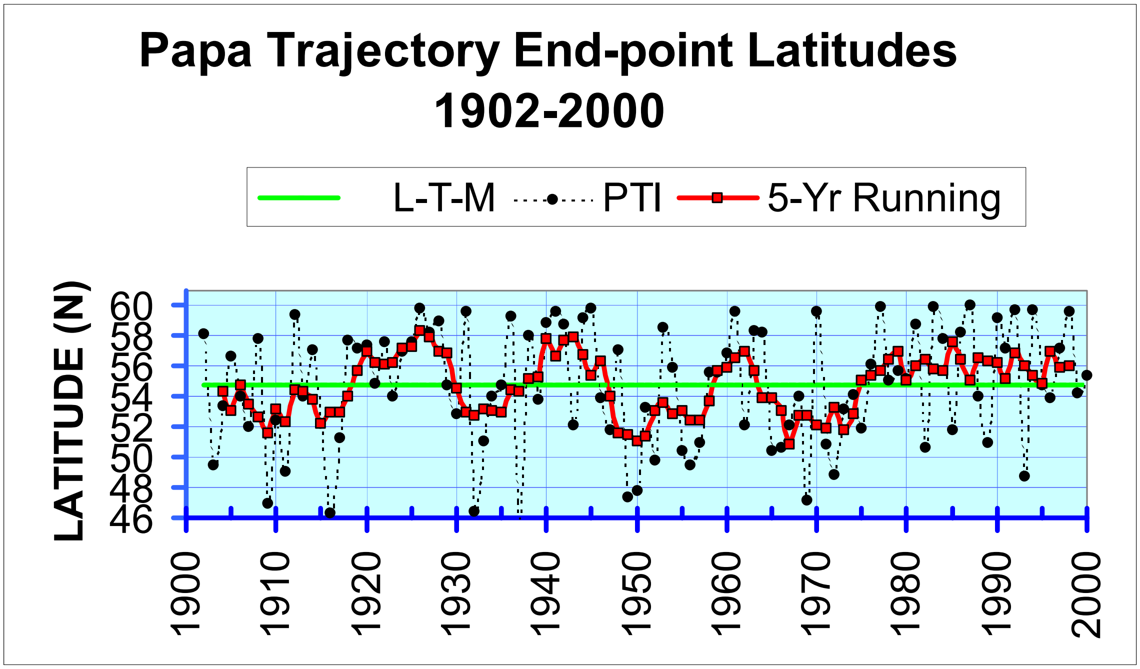


Figure 1. Annual and 5-year running mean values of the PAPA Trajectory Index (PTI) time-series from winter 1902-2000. Large dots are annual values of latitude of the end points of 90-day trajectories started at Station PAPA (50º N, 145º W) each December 1, 1901-1999. The straight line at about 55º N is the mean latitude of the series. The oscillating thick line connecting the squares is the 5-year running means.

Sea surface drift trajectories with start-points from Ocean Weather Station PAPA (50° N, 145° W) were simulated using the OSCURS model for each winter (Dec. 1- Feb 28), 1901-2000. To reveal decadal fluctuations in the oceanic current structure, the trajectories were smoothed in time with a 5-year running boxcar filter. Values above the mean indicate winters with anomalous northward surface water circulation in the eastern Gulf of Alaska; values below the mean indicate winters with anomalous southward surface water circulation. The 5-year running mean shows four complete oscillations but the time intervals were not constant; 28 years (1902-1930), 17 years (1930-1947), 17 years (1947-1964), and 33 years and continuing (1964-1997). The drift from Ocean Weather Station Papa has fluctuated between north and south modes about every 23 years over the last century and the shift from north to south modes appears to be overdue or at least the longest oscillation this century. The time-series has been updated with winter 2000 calculations.

Ecosystem Indicators and Trends Used by FOCI

Contributed by FOCI

NORTH PACIFIC REGION

Recent indicators suggest that the climate of the North Pacific region is changing. Scientists think this may have started as early as 1989 when the Arctic Oscillation (AO) changed phase. However, the most significant change is the cooling of coastal waters of the Pacific Northwest and Alaska since 1997-1998 when the Pacific Decadal Oscillation (PDO, see below) probably switched phase. With coastal cooling have come shifts in marine abundance, e.g., West Coast salmon that were suffering declines in abundance early in the 1990s appear to be recovering, while Alaska salmon abundance is waning. The following sections discuss some of FOCI's climate and pollock abundance indicators in light of climate change.

Interannual variability of atmospheric forcing

The winter magnitude and position of the Aleutian Low explain much of the interannual variability of atmospheric forcing and physical oceanographic response of the North Pacific Ocean and Bering Sea. The Aleutian Low is a statistical feature formed by averaging North Pacific sea level pressure for long periods. Because this is a region of frequent storms, the averaged pressure pattern describes a closed-cell, low-pressure area over the North Pacific, much like an individual storm on a weather map. The amplitude and location of the Aleutian Low have a strong bearing on weather and ocean conditions in the region and are correlated with other climate indices such as ENSO (El Niño Southern Oscillation), AO, and PDO. A strong Aleutian Low (low pressure) is accompanied by strong winds that drive warm water from the central Pacific into the coastal regions of Alaska and the Pacific Northwest. Conversely, when the Aleutian Low is weak (higher pressure), winds are weak and coastal sea surface temperatures cool.

A measure of the strength of the Aleutian Low is the North Pacific Index (NPI, Fig. 1). It is the sea level pressure over the North Pacific averaged for January through February. The index contains strong decadal variability. For example, there is a shift from high to low values of the index in 1925, a return to high values in 1946, and a shift back to low in 1977. If the data are smoothed, secondary shifts appear (one and a half secondary shifts for each major shift) such as in 1958 and 1989. In the past two years, NPI values have been higher, indicating a weaker Aleutian Low. Consequently, wind-driven advection of warm water from the central North Pacific into the coastal regions of Alaska and the U.S. Pacific Northwest has diminished, and local processes play a larger role in determining ocean temperature near the coast.

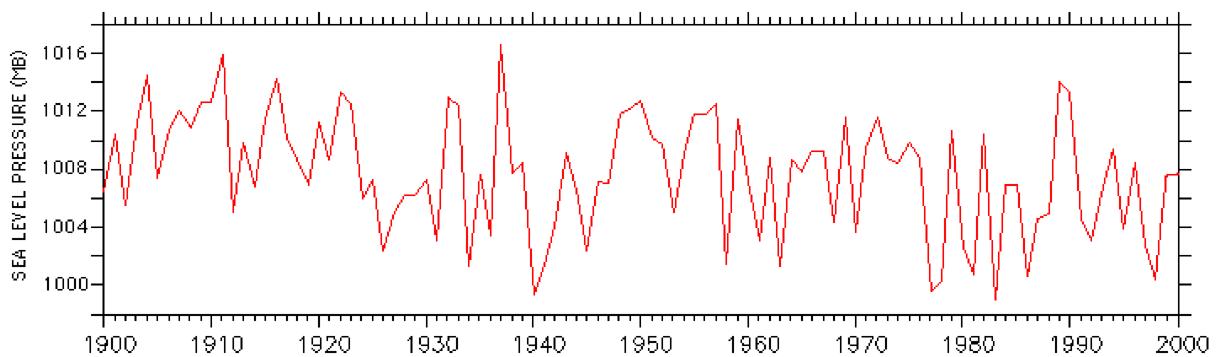


Figure 1. The North Pacific Index (NPI) from 1900 through 2000 is the sea-level pressure averaged for January through February.

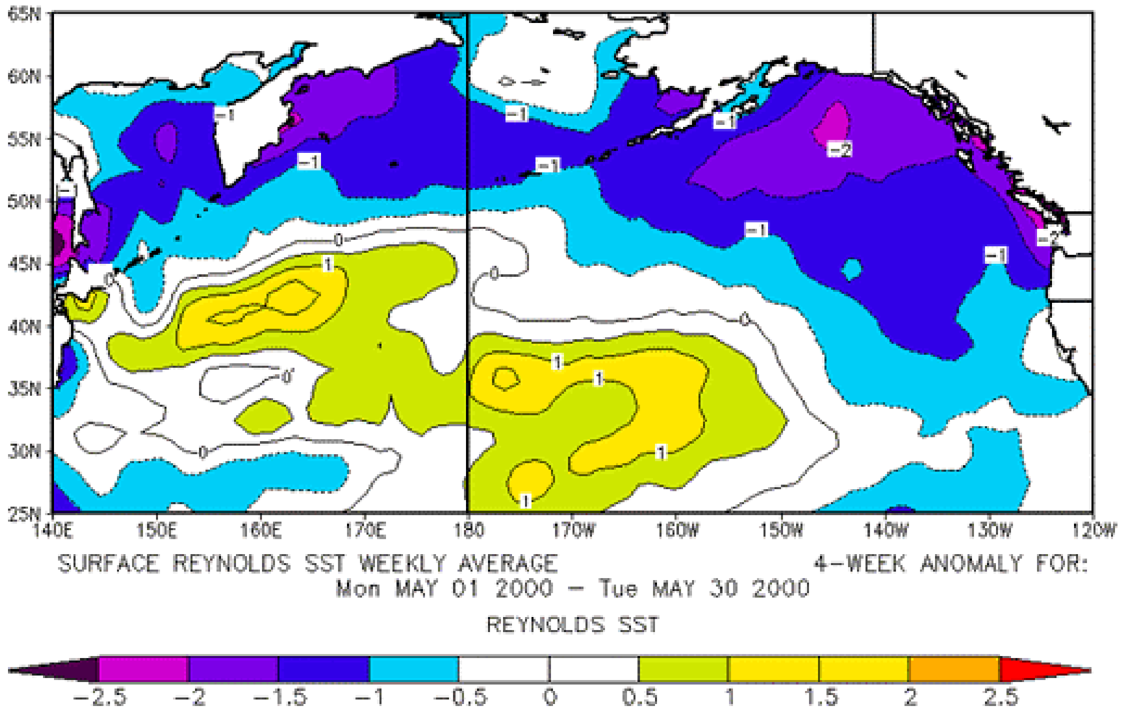


Figure 2. The pattern of sea surface temperature anomalies for May 2000 shows a return to cool coastal waters with warmer central Pacific waters.

Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) Index (Fig. 3) is defined as the leading principal component of North Pacific monthly sea surface temperature variability. The PDO is a long-lived, El Niño-like pattern of North Pacific Ocean climate variability. Two main characteristics distinguish PDO from ENSO. First, 20th century PDO "events" persisted for 20-to-30 years, while typical ENSO events persisted for 6 to 18 months. 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 ENSO. Several independent studies find evidence for just two full PDO cycles in the past century: "cool" PDO regimes prevailed from 1890-1924 and again from 1947-1976, while "warm" PDO regimes dominated from 1925-1946 and from 1977 through (at least) the mid-1990s. Some researchers have identified a cold phase

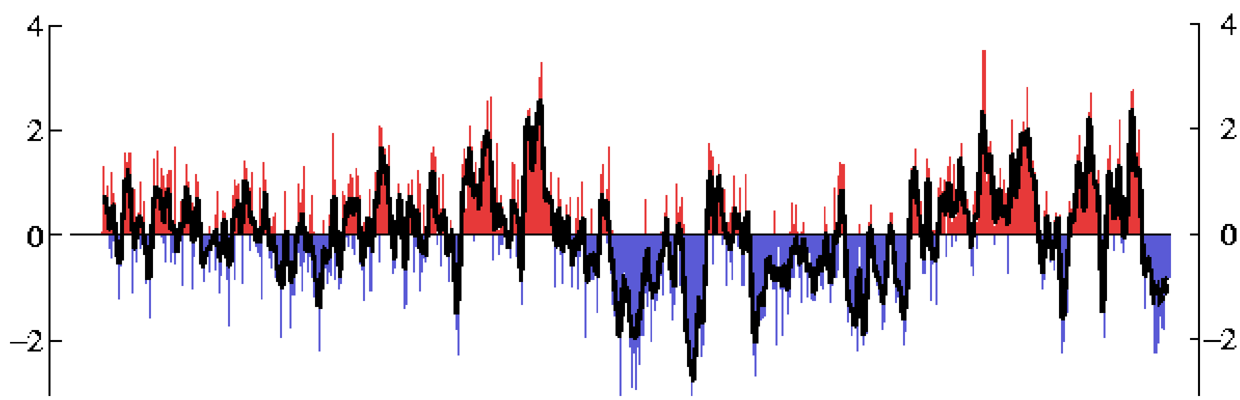


Figure 3. Monthly and smoothed (black line) values of the Pacific Decadal Oscillation (PDO) index, 1900-2000.

starting in 1989, others point to 1997. Beginning in early 2000, it became apparent that a shift had occurred from changes in ocean temperature (Fig. 2) and distribution of salmon and other marine species. A weaker Aleutian Low (Fig. 1) certainly is associated with this change. Major changes in northeast Pacific marine ecosystems have been correlated with phase changes in the PDO. Warm eras bring enhanced coastal ocean biological productivity in Alaska and inhibited productivity off the west coast of the contiguous United States, while cold PDO eras produce the opposite north-south pattern of marine ecosystem productivity. Causes for the PDO are not currently known. Even in the absence of a theoretical understanding, PDO climate information improves season-to-season and year-to-year climate forecasts for North America because of its strong tendency for multi-season and multi-year persistence. From a societal perspective, recognition of PDO is important because it shows that "normal" climate conditions can vary over time periods comparable to a human's lifetime.

WESTERN GULF OF ALASKA

Seasonal rainfall at Kodiak

Patches of larval walleye pollock have been located within mesoscale eddies. For early larvae, presence within an eddy may be conducive to survival. Eddies in Shelikof Strait are caused by baroclinic instabilities in the Alaska Coastal Current (ACC). The baroclinity of this current fluctuates with the amount of fresh water discharged along the coast. A time series of Kodiak rainfall (inches) is a proxy for baroclinity and thus an index for survival success of species such as walleye pollock that benefit from spending their earliest stages in eddies. Greater than average late winter (January, February, March) precipitation produces a greater snow pack for spring and summer freshwater discharge into the ACC. Similarly, greater than average spring and early summer rainfall also favor increased baroclinity after spawning. Conversely, decreased rainfall is likely detrimental to pollock survival. A pollock survival index based on precipitation is shown in Figure 4. Although there is large interannual variability, a trend

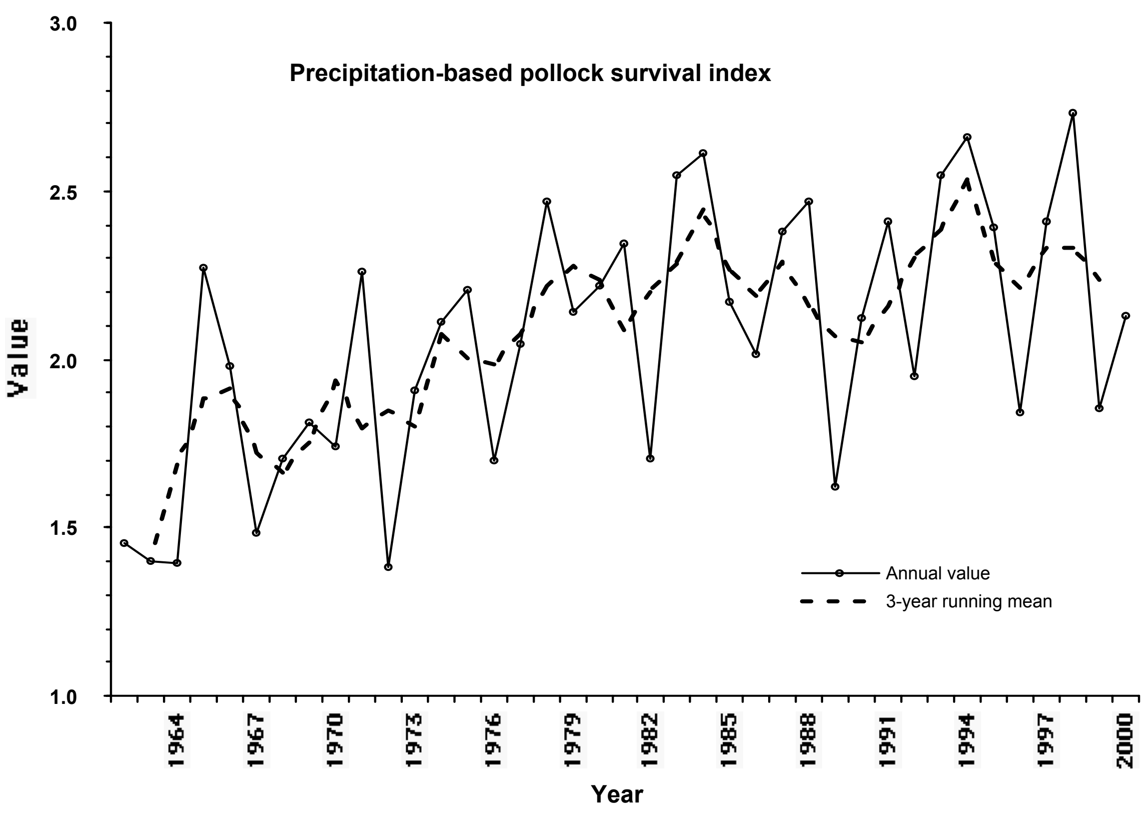


Figure 4. Index of pollock survival potential based on measured precipitation at Kodiak from 1962 through 2000. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

toward increased survival potential is apparent from 1962 (the start of the time series) until the mid-1980s. Over the last 15 years, the survival potential has been more level. Are the lower values of the last two years commensurate with a phase change of the PDO?

Wind mixing south of Shelikof Strait

Another survival index relates to first-feeding pollock larvae, a key survival stage when baby fish have exhausted their yolk sacs and need to capture food. Possibly because increased turbulence interferes with larvae's ability to feed, strong wind mixing events during the first-feeding period are detrimental to survival of pollock larvae. A time series of wind mixing energy (W m^{-2}) at [57°N, 156°W] near the southern end of Shelikof Strait is the basis for a survival index (Fig. 5) wherein stronger than average mixing before spawning and weaker than average mixing after spawning favor survival of pollock. As with precipitation at Kodiak, there is wide interannual variability with a less noticeable and shorter trend to increasing survival potential from 1962 to the late 1970s. Recent survival potential has been high. Monthly averaged wind mixing in Shelikof Strait has been below the 30-year (1962-1991) mean for the last three January through June periods (1998-2000). This may be further evidence that the North Pacific climate regime has shifted in the past few years.

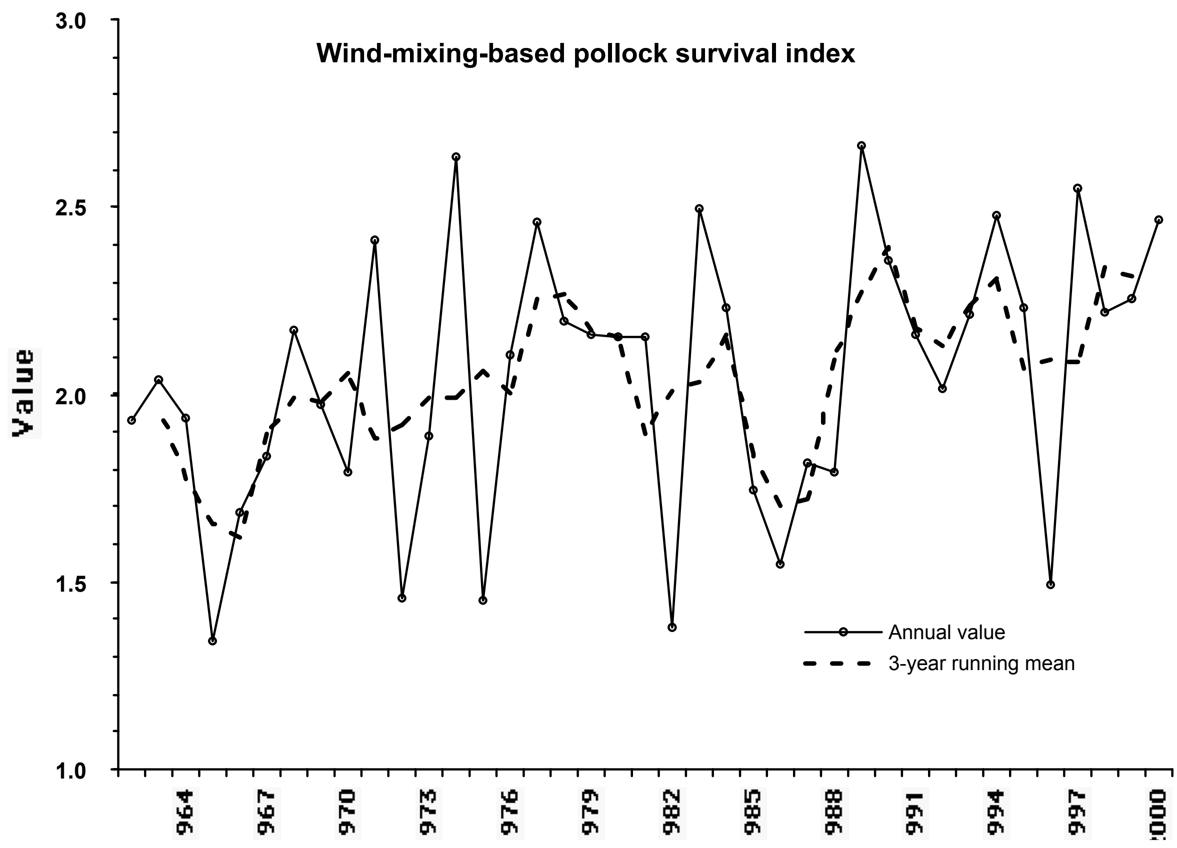


Figure 5. Index of pollock survival potential based on estimated wind mixing energy at a location south of Shelikof Strait from 1962 through 2000. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

EASTERN BERING SEA

Sea ice extent and timing

The extent and timing of seasonal sea ice over the Bering Sea shelf plays an important role, if not the determining role, in the timing of the spring bloom and modifies the temperature and salinity of the water column. Sea ice is formed in polynyas and advected southward across the shelf. The leading edge continues to melt as it encounters above freezing waters. The ice pack acts as a conveyor belt with more saline waters occurring as a result of brine rejection in the polynyas and freshening occurring at the leading edge as the ice melts. Over the southern shelf, the timing of the spring bloom is directly related to the presence of ice. If ice is present in mid-March or later, a phytoplankton bloom will be triggered that consumes the available nutrients. If ice is not present during this time, the bloom occurs later, typically during May, after the water column has stratified.

The presence of ice will cool the water column to -1.7°C. Usually spring heating results in a warm upper mixed layer that caps the water column. This insulates the bottom water, and the cold water (<2°C) will persist through the summer as the "cold pool." Fish, particularly pollock, appear to avoid the very cold temperatures of the cold pool. In addition the cold temperatures delay the maturing of fish eggs and hence affect their survival.

Figure 6 shows the presence of ice over the southeastern shelf between 57° and 58° N during the last 28 years. The figure is divided into three panels, each representative of a climate regime: 1972-1976 ice conditions occurred during a cold PDO phase, 1977-1989 during a warm PDO and AO phase, and the years hence which seem to be in an intermediate regime reflecting a warm PDO and a cold AO. The possible change in the PDO that may have occurred about 1997 is reflected in the extreme ice conditions observed in 2000. During the first regime ice was common over this part of the shelf. In the warm period thereafter, ice was less prevalent. Since then, ice has been more persistent but not as extensive as it was prior to 1977. Recently, 2000 had the most extensive seasonal sea ice pack since 1976. There appears to be a slight reduction in ice cover during El Niño years, but the relationship is weak.

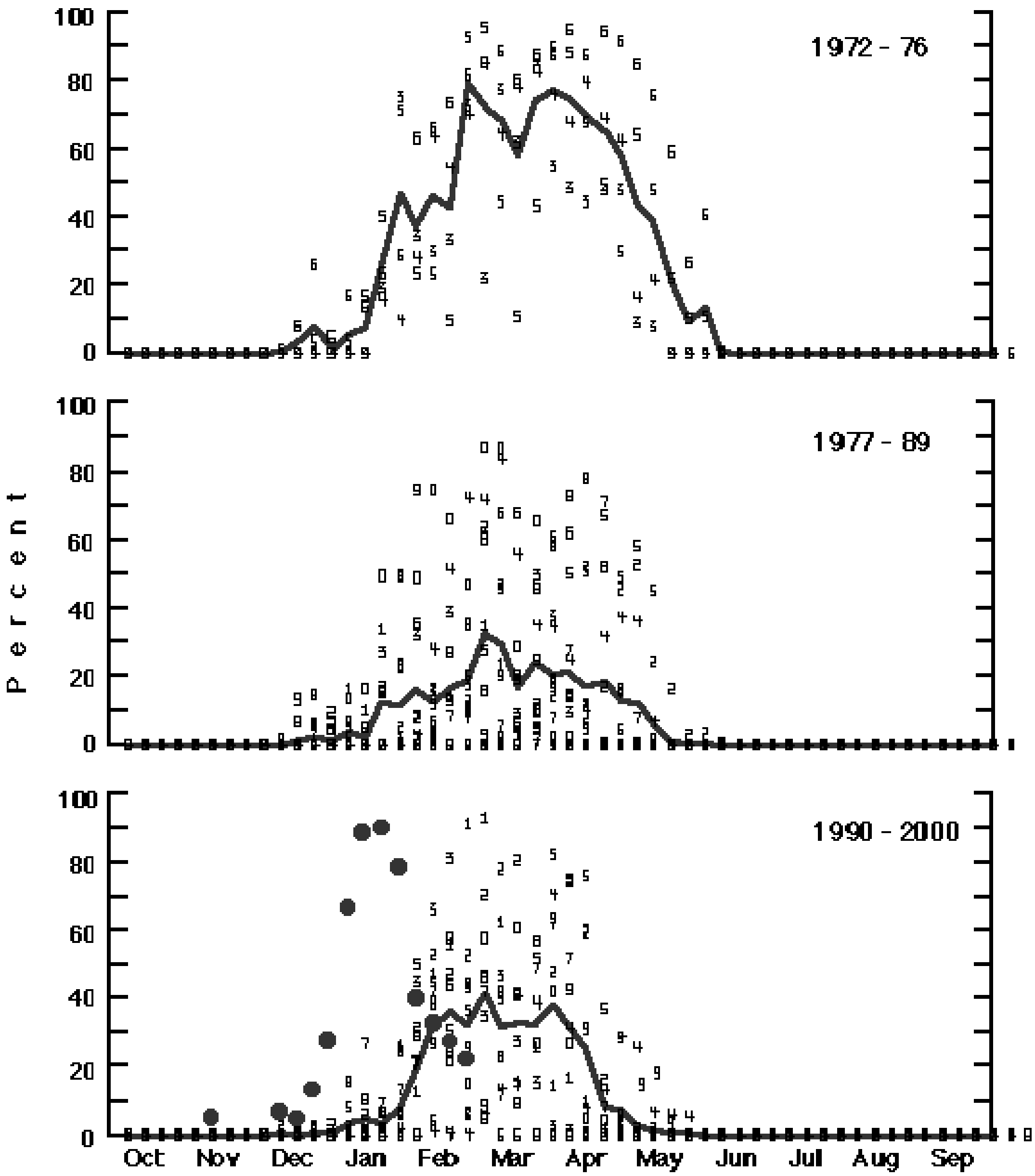


Figure 6. Percent ice concentration over the southeastern Bering Sea shelf between 57° and 58° N from 1972 through 2000. The black dots in the lowest panel are for 2000.

Mooring 2: The cycle in the middle shelf

The cycle in water column temperatures is similar each year. In January, the water column is well mixed. This condition persists until buoyancy is introduced to the water column either through ice melt or solar heating. The very cold temperatures (shown in black in Fig. 7) that occurred in 1995, 1997, 1998 and 1999, resulted from the arrival and melting of ice. Shelf temperature during 1999 was the coldest, well below 1995 and 1996, and approaching the cold temperatures of the negative PDO phase of the early 1970s. During 1996, ice was present for only a short time in February, however no mooring was in place. A phytoplankton bloom occurs with the arrival of the ice pack in March and April. If ice is not present during this period, the spring bloom does not occur until May or June, as in 1996 and 1998. Generally, stratification develops during April. The water column exhibits a well defined two-layer structure throughout the summer consisting of a 15 to 25-m wind-mixed layer and a 35 to 40-m tidally mixed bottom layer (the cold pool if temperatures are sufficiently low). Deepening of the mixed layer by strong winds and heat loss begins in August, and by early November the water column is again well mixed.

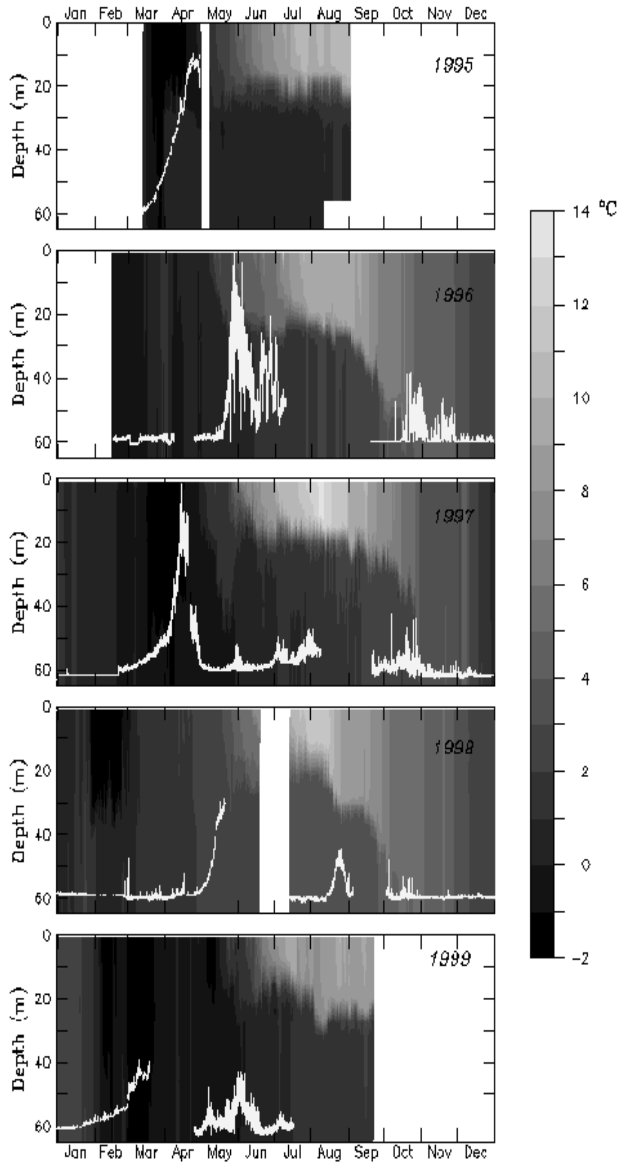


Figure 7. Ocean temperature (°C) as a function of depth (m) and time (month of year) and fluorescence as a function of time measured at mooring site 2 during 1995 through 1999.

The depth of the upper mixed layer and the strength of the thermocline contribute to the amount of nutrients available for primary production. A deeper upper mixed layer makes available a greater amount of nutrients. In addition, a weak thermocline (more common with a deeper upper mixed layer) permits more nutrients to be “leaked” into the upper layer photic zone and thus permits prolonged production. The temperature of the upper layer influences the type of phytoplankton that will flourish. For instance, warmer sea surface temperatures (>11°C) during 1997 and 1998 may have supported the coccolithophorid bloom.

Timing of the last spring storm

One of the striking features of the atmosphere during 1997 and 1998 was a change in the timing of the last storm and strength of summer mixing over the eastern Bering Sea. This ecosystem is particularly sensitive to storms during May. The spring bloom strips nutrients from the upper layer, and the stability of the water column isolates nutrients in the lower layer. Thus mixing and deepening of the upper mixed layer by storms in mid to late May provide important nutrients for continuation of blooms into summer. June and July storms are less effective mixers because they are weaker and the thermocline has strengthened. May storms also lessen the density difference between the two layers (entraining denser water into the upper layer), thus permitting subsequent minor mixing events to supply nutrients into the photic zone. From 1986 to 1996, the weather during May was particularly calm; during May 1999, winds were again light. By contrast, May of 1997 and 1998 were characterized by strong individual wind events (Fig. 8). These storms presented a pathway for greater nutrient supply, more prolonged primary production, and weaker stability of the water column than observed between 1986 and 1996 and in 1999. In addition to stronger winds in May, the summers of 1997 and 1998 had the weakest mean wind speed cubed (a measure of mixing energy) since at least 1955. This allowed for a shallow mixed layer and thus higher sea surface temperatures. A pattern of late spring storms and weak summer winds could change

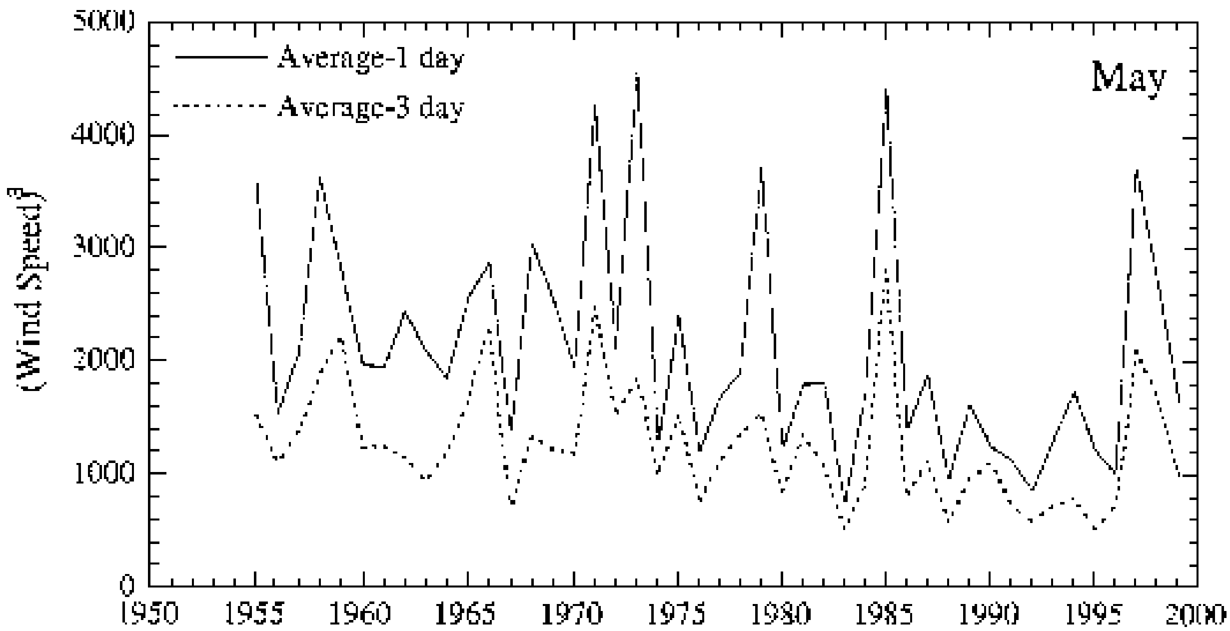


Figure 8. Cube of wind speed (proportional to wind mixing energy) measured at St. Paul, Alaska. The solid line is the daily average; the dashed line is the 3-day average.

the phytoplankton community. If production is prolonged into summer, the total productivity of the shelf could be enhanced, thereby affecting higher trophic levels.

Cross shelf advection

Each spring and summer over the Bering Sea shelf, approximately half the nutrients are consumed. These nutrients apparently are replenished during winter and early spring. Cross shelf advection moves nutrient-rich basin water onto the shelf. A reduction of onshelf flow will reduce the available nutrients and thus productivity of the shelf. Understanding and monitoring the mechanisms that induce cross shelf flow are critical to management of the Bering Sea's living resources.

During the last ten years, FOCI released more than 100 satellite-tracked drift buoys in the Bering Sea. Prior to 1996, drifters deployed in the southeastern corner of the Bering Sea typically revealed persistent northwestward flow along the 100-m isobath, with cross shelf flow occurring intermittently. In 1997, 1999 and 2000, flow along the 100-m isobath was weak or nonexistent, and there were no occurrences of onshelf flow. Flow patterns in 1998 are less well known as no drifters were deployed that year. Indices of onshelf flow and strength of the 100-m-isobath flow are derived from trajectories of the satellite-tracked drifters. Such indices are important in determining changes in flow patterns, particularly if there has been a climate regime shift as some scientists believe occurred in 1997.

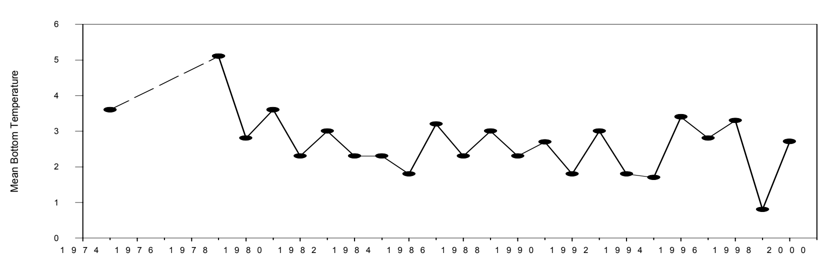
Summer bottom and surface temperatures – Eastern Bering Sea

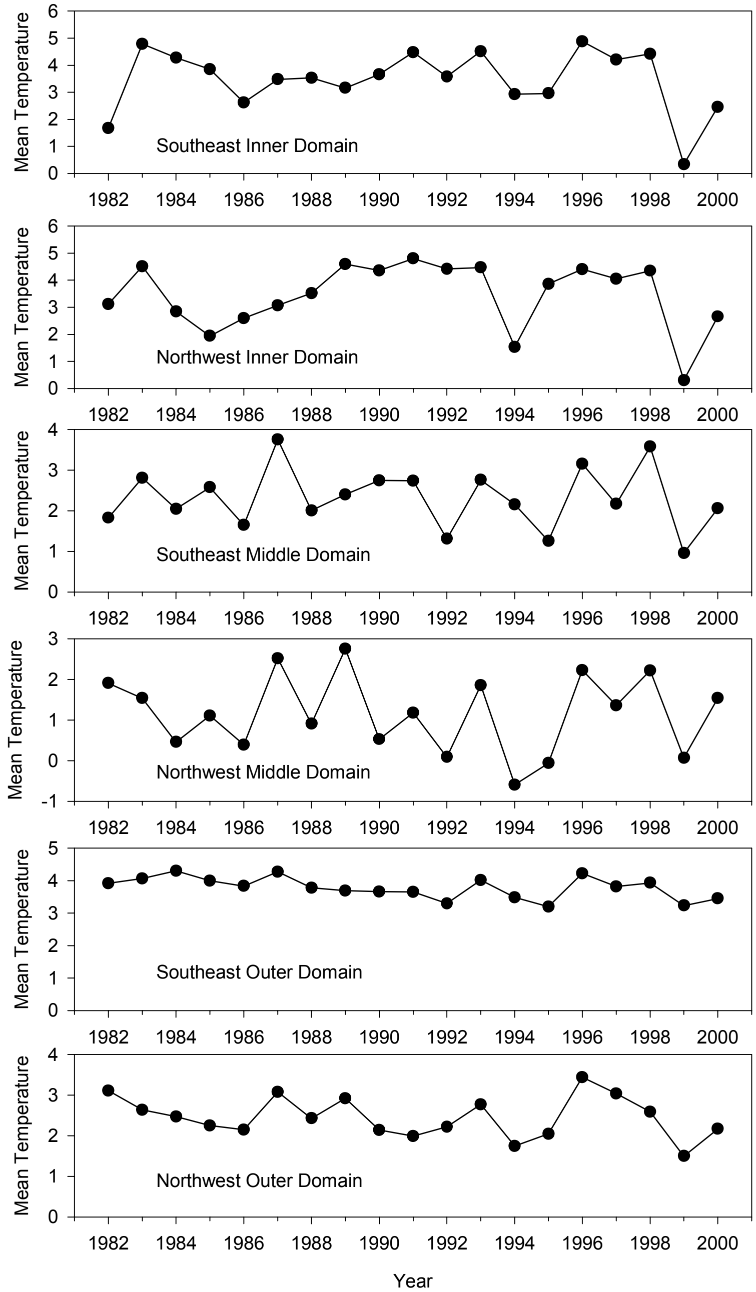
Contributed by Gary Walters

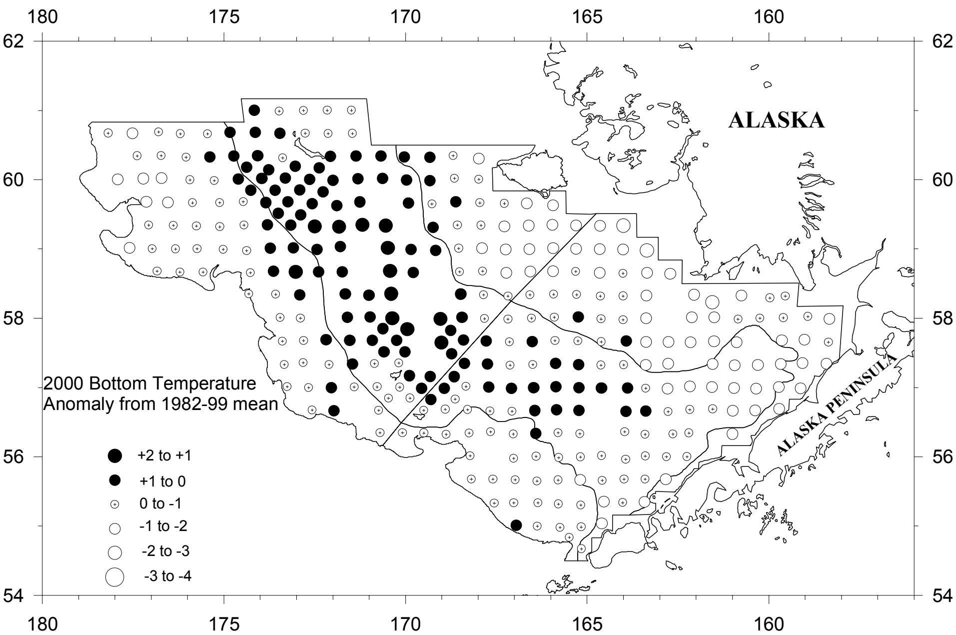
The annual AFSC bottom trawl surveys are traditionally conducted in a time sequence from inner Bristol Bay to the continental shelf edge over a period from early June to approximately 1 August. Therefore overall mean temperatures are not synoptic shelfwide but individual stations are sampled within a few days of the same date each year and represent comparative synopses. However, due to charter vessel time contraints, the survey was started for the second consecutive year on 23 May, about 10-12 days early.

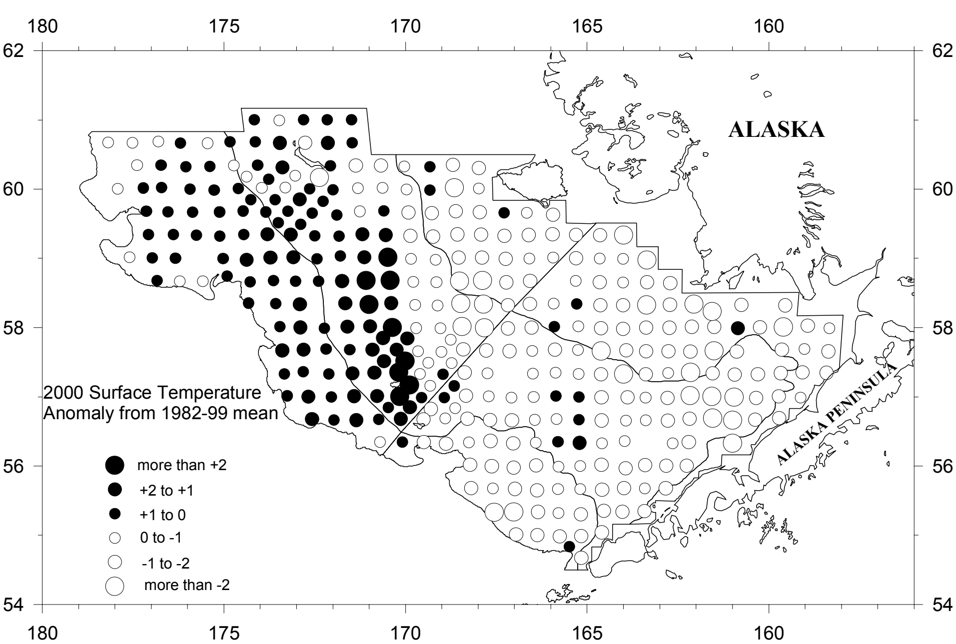
In contrast to the record cold year of 1999, the overall mean bottom temperature for 2000 was very near the long term mean from 1982-1999 (1999, 0.81^{o}C; 2000, 2.17^{o}C; long term mean, 2.43^{o}C). However, the per station anomalies had an interesting set of patterns. Bottom temperatures were slightly colder than the long term means in shallow waters less than 50m and on the outer shelf in waters greater than 100m. In the mid-shelf area where the cold-pool resides, the bottom temperatures were slightly warmer than the long term means. Surface temperatures were colder than the long term means out to a longitude of near -170^{o}W and then warmer as the survey proceeded westward to the shelf edge.

In 1999 the colder temperatures appeared to force the demersal population of walleye pollock (*Theragra chalcogramma*) onto the outer shelf. The lower contrast of temperatures across the shelf in 2000 apparently resulted in a much wider distribution with highest densities on the middle shelf. As seen previously, flatfish distributions change relatively little from year to year no matter what the temperature regime. This suggests that bottom type and food availability are more important to the flatfish.




Mean Temperature
Southeast Inner Domain
Northwest Inner Domain
Southeast Middle Domain
Northwest Middle Domain
Southeast Outer Domain
Northwest Outer Domain
Year


ALASKA
ALASKA PENINSULA
2000 Bottom Temperature
Anomaly from 1982-99 mean
+2 to +1
+1 to 0
0 to -1
-1 to -2
-2 to -3
-3 to -4

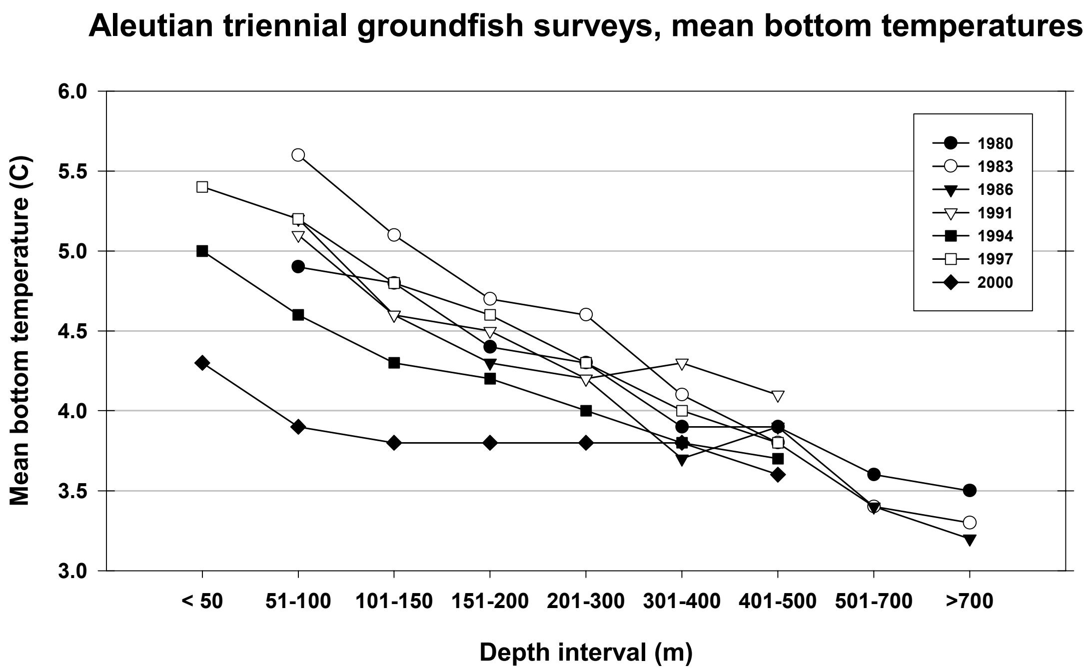

ALASKA
ALASKA PENINSULA
2000 Surface Temperature
Anomaly from 1982-99 mean
more than +2
+2 to +1
+1 to 0
0 to -1
-1 to -2
more than -2

Summer bottom temperatures – Aleutian Archipelago

Contributed by Harold Zenger

Groundfish assessment surveys conducted in the Aleutian region have occurred on a more or less triennial basis since 1980. Survey periods have ranged from early May to late September, with no fixed sampling pattern or time schedule. Generally, sampling progresses from east to west. Bottom temperatures have been routinely collected in conjunction with bottom trawl hauls. Of the seven survey years cited in the figure below, all except 1991 had temperature samples from throughout the entire Aleutian region.

Tidal currents that flow across the relatively narrow Aleutian shelf and upper slope are often very strong, as vast amounts of water are exchanged between the north Pacific Ocean and the Bering Sea. Bottom temperatures are most influenced by those large water masses



In the Aleutian region, the year 2000 was the coldest year yet detected during AFSC groundfish surveys. The warmest years tend to be lagged about a year behind El Niño events. The coldest years thus far detected have occurred within the same decade, six years apart. Generally, temperatures at shallower depths vary more than at depths deeper than 300 m where temperatures are within a range of about one-half degree or less. Perhaps the year 2000 temperatures are not as anomalous as they appear, but many individual fish were visibly thinner than during other surveys. Unfortunately, we have no data to compare for the intervening years. Aleutian groundfish assessment surveys are scheduled to occur biennially in the future.

Habitat

Indices of contaminant levels in sediments, groundfish and their prey.

Contributed by Jawed Hameedi, NOAA

Scientific information on environmental contamination in the northern North Pacific Ocean, inclusive of Gulf of Alaska and Bering Sea, can be derived from data, reports and information products of multi-disciplinary environmental research, assessment and monitoring programs, such as the Outer Continental Shelf Environmental Assessment Program (OCSEAP), the Environmental Studies Program (ESP) of the Minerals Management Service, a program of long-term ecological research of ecosystems of the Bering and Chukchi seas and the Pacific Ocean called BERPAC, and NOAA's National Status and Trends (NS&T) Program. Additional incidental data on contaminant levels in the air, surface waters and biota can be obtained from results of multi-year cruises in the Indian and North Pacific Ocean during the period 1975 to 1982 (Tanabe and Tatsukawa, 1980; Kawano, et al., 1988). The recently published "Arctic Monitoring and Assessment Program (AMAP) Assessment Report: Arctic Pollution Issues" and its separate summary report entitled "Arctic Pollution Issues: A State of the Arctic Environmental Report" provide a limited amount of data from the eastern Bering Sea (AMAP, 1997; AMAP, 1998).

The following summary is based on data from NOAA's National Status and Trends (NS&T) Program. The program, initiated in 1984, directly responds to NOAA's environmental stewardship portfolio relating to "Sustainable Healthy Coasts." The program's objectives are to:

1) Assess the status and trends of environmental quality in relation to levels and effects of contamination and other sources of environmental degradation in US marine, estuarine and Great Lake environments;
2) Develop diagnostic and predictive capabilities to determine effects of contaminants and other sources of environmental degradation on coastal and marine resources and human uses of thos resources; and
3) Develop and disseminate scientifically sound data, information and services to support effective coastal management and decision making.

The program consists of a number of elements, for example the Mussel Watch Project. Not all of the program elements have been applied in the North Pacific or US Arctic, such as sediment toxicity assessment, evaluation of biomarkers, and benthic community changes in relation to regional contamination. Studies are underway or planned to assess historic trends in coastal contamination in coastal Beaufort Sea and to set up permanent coastal environmental monitoring sites in the region. Program data, a list of publications, and other information, including essays on NOAA's on-line State of the Coast Report can be found on the Internet at: http://ccmaserver.nos.noaa.gov/NSandT/New_NSandT.html.

<u>Mussel Watch Project</u>

This project determines concentrations of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyl (PCB) congeners, several pesticides, butyltins, and certain toxic elements in sediment and mollusk -- typically mussels or oysters -- samples from U.S. coastal waters (Table 1). The sampling sites are generally 10 to 100 km apart and are selected to avoid locally contaminated areas or "hot spots." In Alaska, the Mussel Watch sites are located only in the Gulf of Alaska, including Cook Inlet (Table 2). Data and results of chemical analyses from these sites have recently been summarized (Cantillo, et al., 1999). The contaminant concentrations are generally low, except for some metals. In a few instances, metal concentrations approach or exceed the 85th percentile values of the nationwide database: chromium at Homer Spit and Siwash Bay; nickel at Sheep Bay, Siwash Bay, and Mineral Creek Flats; and selenium at all sites in Prince William Sound and southeastern Alaska. Selenium concentrations in mussel samples from Cook Inlet and western Gulf of Alaska were at or below the nationwide median value, 2.8 (g/g dry weight. The concentration of organic contaminants did not exceed the 85th percentile values of the nationwide database.

An analysis of hexachlorocyclohexane (HCH) isomers, including lindane, levels in bivalve tissues, was recently completed as part of NOAA's National Status and Trends Program (Johnson 2000). The sampling sites ranged in latitude from 18 N (Puerto Rico) to 61 N (Alaska). It was shown that 10 of the 11 Alaskan sites exceeded the 85th percentile of the alpha-HCH concentration, although the correlation coefficients between the latitude and HCH levels (for both the alpha- and gamma isomers) were weak. The correlation improved when sites near high population centers were excluded from analysis.

Benthic Surveillance Project

From 1984 through 1993, this project measured the levels of contaminants and their metabolites in bottom-dwelling fish and in sediment samples at selected urban and non-urban sites in U.S. coastal waters. The project also included measurements of pathological conditions, such as incidence of neoplasia and tumors, and physiological responses to contaminant exposure, i.e., induction of certain enzymes. Nearly 120 sites were sampled in all. Thirteen (13) sites were located in Alaska, extending from Ketchikan in southeastern Alaska to Prudhoe Bay on the North Slope. The Benthic Surveillance Project data have been compiled and reported (Harmon, Gottholm and Robertson, 1998). The project data have also been extensively published in the scientific literature, most recently in special issue of the journal Marine Pollution Bulletin (Meador, et al., 1998; Brown, et al., 1998). The project demonstrated the utility of a regionally extensive database and showed that concentration of PAHs and chlorinated hydrocarbons in sediment generally correlated well with the levels of these compounds or their metabolites in bottom-dwelling fish. It also indicated that the sequence of events leading to necrotic and pre-neoplastic lesion following exposure to PAHs might occur at concentrations below sediment quality criteria used in different states or regions. However, data from sites in Alaska are extremely limited. This fact together with an inherently high variability in biological responses to contaminant exposure precludes any conclusions pertaining to the northern North Pacific and Bering Sea fauna.

Arctic Regional Assessment

In 1993, CCMA initiated a regional study in the United States Arctic responding to public concerns about widespread dumping of radioactive wastes, reactors and other vessels in the Arctic seas by the former Soviet Union. It was also recognized that there was a general lack of information on the levels and likely sources of radionuclides and contaminants in the region. The radioactivity component of the study was performed as a collaborative effort with the Office of Naval Research, United States Navy, as part of its Arctic Nuclear Waste Assessment Program. The study is nearing completion with all samples having been analyzed. Recent reports on this study have provided data and results from the Beaufort Sea (Efurd, et al, 1997; Hameedi et al., 1997; Inkret, et al., 2000; Valette-Silver, et al., 1999). Preliminary results from the eastern Bering Sea samples have also been reported (Hameedi, et al., 1998) and additional reports are forthcoming.

Radionuclides: In general, the anthropogenic radionuclide activity in the US Arctic is low but quite pervasive, indicating that global fallout is the predominant and perhaps the only source. The global fall-out origin of the anthropogenic radionuclides in the region is also affirmed by source diagnostic ratios using relative activities and amounts of various radionuclides, such as the plutonium-239 to plutonium-240 atom ratio in sediment samples. There are sub-regional differences in the radionuclide activity: the mean activity level of cesium-137 in the Beaufort Sea sediment samples (5.6 Bq/kg dry weight) is considerably higher than in the eastern Bering sea (1.93 Bq/kg dry weight). In the eastern Bering Sea, Norton Samples had higher mean activity levels than the Bristol Bay samples. Similarly, the mean activity levels of plutonium239+240 in the Beaufort Sea sediment were higher than in the Bering Sea.

Among the species used for subsistence by communities in the North Slope Borough, radioactivity levels differ markedly between the terrestrial and marine species with the highest activity levels in the caribou tissues. It was shown that typical consumption of caribou meat adds a very small amount (0.0045 mSv) to the annual radiation dose from natural (3.0 mSv) and other anthropogenic sources, such as x-rays, air travel, and consumer products (0.6 mSv). In comparison, subsistence foods derived from marine food chains, for example, seals and bowhead whale, pose a much smaller, and nearly negligible, radiation dose.

A follow-up study, using age-dependent dose coefficients, has demonstrated that the North Slope Borough communities that rely on traditional food resources would incur larger radiation doses but that all committed dose estimates were well within dosage from natural background and atmospheric fall-out.

Toxic Elements: There is an increasing concern about the adverse health effects in fish and wildlife in the US Arctic, both at individual and population levels, from exposure to toxic elements. In certain instances, the body burden of metals in the tissues of species collected in western Alaska exceeds the levels at which physiological dysfunction or impaired reproduction is known to occur. Examples include cadmium in walrus kidneys, selenium in emperor geese blood, and lead in spectacled eiders and common eiders. As noted in the Mussel Watch data, concentration of some metals in the sediment and mussels from the Gulf of Alaska are high in comparison with the nationwide median and 85th percentile values. Historic data, as well as data based on chemical analyses of samples collected in 1993 and 1994, show generally elevated levels (approaching or exceeding the nationwide median value) of arsenic, chromium, copper and nickel in the eastern Bering Sea and Beaufort Sea sediment, with higher values generally found in the Beaufort Sea. Considering the lack of anthropogenic sources of toxic metals in the US Arctic, i.e., large urban areas or manufacturing industries, such elevated levels may be due to enriched source rocks and regional mineralogy. The Red Dog Mine off the coast of Chukchi Sea is an example of highly enriched source rocks forming one of the world's largest deposits of zinc, lead and associated minerals. Nonetheless, there is little scientific data on the environmental pathways, including food chain transfers, and biological effects of toxic elements on the fish and wildlife resources of the Arctic.

Organic Contaminants: The levels of organic contaminants are generally very low and are among the lowest recorded by the NS&T Program. Several specific compounds or groups of compounds are undetectable both in the sediment biological samples (invertebrate and fish samples). Total chlordanes (the sum of cis-chlordane, trans-nonachlor, heptachlor, and heptachlor epoxide) levels were somewhat higher than the sum of DDT isomers and metabolites. Still, total chlordanes in eastern Bering Sea varied from below detection level to 0.46 ng/g in sediment, and between 0.4 and 7 in biological samples. Endosulfan II was measurable in only two sediment samples with values ranging 0.07 to 0.11 ng/g.

Total PCB concentration (sum of 18 congeners in sediment was low but rather pervasive and uniformly distributed. It varied between 3 and 8 ng/g suggesting atmospheric deposition as the principal source. In the few biological samples analyzed for PCBs, the total PCB concentration ranged from 2 (in starfish) to 11 (in flatfish).

In contrast, the PAH distribution in Alaska shows marked regional differences (Figure 1). The coastal waters along the North Slope Borough are very rich in PAHs, with mean values often exceeding 300 ng/g dry weight in sediment. Off the Colville River in East Harrison Bay, the values are much higher, ca. 2,500 ng/g dry weight. The presence of certain biogenic markers in the hydrocarbon samples (such as steranes and triterpanes), source diagnostic ratios of certain PAHs, alkanes and cycloalkanes, and hydrocarbon composition in the riverine sediment suggest that extensive coastal erosion and discharge from rivers are the primary hydrocarbon sources in the region.
In the eastern Bering Sea, total PAH concentrations in sediment are high, and in Norton Sound they are generally higher than in Bristol Bay. Many samples from Norton Sound contained relatively high

amounts of perylene, whose presence in coastal marine sediments is usually attributable to terrigenous plant residues. Off the Yukon River Delta, perylene concentration was as much as 40 ng/g and contributed ca. 28% of the total PAHs. Previous studies in the region, conducted under OCSEAP, have shown a strong correlation between the terrigenous flux and perylene content in Norton Sound and Cook Inlet (Venkatesan, et al., 1988). In Bristol Bay, the lower tPAH values are perhaps indicative of a lack of fine-grained sediment, riverine input or industrial activities; the 1994 data ranged between 18 and 73 ng/g. Low as these levels are, detailed examination of composition and source diagnostic ratios of certain PAH compounds suggest that a major source of PAHs in the area is diesel fuel. In comparison with the Norton Sound samples, the Bristol Bay samples lacked chrysenes, had relatively high amounts of alky-substituted naphthalenes and phenanthrenes, and contained small amounts of dibenzothiophenes in all samples. Perylene was not detected at several of the of Bristol Bay stations. Further, the fossil fuel pollution index values (Steinhauer and Boehm, 1992) for Bristol Bay samples was generally higher. This index can range between 100 for certain crude oils to nearly zero for pyrogenic PAHs. Data on other petroleum hydrocarbons, such as n-alkanes, isoalkanes, and cycloalkanes, are not available to further examine the likely sources of hydrocarbons in the eastern Bering Sea.

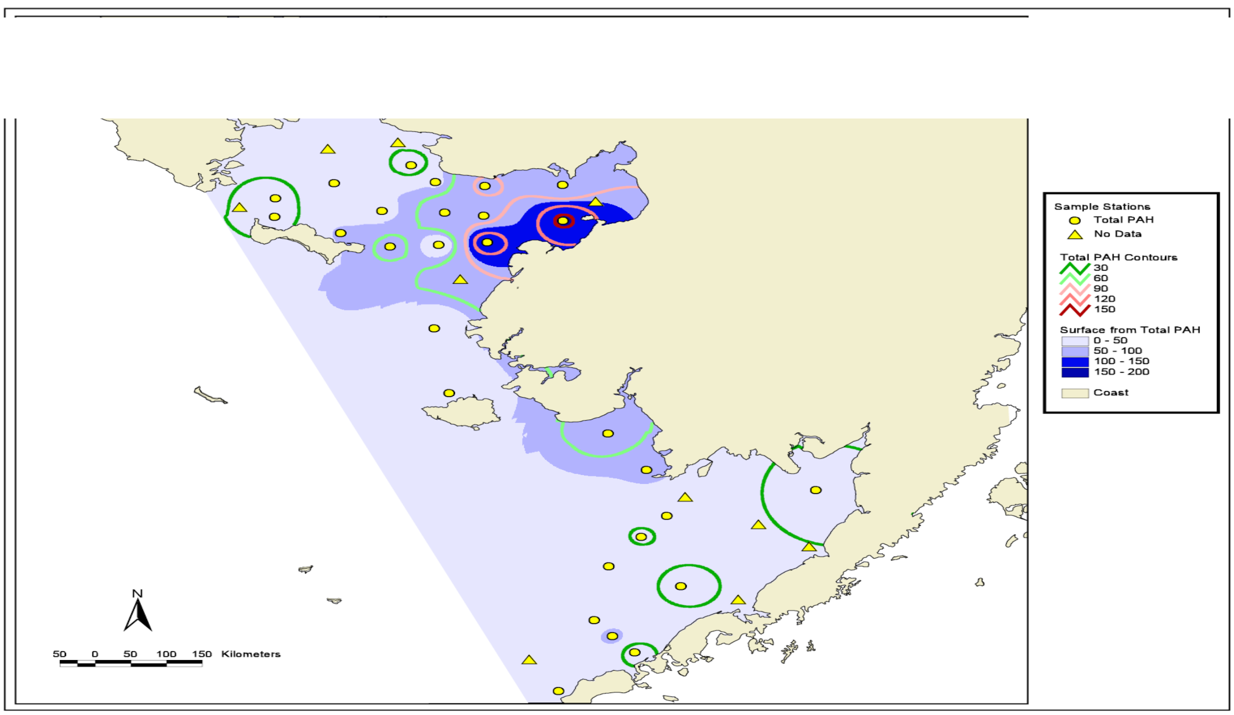


Figure 1. Total PAH concentration levels in samples from the eastern Bering Sea.

Table 1. Organic contaminants and major and trace elements that have recently been measured as part of NOAA's National Status and Trends Program

Chlorinated pesticides

2,4'-DDD
4,4'-DDD
2,4'-DDE
4,4'-DDE
2,4'-DDT
4,4'-DDT
Aldrin
Dieldrin
Alpha-chlordane
Cis-nonachlor
Trans-nonachlor
Oxychlordane
Heptachlor
Heptachlor epoxide
Lindane (gamma-HCH)
Alpha-HCH
Hexachlorobenzene

Mirex
Endrin
Endosulfan I
Endosulfan II
Chlorpyrifos

Polychlorinated Biphenyls
Congeners PCB-8,18, 28, 44, 52, 66,101, 105, 118, 128, 138, 153, 179, 180, 187, 195, 206, 209

Mono-, Di, Tri-butyltin

Polycyclic aromatic hydrocarbons

2-ring
Biphenyl
Naphthalene
1-Methylnaphthalene
2-Methylnaphthalene
2,6-Dimethylnaphthalene
1, 6, 7-trimethylnaphthalene
C1-C4 naphthalenes

3-ring
Fluorene
Phenanthrene
1-Methylphenanthrene
Anthracene
Acenaphthene
Acenaphthylene
Dibenzothiophene
C1-C2 Fluorenes
C1-C4 Phenanthrenes
C1-C3 Dibenzothiophene

4-ring
Fluoranthene
Pyrene
Benz(a)anthracene
Chrysene
C1-C4 Chrysene

5-ring
Benzo(a)pyrene
Benzo(e)pyrene
Perylene
Dibenz(a,h)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene

6-ring
Benzo(ghi)perylene
Indeno(1,2,3-cd)pyrene

Major elements

Aluminum
Iron
Manganese
Silicon

Trace elements

Antimony
Arsenic
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Selenium
Silver
Tin
Zinc

Related parameters
Grain Size
Total Organic Carbon
Temperature
Salinity
Dissolved oxygen

Table 2. NOAA's Mussel Watch Sites in Alaska

Site Name	Area	Years Sampled
Shuyak Harbor	Kodiak Island	1
Windy Bay	Kenai Peninsula	1
Homer Spit	Kachemak Bay	2
Sleepy Bay	Prince William Sound	1
Disk Island	Prince William Sound	1
Siwash Bay	Prince William Sound	9
Minerals Creek Flats	Port Valdez	9
Knowles Head	Prince William Sound	1
Sheep Bay	Prince William Sound	1
East Side	Skagway	2
Mountain Point	Ketchikan	2

Table 3. Mean concentration, (g/g dry weight, of selected toxic elements in sediment samples in the United States Arctic. Samples were collected by CCMA/NOAA in 1993 and 1994 (n denotes the number of samples analyzed). The nationwide median and percentile values are derived from ca. 200 samples. ER-L represents a value (10^{th} percentiles of the effects data) below which adverse biological effects would be rarely observed; ER-M represents a value (50^{th} percentile of the effects data) above which adverse biological effects would frequently occur (Long, et al., 1995).

	Arsenic	*Cadmium*	*Chromium*	*Copper*	*Nickel*	*Selenium*
Bristol Bay (n=11)						
Mean	14.4	0.08	54	12.5	14.3	0.21
Std. Dev.	7.0	0.03	26	0.01	3.3	0.06
Norton Sound (n=14)						
Mean	14.7	0.09	59	9.2	18.9	0.22
Std. Dev.	4.1	0.03	21	8.7	10.5	0.08
Beaufort Sea (n=10)						
Mean	29	0.15	87	35	46	0.36
Std. Dev.	12	0.11	11	17	18	0.22
Nationwide (1986-97)						
Median	6.9	0.19	54	14	17	0.38
85^{th} percentile	12	0.56	120	47	36	0.74
ER-L	8.2	1.2	81	34	20.9	N/A
ER-M	70	9.6	370	270	51.6	N/A

Current Research on the Effects of Fishing Gear on Seafloor Habitat in the North Pacific

Contributed by Jonathan Heifetz (Alaska Fisheries Science Center, Auke Bay Lab)

In 1996, the Alaska Fisheries Science Center (AFSC) initiated a number of sea floor habitat studies directed at investigating the impact of fishing on the sea floor and evaluation of technology to determine bottom habitat type (Heifetz, 1997). A progress report for each of the major projects is included below. Scientists primarily from the Auke Bay Laboratory (ABL) and the Resource Assessment and Conservation Engineering (RACE) Divisions of the AFSC have been conducting this work. In 2000 a web page (http://www.afsc.noaa.gov/abl/MarFish/geareffects) was developed that highlights these research efforts.

A Description of Seafloor Habitat in a Trawled and Adjacent Protected Region of the Central Gulf of Alaska
Principal Investigator - Robert P. Stone (Alaska Fisheries Science Center - ABL)

In June 1998 and August 1999 a study was conducted near Kodiak Island, Alaska to assess changes to the seafloor caused by chronic long-term trawling in soft-bottom areas in the Central Gulf of Alaska. Study objectives were to compare areas open to benthic trawling to areas closed to benthic trawling and to determine if differences exist for epifauna and infauna composition, abundance, and diversity, and substrate characteristics including total organic carbon and grain-size composition. These areas were closed to bottom trawling by the North Pacific Fisheries Management Council (NPFMC) in 1986 to assist in rebuilding severely depressed crab stocks.

Forty-one transects were established at 3 sites near Kodiak, Alaska. The level of trawling that occurred at our study sites, although moderate for the Central Gulf of Alaska (Coon et al., 2000), was relatively low compared to other areas worldwide (24 to 43% maximum bottom area trawled per year during the period 1993-98). Each transect was 3 km long and bisected the boundary between areas open to and closed to non-pelagic trawling. The research submersible *Delta* was used to enumerate epifauna and make observations of the seafloor along each transect. Shipek grab samples were collected at regular intervals along each transect. Samples for infauna, total organic carbon, and grain size were collected from each grab sample. Data were analyzed with both univariate and multivariate techniques. Epifauna counts should be completed by Spring 2001. Infauna and substrate characteristic data analysis is nearly complete.

A total of 181 grab samples were collected during the two-year study. No significant differences in infauna indices were found at any of the sites. We found significantly higher total organic carbon levels in the area open to trawling at Site 1 in both 1998 and 1999; the other two sites had no significant differences. Differences in median grain size and sorting were not significant at Sites 1 and 2, but were significantly different at Site 3. This site was notable for the clear demarcation in substrate type near the open/closed boundary. Trawling cannot be ruled out as a factor in this demarcation.

We found some evidence that chemical and physical substrate characteristics differ between adjacent areas open to and closed to benthic trawling. However, we cannot definitely conclude that changes have occurred to the substratum due to benthic trawling.

Trawl Impact Studies in the Eastern Bering Sea Principal Investigator - Robert A. McConnaughey (Alaska Fisheries Science Center - RACE)

This project is examining possible adverse effects of bottom trawls on soft-bottom benthos in the eastern Bering Sea. Earlier studies revealed chronic effects on community diversity and on individual macrofauna populations (McConnaughey *et al*. 2000). However, interpretation of these findings and effective use for management purposes requires some understanding of the underlying processes. To address this need, a new multi-year study in the Crab and Halibut Protection Zone 1 (also known as management area 512) is being planned. The project will investigate acute effects and recovery from a single repetitive trawling event. Detailed physical information and historical trawl effort data have been assembled to identify suitable experimental sites (Marlow *et al.* 1999; Smith and McConnaughey 1999). Epifauna and infauna data collected in 1996 and 1997 have been analyzed to identify appropriate sample sizes for the research trawl (epifauna) and benthic grab (infauna) sampling efforts. Sidescan sonar, acoustic seabed classification and subsampling of benthic grabs will be used to characterize physical effects on sediment properties and bedforms. This project was scheduled to begin in summer 2000, but the start date was postponed until Summer 2001 because of an unsuccessful charter vessel solicitation.

The before-after/control-impact (BACI) experimental design involves repeated sampling of specific sites to compare biotic and abiotic conditions before and after trawling. This requires accurate real-time positioning of sampling gear and the commercial trawl used to impact the experimental corridor. In May 1998, three ultra-short baseline (USBL) systems were tested in a fixed short baseline (SBL) tracking array maintained in Puget Sound by the U.S. Navy Naval Undersea Warfare Center Division Keyport. Using a chartered Bering Sea trawler operating under representative study conditions, this project demonstrated the feasibility of real-time trawl positioning. Comparison with Navy SBL fixes provided estimates of USBL positioning error for two systems, the Nautronix *ATS II* (3.7 $\pm$ 0.2 m) and the ORE *Trackpoint II Plus* (5.9 $\pm$ 0.2 m). The *Simrad ITI*, as tested, was considerably less accurate than these other systems. When all other sources of error (*e.g.* errors due to the gyro and sound velocity estimates) are considered, total cross-track positioning errors were 11.6 m (*ATS II*) and 13.8 m (*Trackpoint II Plus*), while total along-track errors were 8.4 m (*ATS II*) and 10.6 m (*Trackpoint II Plus*) for a trawl fishing 350 m behind the vessel in 60-65 m of water. An over-the-side hydrophone pole suitable for chartered F/Vs was also developed and tested. Complete details are available in a Final Report, incorporating technical input from all contractors.

Evaluation of Acoustic Technology for Seabed Classification Principal Investigator - Robert A. McConnaughey (Alaska Fisheries Science Center - RACE)
Detailed knowledge of seafloor properties is required to design effective studies of fishing gear impacts. Because benthic organisms have strong affinities for particular substrates, experimental areas must be carefully selected so as to minimize confounding effects. Moreover, substrate properties may prove to be a useful stratification variable that will advance our research programs from exploratory case studies to more systematic study of benthic habitat sensitivity. Acoustic technology is particularly suited to synoptic substrate mapping since quantitative data are collected rapidly and in a cost-effective manner. A recently completed study demonstrated that the *QTC View* seabed classification system (Quester Tangent Corporation, Sidney, B.C.; QTC) is capable of background data acquisition during routine survey operations (von Szalay and McConnaughey 2000). As part of large-scale studies to evaluate the utility of this system, an ISAH-S waveform recorder was installed aboard the research vessel *Miller Freeman* and adapted to the ship=s EK-500 echosounder during gear trials in Puget Sound (24-30 March 1999). Subsequently, nearly 8 million digitized echo returns from the seafloor were collected along a 9,000 nm trackline in the eastern Bering Sea during a hydroacoustic fishery survey by the *Miller Freeman* (cruise MF 99-09, June-August 1999). Data were simultaneously collected at two frequencies (38 and 120 kHz).

Collaborative work with the QTC evaluated performance of the *QTC View* system and optimized it for use in the EBS. The project had three distinct components: (1) data pre-processing and evaluation; (2) data processing to determine optimum acquisition parameters and identify acoustically distinct bottom types from the 38 and 120 kHz data sets using unsupervised classification methods; and (3) produce final classification maps at each frequency and identify sites for *QTC View* calibration and seafloor class groundtruthing. A quality assessment procedure indicated the data at both frequencies are of very high quality. Signal clipping was the most common deficiency and occurred in 10% of the high frequency data. A low signal to noise ratio was observed in less than 2% of the low frequency data. For each frequency, an optimum classification scheme was identified. The optimal number of acoustic classes in the 38 kHz data set was 18 and in the 120 kHz data set was 25. The greater number of classes is consistent with theoretically greater sensitivity to near-surface/small features at a higher frequency, with diminished response to general sediment characteristics. Stacking 50 pings and a reference depth of 150 m was optimal for acquisition at both frequencies. These findings suggest that 38 kHz is a better choice for classifying the basin into sediment types, while 120 kHz is a better choice for classifications based on near-surface differences, and perhaps over smaller areas. However, this conslusion is based only on maps of acoustic diversity and must be regarded as tentative pending some future comparison with appropriate ground truth. A specially configured *QTC View Series IV* will be deployed in summer 2001, as part of the acute trawl impacts study in the eastern Bering Sea. In addition to applications in gear impact studies, this technology may also be useful for characterization of groundfish habitat, given recent evidence that flatfish species in the Bering Sea associate with specific sediment textures (McConnaughey and Smith 2000).

Development of a benthic sled to observe seafloor habitat Principal Investigator - Ken Krieger (Alaska Fisheries Science Center - ABL)

Fishing impact studies by the ABL have depended on videos of the seafloor to quantify invertebrates and habitat. A manned submersible has been our primary method of collecting seafloor videos. As a method of supplementing video collected via the submersible, a benthic sled was developed and tested in 1999 by ABL with assistance from RACE. The sled was constructed and tested in waters near Kodiak using video equipment that was developed for attachment to bottom-trawls. The sled was tested at speeds of 1-3 knots and it traveled smoothly on the seafloor and produced video of the seafloor.

In 2000, ABL and RACE developed a system that allows video to be collected at 2-4 knots and then replayed at slower speeds without a significant reduction in resolution. In April, 2000 the new digital camera system was installed on the sled and tested aboard the NOAA research vessel *John N. Cobb*. During the two days on the *Cobb* a variety of camera settings and lighting options were tested. The system was tested to 650 feet and survived encounters with boulders and crab pots. The equipment and camera settings providing the best resolution were as follows: manual focus with progressive scan activated and exposure time and lighting set at 1/250 s with 100 w lights or 1/500 s with 150 w lights

The goal of this project was to develop an inexpensive underwater system to survey benthic habitat that could provide high resolution video during playback at slow speeds. This goal was met. The results are that we have a relatively inexpensive system which can be used to observe and enumerate small benthic fauna.

Identification of Habitat Areas of Particular Concern (HAPC) Principal Investigator - Lincoln Freese (Alaska Fisheries Science Center - ABL)

A proposed alternative in the 1999 NPFMC Draft EA/RIR would amend Fishery Management Plans to include deep-water seamounts and shallower pinnacles as HAPC. These habitat features are often highly productive because of their physical oceanography, and host a rich variety of marine fauna (Probert et al., 1997). Perusal of oceanographic charts for the Gulf of Alaska reveals that these features are relatively rare. In August 1999 personnel from the ABL conducted two dives on an isolated pinnacle from the research submersible *Delta*. The pinnacle is located on the continental shelf approximately 40 nautical miles south of Kodiak, Alaska (56^{o} 17' N; 154^{o} 01' W) and rises from a depth of about 40 meters to within 16 meters of the surface. The surrounding habitat is relatively featureless sand. The pinnacle hosted large aggregations of dusky rockfish, kelp greenling, and lingcod, similar to aggregations noted on a pinnacle located in the vicinity of the Sitka Pinnacles Marine Reserve (NPFMC, 1998). The pinnacle provides substrate for dense aggregations of macrophytic kelps beginning at the 20 meter isobath and continuing to the top of the pinnacle. These kelp beds may provide essential rearing habitat, as evidenced by the numerous juvenile fish (presumably rockfish) observed swimming among the kelp fronds. Although no evidence of fishing gear impacts were noted from the submersible, it is located on SW of Kodiak Island adjacent to areas that are extensively trawled (Coon et al., 2000).

In 2000 a survey was completed of a potential HAPC in the eastern Gulf of Alaska. The survey was designed to determine if the site met the criteria for designation as HAPC. The extent of the potential HAPC site was successfully charted from the *Media*. The site measures approximately 400 x 600 m. Maximum vertical relief is approximately 55 m, and water depths range between 201 and 256 m. The area studied is likely an extension or ridge projecting southeastward from the 200 m isobath on the continental shelf, and may be part of a series of such features. Using the research submersible *Delta*, we conducted a total of 7 dives at the site to document habitat and associated biota. An additional 5 dives were performed to collect specimens of red tree coral, sponges, and predatory starfish. The substrate is primarily bedrock and large boulders, most likely composed of mudstone, and provides abundant cover in the form of caves and interstices of various sizes. The epifaunal community is rich and diverse, much more so than the surrounding low-relief habitat. The largest epifauna were gorgonian red tree coral colonies and several species of sponges. These organisms are not evenly distributed at the study site. Review of the video and audio data may provide insights into habitat features or oceanographic processes affecting distributions. Numerous species of fish, including several species of rockfish, are present in relatively large numbers. Redbanded rockfish and shortraker/rougheye rockfish were often associated with gorgonian coral colonies and at least one species of sponge. Water currents at the site are generally very strong, but are variable in both direction and strength depending on location.

Trawl-Induced Damage to Sponges Observed from a Research Submersible Principal Investigator - Lincoln Freese (Alaska Fisheries Science Center - ABL)

An experiment (Freese et al., 1999) conducted on hard bottom (pebble, cobble and boulder) substrate on the continental shelf break in the vicinity of Kruzof Is., Alaska showed that a single pass of a commercial trawl can reduce densities, and increase incidence of damage to several taxa of sessile invertebrates, including sponges and anthozoans, and can disturb abiotic habitat features by dislodging boulders and causing grooves up to 8 cm deep in the substrate. Personnel from the ABL returned to these trawl tracks one year after trawling and made observations from the research submersible *Delta*. Trawl tracks were readily identifiable and there appeared to be minimal backfilling of grooves in the substrate caused by the prior year=s trawling. Sponges were examined for evidence of repair or regrowth. None of the 115 damaged sponges in the trawl paths showed signs of repair or regrowth. All wounds and tears appeared to be fresh with irregular surfaces, and no evidence of rounding due to regrowth was noted. On the other hand, many sponges that had been knocked over, or pieces of sponge that had been torn free and were lying on the bottom, still appeared viable after one year.

We conclude, that unlike sponge communities in warm shallow waters, sponge communities in the Gulf of Alaska (GOA) do not appear to have the ability to quickly return to pre-trawl population levels, nor do individual sponges appear to have the ability to quickly recover from wounds suffered from trawl gear. Little is known concerning the biogeography or community associations of sponges in deep waters in the GOA. However, because of the complex habitat that they provide, and because of the demonstrated vulnerability of sponge communities to trawling, it is recommended that further studies be carried out to document the geographic distribution and abundance of these organisms in the GOA and to ascertain the relative importance of sponges as habitat for commercially important managed species.

Effects of Trawling on Hard Bottom Habitat in the Aleutian Region at Seguam Pass Principal Investigator - Harold Zenger (Alaska Fisheries Science Center - RACE)

In August 1999, a 14-day cruise was conducted aboard the chartered fishing vessel *Vesteraalen* to gather underwater video images of the demersal habitat in the Seguam Pass area. The objectives of this study were: 1) examine whether the corals in heavily trawled areas are more damaged and less abundant than in nearby, less trawled areas; and, 2) attempt to verify the extent to which fish and in vertebrates use coral for shelter. Twenty-five successful camera tows were completed. Images were recorded digitally on videotape. The videotapes have been reviewed and the results are being catalogued in a database. In general, the study area was found to be extremely varied, ranging from dense Agardens@ of benthic invertebrates to large underwater sand dunes. On several occasions what appeared to be Atka mackerel spawning activity on large, offshore rockpiles and pinnacles, was recorded. A summary video was prepared for viewing at a meeting of the North Pacific Fishery Management Council in Seattle. No field work was performed during 2000.

Growth and Recruitment of an Alaskan Shallow-water Gorgonian. Principal Investigator - Robert P. Stone (Alaska Fisheries Science Center - ABL)

At least 20 species of gorgonian corals inhabit Alaskan waters. Specimens of all but one species have been incidentally entangled in fishing gear (e.g., hook and line, longlines, trawls, crab pots, and fish traps) and detached from the seafloor. Several species attain large size and provide habitat in the form of structure and refuge for species of demersal fish and invertebrates. The effects of coral habitat alteration on benthic communities are unknown, but may be substantial due to the reported longevity and slow growth rates of cold-water corals. The North Pacific Fishery Management Council is currently considering measures to establish several marine protected areas where gorgonian corals are abundant. In this study we examined growth and recruitment of *Calcigorgia spiculifera*, a shallow-water Alaskan gorgonian, in an effort to elucidate the effects of fishing activities on coral habitat.

We used computer image analysis tools to measure the linear length of colony branches from digitized video images collected on tagged specimens *in situ*. Length of a branch was measured along the medial axis from the point opposite its origin. This method provides a permanent record of colony morphometry. Highly accurate measurements are possible with proper colony orientation with respect to the calibration grid and parallel alignment of the camera lens with the grid.

Thirty five colonies were tagged at 2 sites in July 1999. We relocated 32 (91%) of those colonies in July 2000. The missing colonies were presumably detached from the seafloor. Growth measurements were possible for 16 colonies. Growth rate was variable for branches from the same colony and also between colonies. Mean branch growth rate at both sites ranged from -1.82 to 14.83 mm yr^{-1}. Growth rates (mean = 5.81 mm yr^{-1}, std = 4.99) measured during this study were generally much lower than those reported for other gorgonians worldwide, including Alaskan *Primnoa*, a deep-water species. Recruitment of new colonies had not occurred at either study site for a minimum of several years indicating that recruitment in this species, at least at our study sites, is a rare sporadic event.

The slow growth rates measured during the first year of this study, although preliminary, are noteworthy since shallow-water corals are widely believed to have faster growth rates and shorter life spans than deep-water corals. Additionally, recruitment appears to be a rare, sporadic event. Shallow-water gorgonian communities may therefore exhibit slow recovery rates from sea floor perturbations. Our future research priorities are to focus on growth of smaller colonies and to establish a third study site where colonies are more numerous and more variable in size (i.e., age).

Workshop on effects of fishing gear on benthic habitat Principal Investigator - Jonathan Heifetz (Alaska Fisheries Science Center - ABL)

Research efforts thus far have led to important findings that have increased our understanding of fishing gear effects on benthic habitat. These efforts have focused on 1) understanding the direct effects of bottom trawling on seafloor habitat; 2) the associations of fish and invertebrate species with habitat features that may be affected by fishing gear; 3) the evaluation of technology to determine gear effects and benthic habitat features; and 4) retrospective analyses of spatial and temporal patterns of bottom trawling. Most of the field-oriented studies (i.e., 1-3 above) have focused on small geographic areas in specific habitat types. Similarly in the last few years, the US Geological Survey Coastal and Marine Geology Program has embarked on applying high resolution mapping tools to mapping benthic habitats in Alaska. These mapping efforts address small specific areas and local issues. NOAA and the USGS have launched a national initiative that if successful will provide additional funding to expand NOAA and USGS research efforts over larger geographic areas and a variety of habitat types. This research will provide fisheries managers the information needed to develop measures for minimizing the adverse impacts of fishing gear, as required in the Magnuson-Stevens Fisheries Management Act.

During a three-day workshop held in January 2000 in Juneau, Alaska, future research projects were identified and a time table for completion was drafted for inclusion in the NOAA/USGS initiative. The suite of projects identified take a comprehensive and scientific approach to the issue of fishing gear effects on habitat. During the initial phase of this research, the focus is on identifying the effects of the various gear types on fish habitat for a range of habitat types, mapping habitat, examining the associations between habitat features and fish utilization, and defining the geological processes that will allow comparison of natural versus gear effects processes. After this initial phase, studies will transition to those that establish the connections between habitat and fish production and population dynamics. In addition to NOAA and USGS, this research will be implemented through collaborative projects with the Alaska Department of Fish and Game, the University of Alaska, and others.

Program Publications

Besides the program publications cited above (see the full citations of these in the literature cited section at the end), the program research is resulting in many other new publications. Some of the program member's recent publications that have been published or that are in review or waiting for publication are listed below.

Fossa, J.H., D.M. Furevik, P. B. Mortensen, and M. Hovland. 1999. Effects of bottom trawling on Lophelia deep water coral reefs in Norway. Poster presented at ICES meeting on Ecosystem Effects of Fishing, March, 1999. Institute of Marine Research, Bergen, Norway.

Heifetz, J. 2000. Coral in Alaska: Distribution, abundance, and species associations. International Symposium on Deep Sea Corals Halifax, Nova Scotia, Canada (submitted).

Krieger K. J. and B. L Wing. 2000. Megafauna associations with gorgonian corals (*Primnoa* spp.) in the Gulf of Alaska. Hydrobiologica. (submitted).

Krieger, K. J. Coral impacted by fishing gear in the Gulf of Alaska . International Symposium on Deep Sea Corals Halifax, Nova Scotia, Canada (submitted).

Risk , M. J., McAllister D. E., and Behnken, L. 1998. Conservation of cold-and warm-water seafans: Threatened ancient gorgonian groves. Sea Wind 10(4): 20-22.

Stone, R .P. 2000. Growth and recruitment of an Alaskan shallow-water gorgonian. International Symposium on Deep Sea Corals Halifax, Nova Scotia, Canada (submitted).

Wion, D.A. and R.A. McConnaughey. 2000. Mobile fishing gear effects on benthic habitats: a bibliography. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-116. 163 p.

Current Research on the Essential Fish Habitat in the North Pacific

Contributed by K Koski (Alaska Fisheries Science Center, Auke Bay Laboratory) and Cindy Hartmann (Alaska Regional Office, National Marine Fisheries Service)

Several EFH projects were funded this year (see project reports below). In addition, EFH funding provided partial support to several projects that also received partial support from funds available under the "Effects of Fishing on Seafloor Habitat" Program. These projects are: Identification of Habitat Areas of Particular Concern (PI: Lincoln Freese), Trawl Induced Damage to Sponges Observed from a Research Submersible (PI: Lincoln Freese), Effects of Fishing on Hard Bottom Habitat in the Aleutian Region at Seguam Pass (PI: Harold Zenger), Growth and Recruitment of an Alaskan Shallow-water Gorgonian (PI: Robert P. Stone). Full description of these projects are found in the previous section on Effects of Fishing on Seafloor Habitat.

Nearshore Habitat Utilization by Juvenile Groundfish

Principal Investigators - Scott Johnson, Michael Murphy (Alaska Fisheries Science Center - ABL)

Out of necessity, groundfish sampling has been predominantly on adult fish to obtain knowledge for fishery management, mostly on the continental shelf and slope. Due to the remoteness of most of Alaska=s coastline, very little sampling has occurred in nearshore habitats where many species spend part of their early life history. In FY00, objectives were to determine patterns in the distribution and habitat of juvenile and adult groundfish in nearshore waters of Southeast Alaska and to determine the function (food, cover, etc.) of habitats such as eelgrass meadows. Beach seines and a remotely operated vehicle (ROV) equipped with a video camera were used to sample or observe groundfish in a variety of habitat types (e.g., eelgrass meadows, complex bottoms of boulders or broken rock).

A two-year study on juvenile rockfish was completed in September 2000. In summer 1999, movement of age-1 copper and quillback rockfish was investigated in Sitka Sound, Alaska, to determine residence time in eelgrass and kelp habitats (areas of particular concern under Essential Fish Habitat). Results from a pilot mark-recapture experiment in the first year, showed that juvenile rockfish move into shallow eelgrass and kelp habitats in May, and remain in the same local area through late summer. An intensive mark-recapture study was conducted in summer 2000 to determine residence time, growth, and diet of age-1 copper and quillback rockfish. Eelgrass and understory kelp (*Laminaria*) sites near Sitka were sampled with a beach seine monthly from May to September. Fish were injected with elastomer tags to distinguish month and site and with sequential coded wire tags (CWT) to obtain unique identification. A total of 4636 juvenile rockfish were captured, of which 2969 were tagged, and 720 were recaptured. In addition, 64 age-2+ copper, quillback, and brown rockfish were recaptured from fish marked the previous year; 72% were recaptured at the same site that they were originally tagged. Growth rates will be compared between the two habitat types. In addition, fish were collected for diet description and diel sampling was conducted to calculate diet ration within each habitat.

Additionally, in June, July, and August, 2000, the NOAA ship *John N. Cobb* was used as a platform to stage ROV studies. To date, over 200 ROV dives have been completed in a variety of habitat types from southern southeast Alaska near Craig to northern southeast Alaska near Sitka and to inside waters near Juneau. Important species observed included black rockfish, dusky rockfish, quillback rockfish, silvergray rockfish, yelloweye rockfish, yellowtail rockfish, Pacific cod, walleye pollock, and lingcod. Most rockfish were in areas with vertical bedrock walls or complex habitat (e.g., boulder piles) with numerous cracks and overhangs for cover, whereas areas with not much relief (e.g., soft-bottom basins) were usually void of rockfish. Juvenile rockfish were often seen in shallower water than adults, particularly in areas with vegetation, such as eelgrass meadows, *Laminaria* beds, and *Nereocystis* forests.

Distribution of rockfish differed between outside and inside waters and between southern and northern Southeast Alaska. For example, juvenile yelloweye rockfish were seen in outside waters between Craig and Sitka but not in inside waters near Juneau. Similarly, most lingcod were seen in outside waters near Sitka, whereas few were observed in inside waters. Quillback rockfish were the most ubiquitous, occurring in both inside and outside waters between Craig, Sitka, and Juneau. Differences in physical and biological factors, such as salinity, temperature, food, and cover likely account for the presence or absence of some species among our ROV sites. Future studies will focus on determining factors that limit the distribution of groundfish between inside and outside waters of northern and southern Southeast Alaska.

Essential Fish Habitat in Estuarine Wetlands of Southeast Alaska
Principal Investigators - Mitch Lorenz, K Koski (Alaska Fisheries Science Center - ABL)

Estuarine wetlands are considered some of the most productive habitats worldwide and are known to sustain important marine fisheries. Little is known, however, about their role in production of FMP species in Alaska. Currently, Alaska=s estuarine wetlands are also designated as Ahabitat areas of particular concern@ for the following reasons: (1) nearly 60 coastal streams in Alaska are listed for impaired water quality and nearly half of those are listed because of urban runoff; (2) most urban areas have lost significant amounts of their original coastal wetlands, and; (3) the effects of urban development and pollution on fish habitat in estuarine wetland have been difficult to estimate due to poor understanding of the functional links between habitat and fish productivity.

Previous research funded by this program indicates that Alaska estuaries and estuarine wetlands provide diverse habitat for important FMP species and also produce food organisms used by such species. Estuaries provide a critical physiological staging area for salmon during migration between salt and fresh water. Salmon and other important FMP and forage species (e.g., yellowfin sole, rock sole, starry flounder, sand lance, herring, capelin, eulachon, and many invertebrates) are also plentiful in coastal wetlands associated with estuaries. This work is establishing patterns of spatial and temporal habitat use, relative abundance, and feeding life stages of several FMP species that use estuarine wetlands, however, links between estuarine habitat abundance and distribution and fish productivity are not well understood.

In 2000, the objectives were to (1) complete two University of Alaska M.S. thesis projects on herring and flatfish utilization of wetlands; (2) develop models to estimate estuarine habitat suitability indices for several FMP species; (3) continue community outreach to develop public awareness and encourage public support for essential fish habitat; (4) develop models to predict the effect of urban development on estuarine fish habitat; (5) establish methods for interpretation of estuarine EFH from remote sensing data; and (6) begin an inventory of estuaries and associated wetland habitats in southeast Alaska. Those objectives reflect both the need to link habitat to fish productivity and the need to develop a plausible framework for a broad based inventory of essential fish habitat in estuarine wetlands.

Development of a user-friendly, high resolution EFH website that facilitates internet access to maps, definitions, tables and other EFH information available to the public on the web.
Alaska Regional Office, NMFS

Section 303 (a) (7) of the MSFCMA requires that fishery management plans describe and identify essential fish habitat for the fishery. Alaska Regions Essential fish Habitat (EFH) amendments became effective January 20, 1999. In March 1999, the region had a map objects (MO) internet map server (IMS) web site available that contained our EFH environmental assessment, the EFH habitat assessment reports and GIS maps. Users can interact with the GIS maps and key into an area of special interest and use a icon to get a list of species for that area.

The NMFS EFH Web-Map site functions to make EFH map data available to the public. The site is mostly used by Federal resource managers, biologists, and contractors as a quick way to determine the EFH species potentially present in a project area. The list of EFH species is used in an EFH analysis which describes the effects of a proposed action on EFH. The EFH source maps can be found at http://www.fakr.noaa.gov.efh/

Querying these maps is somewhat slow, 4 to 6 minutes. A new server has been purchased that will hold the EFH maps and other regional maps. It will take less than a second to query from this server. More advanced software has also been purchased, arc IMS architecture software. The EFH website on the new dedicated server with arc IMS architecture should be up and running by 2001. Work also continues on development of a digital interface to the EFH assessment tables. Since this is state of the art development we have not found a contractor able to do the task. In house, IRO staff are working on this as time is available and expect a completed product by the end of FY 2001.

In addition to the GIS EFH Web-Map site the EFH EA/RIR and the EFH Habitat Assessment Reports can also be found on the NMFS, Alaska Region web site. The Environmental Assessment for Amendment 55 to the Fishery Management Plan for the Groundfish Fishery of the Bering Sea and Aleutian Islands Area; Amendment 55 to the Fishery Management Plan for Groundfish of the Gulf of Alaska; Amendment 8 to the Fishery Management Plan for the King and Tanner Crab Fisheries in the Bering Sea/Aleutian Islands; Amendment 5 to the Fishery Management Plan for Scallop Fisheries off Alaska; Amendment 5 to the Fishery Management Plan for the Salmon Fisheries in the EEZ off the Coast of Alaska Essential Fish Habitat can be found on the web at http://www.fakr.noaa.gov/habitat/efh_ea/. Habitat Assessment Reports for Essential Fish Habitat can be found on the web at http://www.fakr.noaa.gov/habitat/efh_har/.

EFH Consultation Requirements of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA)
Alaska Regional Office, NMFS
Section 305 (b)(2) of the MSFCMA requires Federal Agencies to consult with the Secretary with respect to any action authorized, funded or undertaken, or proposed to be authorized, funded, or undertaken by such agency that may adversely affect any essential fish habitat identified under the MSFCMA. In accordance with directives to utilize existing processes to the maximum extent possible, the Alaska Region has completed four findings (two with the Corps of Engineers, one with the Federal Highways Association, in conjunction with the Alaska Department of Transportation, and one with the U.S.D.A. Forest Service), and one currently in review for the Environmental Protection Agency (EPA). Two additional findings are currently in development (one with EPA, and one with the Minerals Management Service). Un addition, two programmatic consultations have been completed (The Anchorage Wetlands Management Plan General Permits and the Abbreviated Permit Program for Village Sanitation and Wastewater) and one for the Juneau Wetlands Management Plan is currently being developed.

Community-based Restoration
Alaska Regional Office, NMFS

The community-based Restoration Program archives habitat restoration through individual small-scale projects that foster local natural resource stewardship. Projects are identified through partnerships with the American Sportfishing Association, the National fish and Wildlife Foundation, and corporate environmental trusts. The Alaska Region works with Headquarters Habitat Restoration=s Community Based programs, by reviewing and rating proposals submitted for Alaska. In addition, the Alaska Region chairs the Alaska Regional Implementation Team (AKRIT) of the Coastal America Partnership, and works together with other Federal Agencies in a collaborative effort to work towards common objectives in restoring damaged or lost habitat. In the past year the team has been the recipient of several partnership awards.

Benthic Communities and Non-target fish species

Trophic Regime Shift in Benthic Communities in the Gulf of Alaska- Small mesh surveys

Contributed by Paul Anderson

Recently there has been information presented that the Gulf of Alaska (GOA) ecosystem has undergone some abrupt and significant changes (Piatt and Anderson, 1996; Anderson et al., 1997, Anderson and Piatt, 1999). The extent and degree of these changes are poorly documented and is important in determining future strategies for management of the marine ecosystem. Analysis of the historic data is a first step in gaining an appreciation for the rapid and abrupt changes that have occurred in the marine species complex in the last five decades. The data from small-mesh shrimp trawl cruises provides an opportunity to review changes in the composition of forage species and other epi-benthic fish and invertebrates that occurred through time in the GOA from 1953 to present.

Historically, there is evidence of major abundance changes in the fish/crustacean community in the western GOA. Fluctuation in Pacific cod availability on a generational scale was reported for coastal Aleutian communities by Turner (1886). Similarly, landings from the near-shore Shumagin Islands cod fishery (Cobb, 1927) showed definite periods of high and low catches with the fishery peaking in late 1870s. King crab commercial catches in the GOA show two major peaks of landings, one in the mid 1960s and another in 1978-1980 (Blau, 1986). All of the area was closed to fishing in response to low population levels in 1983 (Blau, 1986) and has yet to reopen. By the 1960s there was evidence of high Pandalid shrimp abundance in these same areas (Ronholt 1963). One of the highest densities of Pandalid shrimp known in the world was to spur the development of a major shrimp fishery (Anderson and Gaffney, 1977). By the late 1970s the shrimp population density had declined radically and was accompanied by a closure of the shrimp fishery and the return of cod to inshore areas (Albers and Anderson, 1985). Catches of almost all salmon stocks of Alaskan origin suddenly increased to unprecedented levels in the 1980's (Francis and Hare, 1994, Hare and Francis, 1995). These changes, witnessed over the last century, imply dynamic fluctuations in abundance of commercially fished species. Managers, fisherman, and processors should be aware of these dynamics and their impacts on the ecology and economy.

Shrimp

Caridean shrimp of four major families; Pandalidae, Crangonidae, Hippolytidae, and Pasiphaeidae occupy an important niche in the pelagic realm in Alaskan waters. There is a long history of commercial harvesting of several species of Pandalidae in the Bering Sea and Gulf of Alaska, but no known harvests of members of the other families has occurred. Most of the available biological information in Alaskan waters relates to the commercially important shrimps in the family Pandalidae.

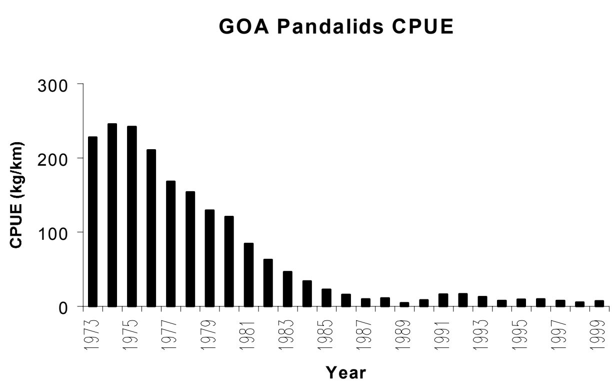
Commercially important pandalid shrimp first hatch as larvae in the spring April through early June. Shrimp larvae remain in near-surface waters until undergoing metamorphosis to the juvenile phase and settle into a semi-benthic existence. Pandalid shrimp are protandric hermaphrodites maturing first as males and then undergoing a transformation to female depending on growth rate of the individual (Charnov and Anderson, 1989). Massive swarms of shrimp take part in the diel migration up into near surface water at night to feed. During daylight shrimp are mostly near bottom. Females, which have eggs on attachments to the pleopods after spawning, do not actively migrate up in the water column until after eggs hatch.

Shrimp are a major food item for important commercial fish species, birds and marine mammals. Albers and Anderson (1985) found that pandalid shrimp were a dominant food item by frequency of occurrence (63%) in Pacific cod diet in Pavlof Bay. Jewett (1978) and Hunter (1979) found significant amounts of shrimp in cod taken from offshore areas but not as high as that found in inshore populations. Shrimp are also important in the diet of almost all fishes where they co-occur with shrimp. Shrimp larvae and juveniles are preyed on by pink, sockeye and coho salmon, sand lance, walleye pollock, longfin smelt, surf smelt, juvenile great sculpin, starry flounder, and rock sole taken from near-shore samples (Blackburn et al., 1983). MacDonald and Peterson (1976) report shrimp in the diet of Beluga whales, Steller's sea lion, and harbor seal. Pitcher (1980, 1981) reports decapod shrimps ranking in the top ten in frequency of occurrence in the prey of Steller sea lion and harbor seals collected between 1973 and 1978 in the GOA. Shrimp are also an important food for newly weaned harbor seal (Bigg, 1973). Lowry and Frost (1981) report shrimp in the diet of all phocid seals found in the boreal North Pacific. Shrimp are important in the diet of some whales and porpoise they have been found in beluga and humpback whales as well as harbor and Dall porpoise (Frost and Lowry, 1981). Hatch et al. (1978) reported glaucous-winged gulls, kittiwakes, and tufted puffins preyed on shrimp. Shrimp therefore, are a major forage species. In turn, shrimp prey on other crustaceans, many demersal and pelagic invertebrates, larval and small fishes, and can feed on dead or decaying organic matter (Rice et al. 1980;Wienberg, 1981; Hopkins et al., 1993; Nickell and Moore, 1992).

Pandalid shrimp have declined uniformly throughout all study areas in the GOA, with the most significant declines occurring after 1981. Total pandalid shrimp biomass averaged 179.3 kg/km in the 1972-81 period. In contrast, abundance has declined in all surveyed areas to only 10.1 kg/km in the recent 1990-97 time period. Of particular note is the humpy shrimp, (*Pandalus goniurus*) that was formerly a significant part of the shrimp biomass became nearly extinct while the other species primarily, northern pink shrimp, (*P. borealis*) has declined, but not to near-extinction levels. Humpy shrimp averaged 19.26 kg/km during the period 1972-81 and declined to very low levels in recent surveys 0.09 kg/km in 1990-97. This observed change demonstrates that some pandalid species are vulnerable to being extinguished from the near-shore ecosystem. Humpy shrimp was not heavily targeted by commercial shrimpers, and declines after closure of commercial fisheries continued. We hypothesize that the near-extinction of *P. goniurus* was caused by sustained high winter temperature in the late 1970s (Royer 1989). This species is commonly found in relatively shallow water subject to high residual winter cooling. In contrast *P. borealis* is found at deeper depths and is buffered from extreme temperature declines in winter. These distribution traits along with abrupt changes in winter temperatures may explain the region-wide mechanism that was responsible for shrimp population declines. Although adult populations were relatively high in 76-79, no strong year-classes were produced by any pandalid species during this period. The mechanism that affected reproductive and larval success occurred simultaneously with the climatic forcing event in the GOA (McGowan.et. al. 1998). Nunes (1984) demonstrated that the thermal history of Pandalid shrimp is important factor in the production of viable larvae.

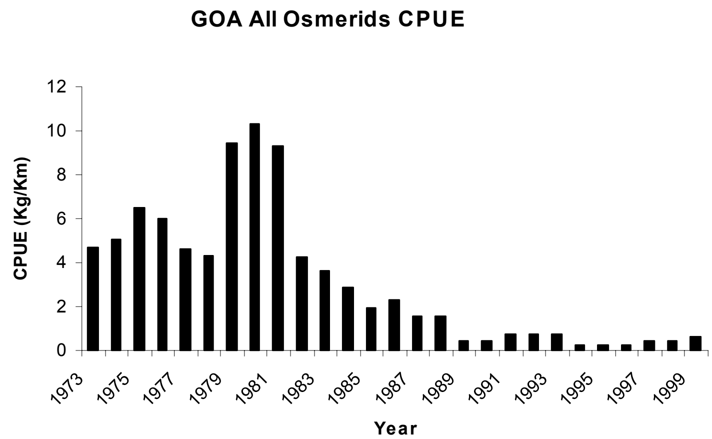
Similarly, other pandalid shrimp species have declined. *Pandalopsis dispar*, side-stripe shrimp has declined in abundance from near-shore sampling areas. This shrimp has a more pelagic characteristic and is found at the deepest locations sampled. It is possible that the distribution of this species has shifted to deeper depth intervals, outside our sampling strata in response to GOA water column warming. *Pandalus hypsinotus*, known locally as the coonstripe shrimp, is typically identified with inshore habitats and a shallow depth range. Both of the above species have declined to near-extinction levels in our sampling areas both less than 0.002 kg/km during recent surveys from higher levels in the early 1970s ~10 kg/km for each species. See Figure 1 for catch summaries.

All of the discussed shrimp species have declined after fishing was largely closed in the near-shore areas where they were once abundant (Orensanz et al., 1998). There is evidence that the more shallowly distributed members of Pandalidae were more vulnerable to the climate change that was observed during the later part of the 1970s (Anderson, 2000).



Forage Fish

Sharp declines in shrimp abundance from 1978-1983 throughout the Gulf of Alaska were paralleled by declines of other species as well (Piatt and Anderson, 1996, Anderson and Piatt, 1999). Abrupt changes in forage fish abundance in the Gulf of Alaska occurred during the period 1978 - 1979. A 21-year time series from scientific trawl surveys from Pavlof Bay showed capelin (*Mallotus villosus*) virtually disappeared while walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus macrocephalus*) and pleuronectid flatfish populations abruptly increased.



Capelin

Capelin in the GOA has never been harvested commercially. In the North Atlantic were commercial harvesting does occur, research on capelin has been conducted. Most of the discussion in this section relating to life history information is drawn from near-shore research in the Kodiak and Cook Inlet region in the early 1970's. Additional information is taken from published work on North Atlantic capelin the same species as found in Alaskan waters.

Capelin spawn in the spring and summer on suitable beaches. The time of spawning in Alaska is highly correlated with high tides in the late spring and early summer but may last until mid-July or well into August (pers.obs.) . Many adult fish die soon after spawning presumably due to depleted energy reserves. Eggs develop quickly and larval capelin may spend as many as 7 days in the sediments before migrating offshore. They spend about a year in the larval and post-larval phase before transforming to adults at about 60 mm FL.

Capelin are primarily planktivores with a relatively short life span. Their abundance is highly variable from year to year and is linked to zooplankton availability and to the feeding influence of their competitors or predators (Gerasimova, 1994). Larval and post larval capelin consume small planktors, in Alaska, this is mostly copepods. As they mature, capelin feed on larger prey items euphasids, shrimp, amphipods, capelin eggs, and copepods. Ichthyoplankton surveys in the GOA showed larval and immature capelin feed almost exclusively on copepods. While mature capelin still feed largely on copepods they also consume euphausids and even larval fishes including sand lance (*Ammodytes hexapteras*). Larval fish do not descend as deep in the water column as adults during the day and stay primarily in surface waters, while adults may descend to the bottom. Adults are occasionally seen in large schools on the surface especially at night. Differences in feeding preference probably explain these behavioral traits as well as the differential distributional patterns exhibited by each life history stage.

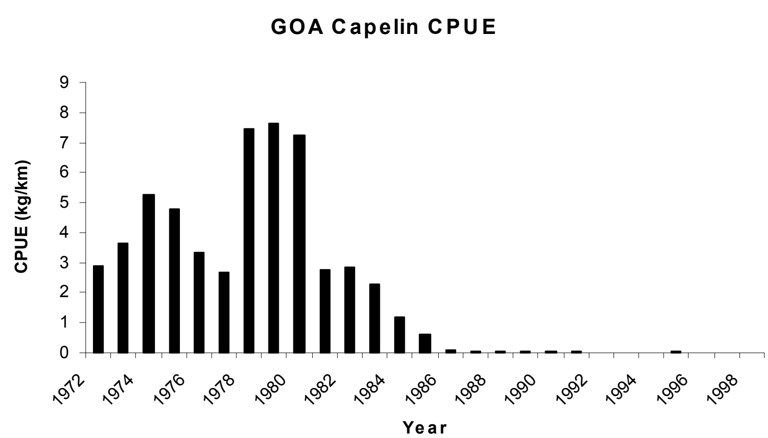
Capelin are prey for Pacific cod and halibut (Hunter, 1979), Dolly varden, chum salmon, juveniles, and yellowfin sole (Blackburn et al., 1983), harbor seals, Steller sea lion (Pitcher, 1980, 1981), whales, murres, puffins, and cormorants, glaucous-wing gulls, kittiwakes, horned and tufted puffins, Arctic and Aleutian terns (Hatch et al., 1978). Capelin comprised the largest component of prey (69%) in sampled shearwaters captured in the GOA (Sanger et al., 1978).

Capelin are also an important winter food in the GOA for marbled murrelet and murres (Krasnow and Sanger, 1982). Humpback whales, *Megaptera novaeangliae*, have been observed to feed heavily on aggregations of capelin in the GOA (Roseneau and Byrd, 1997). Capelin play a key role in the trophic interaction of species, transferring energy from primary production to high trophic level predators in the GOA.

Capelin have shown abrupt declines in occurrence in small-mesh trawl survey samples in the Gulf of Alaska. In both NMFS and ADF&G survey data capelin first declined along the east side of Kodiak Island and bays along the Alaska peninsula. Subsequent declines took place in the bays along the west side of Shelikof Strait. These declines happened quickly and low abundance has persisted for over a decade. The decline was coincident with increases in water temperature of the order of 2° C, which began in the late 1970's. Capelin have fairly narrow temperature preferences, and probably were very susceptible to the increase in water column temperatures (Piatt and Anderson, 1996, Anderson et al. 1997, Anderson and Piatt, 1999).

Data from shrimp cruises in the GOA starting in 1953 and continuing to the present showed no capelin present in catches prior to 1963. A possible reason for this observation may be explained by survey techniques, which ignored "non-commercial" species in the early years when the emphasis was entirely directed toward commercial species. A review of what written material that still remains from these tows revealed that species were simply identified as "smelt" in the early data sets. We believe that many of these records most undoubtedly refer to capelin and eulachon since both of these species have high occurrences in the entire data set. Unfortunately we have no way of telling for sure, except that they are in the family Osmeridae. With the advent of MARMAP program in the early 1970's a more through approach to analyzing catch components in surveys was adopted. In the analysis of the data the year 1970 is useful as a baseline for comparison purposes due to this weakness in the data. Occurrences of capelin between 1963 and 1970 will be used in analyzing distributional patterns only.

Capelin showed two peaks in abundance since 1970 in the GOA. The first peak in abundance occurred in 1974 at little over 4 kg/km in survey catches. The second peak in relative abundance was in 1980 at 7.22 kg/km. In 1980 and 1981 the population dropped to around 1 kg/km and has remained below a tenth of a kg/km since 1985. ADF&G data also clearly shows the peak value of 1980, mostly represented in the Kodiak region. The peaks in relative abundance observed in the mid 1970's, the late 1970's, and 1980 probably reflect strong cohorts or year classes of capelin during those times. Unfortunately data prior to 1970 frequently lacked specificity as discussed above so accurate trends in the data prior to 1970 cannot be assessed.

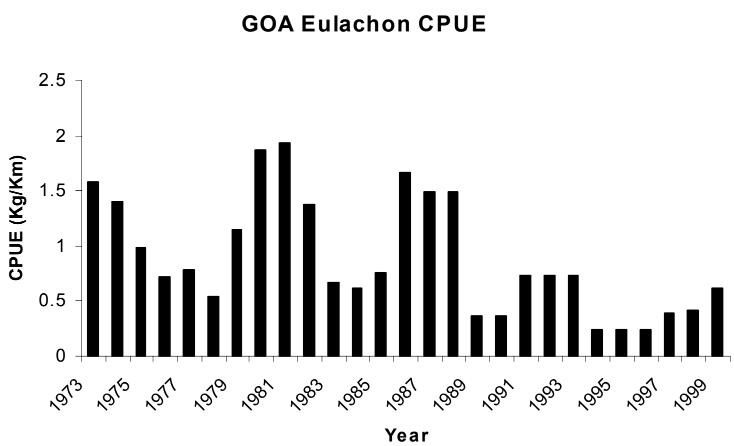


Mapping of relative densities of capelin showed defined areas of relative high abundance. The Shelikof region showed relative high catches in Kujulik, Alitak, and Olga Bays. Most catches of capelin were closely associated with bays with the exception of high catches offshore of Cape Ikolik at the southwest end of Kodiak Island after 1980. Isolated offshore areas east of Kodiak Island showed some high catches, most of the high catches were associated with Ugak and Kazakof Bays. Only isolated catches of less than 50 kilograms were evident in the database from Prince William Sound, Kenai Coast, and Lower Cook Inlet regions. More detailed analysis of these areas of historical high relative abundance will be analyzed in the future.

Eulachon

Eulachon, *Thalicthys pacificus*, are an anadromous smelt that descend several river systems that drain into the GOA in order to spawn in early spring. During these runs are the basis for an important subsistence fishery. Indigenous native use of this important resource has a very long history in the GOA. In addition to its subsistence importance, eulachon is an important forage fish for marine mammals in the GOA. Eulachon were found to be an important part of Steller sea lion diet when stomachs contents were examined 1975-78 (Pitcher, 1981). Eulachon are also an important prey for beluga whales during their spawning runs in Cook Inlet. Studies of proximate composition indicate that eulachon are the highest in oil content of the common forage fish in the GOA, however lower values were observed for spawning and post spawning fish (Payne et. al., 1999).

Eulachon, *Thalicthys pacificus*, showed a peak in abundance in 1981 with an abrupt decline thereafter. Another subsequent peak in abundance at over 1 kg/km occurred in 1986. Since 1987 eulachon has remained at a low level of relative abundance in the data. Eulachon are known to be relatively abundant in areas adjacent to spawning rivers. Subsequent analysis will rely on mapping to better define areas of relative high abundance and abundance trends in those areas along with possible seasonal patterns. Eulachon are apparently recovering from the low recorded levels in the 1990s of 0.01 kg/km current 3 year running average for the species was 0.6 kg/km for 1999. Eulachon typically exhibit cyclic abundance changes possibly due to dominant spawning year-classes.



Pacific sandlance

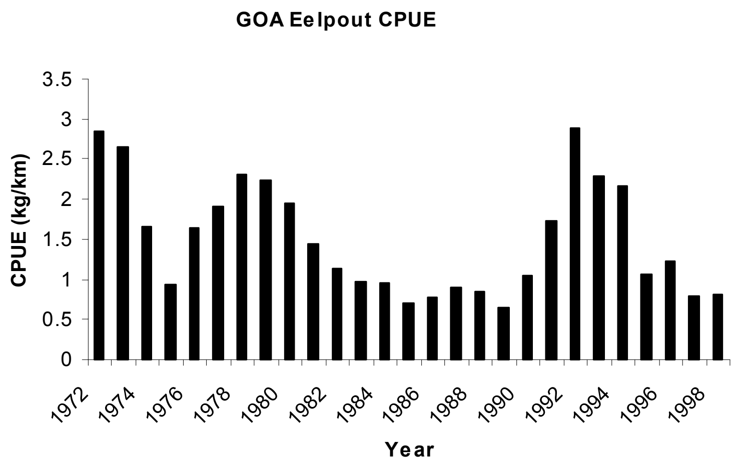
The Pacifc sandlance *Ammodytes hexapterus* is an etremely important forage species in the nearshore zone of the Gulf of Alaska. Massive schools of inshore migrating sand lance have been observed by the authors on numerous occasions near Kodiak Island. These schools provide forage for large cetaceans, surface feeding birds such as kittiwakes, and most near-shore fishes consume sandlance as a major portion of the diet during certain months of the year (Blackburn et al., 1983, Blackburn and Anderson, 1997).

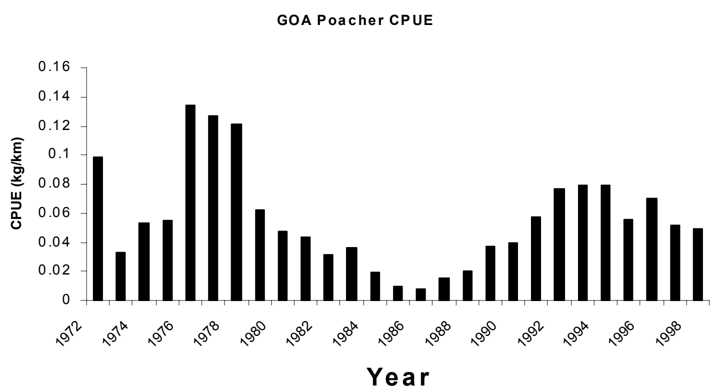
Sand lance in the Kodiak archipelago undergo an extensive migration that is counter to the normal pattern found with many inshore species. Spawning takes place in the late fall and winter, usually being completed in January. Hatching of larvae continues over an extended period of time until March and perhaps April (Blackburn et al., 1983, Blackburn and Anderson, 1997) and some larval fish may spend up to several months in beach sediments. Newly hatched larval sand lance and adults start migrating offshore in the early spring and spend some time in offshore bank areas where they can often be abundant. Offshore ichthyoplankton surveys in the Gulf of Alaska indicate high larval abundance first appearing in early March and remained high until early July, but then disappeared after that (Rugen, 1990). In the late summer, massive schools of fish start migrating inshore to suitable beach habitat for spawning and overwintering. These inshore migrating schools provide important forage for species such as offshore migrating sea birds during late summer and early fall. Hence, sand lance are among one of the few fish which migrate inshore during the late summer months to overwinter near-shore while most other fish migrate offshore prior to winter months.

In the Kodiak area several age classes at different stages of sexual maturity were found during surveys of major resident and spawning beaches. At most, six age categories were found based on the study of otoliths taken from randomly captured fish. Sand lance in the Kodiak area apparently mature at ages 2 or 3 similar to a related species *A. hexapteras marinus* in the Barents Sea. Sandlance are not caught in significant numbers in the small-mesh trawl gear. It is therefore difficult to assess the relative abundance of this species from this data set. However there is a trend towards increases in sandlance larvae from annual plankton samples taken near Kodiak Island since the beginning of the 1980s (based on data from Rugen, 1990).

Other Epibenthic Fishes

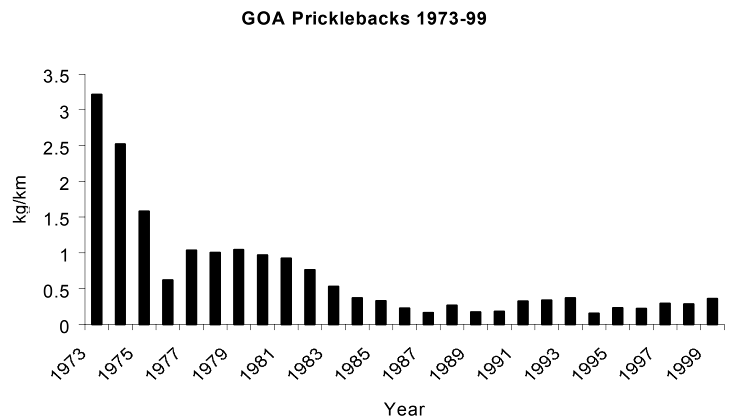
Many non-commercial epibenthic species have also undergone significant declines in abundance. Since many of these species have no known commercial potential they have not always been identified in survey catches as discussed above. However since 1970 most of these species have been identified, enumerated, and weighed in small-mesh trawl surveys.

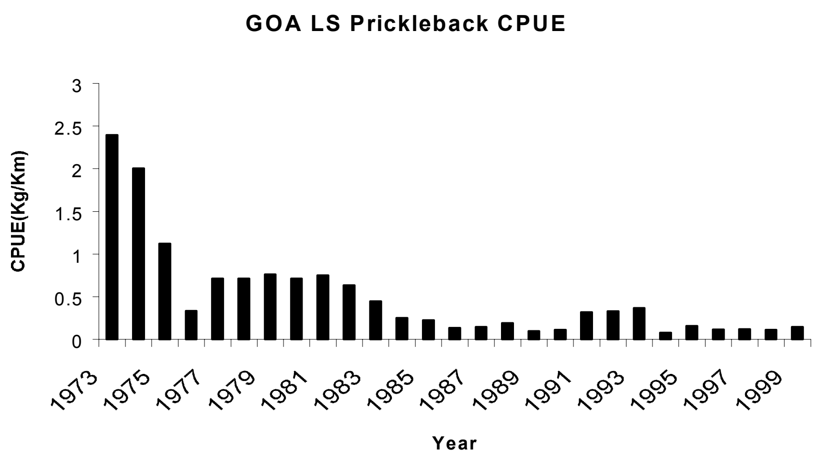




Pricklebacks

Among non-commercial species the most significant change since the early 1970s has been the decline of *Lumpenella longirostris*, long-snout prickleback. Catches of pricklebacks averaged 2 to 3 kg/km in the early 1970s. However since 1981 catches have remained at relative low levels averaging substantially less than 1 kg/km. All pricklebacks combined averaged 0.9 kg/km in the period 1972-99, and have remained stable at 0.3 kg/km in the 1994-99 period. Murres had pricklebacks in their diet during the summer of 1978 (Krasnow and Sanger, 1982).



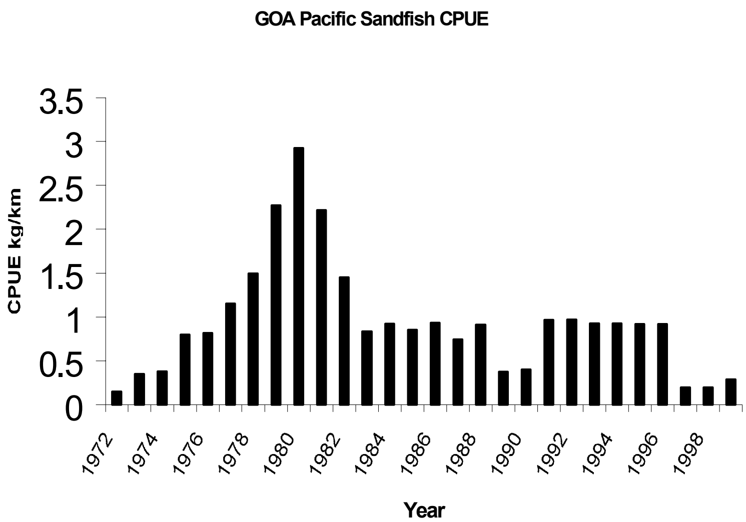


Spiny Lumpsucker

Other minor non-commercial species have also disappeared from inshore sampling areas. *Eumicrotremus orbis*, spiny lumpsucker has completely disappeared from catches in recent years. In the early part of the 1970s this fish was locally abundant in some of the bays along the Alaska peninsula . These species while relatively low in total biomass during the early 1970s are now almost extinct in the near-shore region of the GOA. Highest catch rates of spiny lumpsucker occurred in 1963 and 64, no records of this species in this trawl series have been recorded since 1988. Clearly there is some concern that this species may now be functionally extinct in our survey area.

Pacific Sandfish

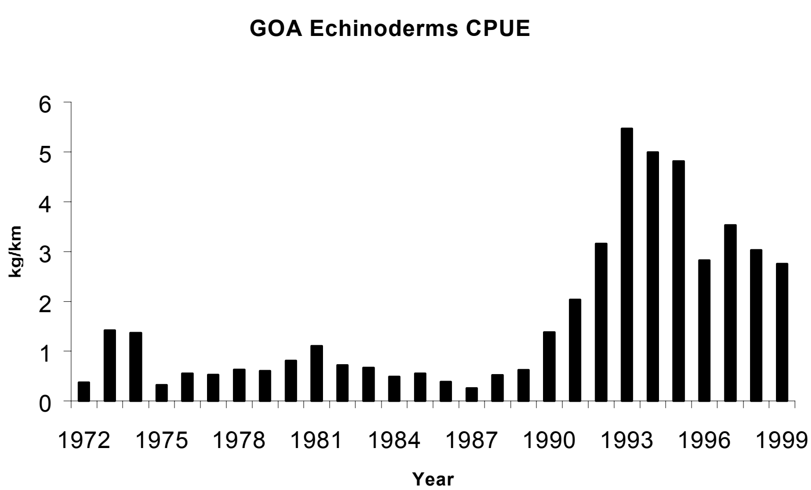
This fish is harvested commercially in Japan because of its desirable row, but is not yet harvested in Alaska. The Pacific sandfish *Trichodon trichodon*, the only member of this genus captured in Alaskan waters, is an important prey for sea birds, seals, and many fishes. Pacific sandfish provided important components of sea bird diet during the breeding season (Krasnow et. al., 1979, Krasnow and Sanger, 1982). Sandfish has been reported in the diet of Pacific halibut, coho and chinook salmon, Pacific cod and seals (Paul et al., 1997, Pitcher, 1980). After reaching a peak abundance in the early 1980s; 3.2 kg/km in 1982, Pacific sandfish show low relative abundance in current data 0.3 kg/km (3 year running average) for 1999.



Other Epibenthic Invertebrates

Sea-stars

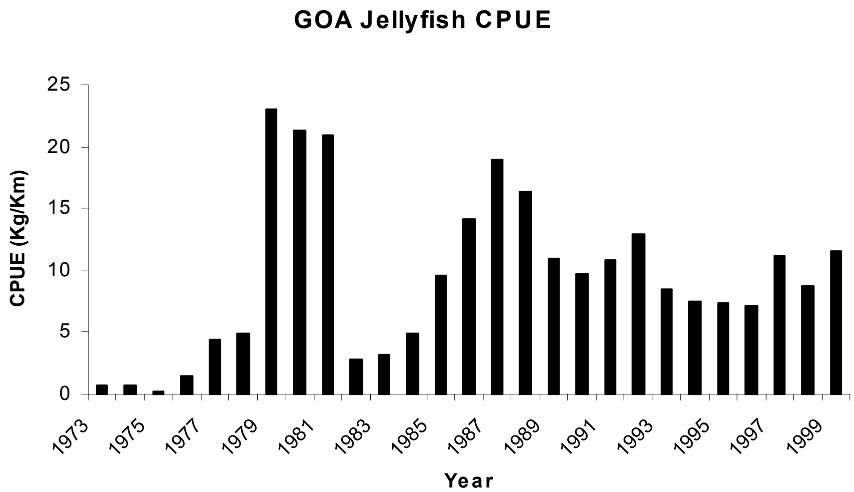
Sea-stars, order Asteroidea, is dominated by only a few species in our historic catch series. The dominant species by far in the recent data from 1972 on is *Asterias amurensis*, the purple orange sea-star. These sea-stars are predators on benthic invertebrates primarily bivalves. This sea-star is also an important food source for crustacean predators such as shrimp and crabs. Catches of this abundant species have fluctuated wildly in recent years. The long-term average abundance of echinoderms (mostly sea-stars) in survey catches is 0.8 kg/km (n=6,924) for 1972-99. Since 1991 catches have been substantially over this long-term index averaging 3.7 kg/km for 1991-99. The highest average catch in a given year was 9.6 kg/km in 1994. These recent high catches of sea-stars probably have significant impact on benthic invertebrate populations and fish species that utilize them for prey. Further studies need to address what impact



a large increase in sea-star biomass may have on epibenthic populations. High king crab populations may have had a mediating effect (predation) on sea-star biomass during periods when crab populations were higher. These relationships between commercial and non-commercial species need to be more fully understood for effective management.

Jellyfish

Jellyfish, in the class Scyphozoa, are not an expected target of the near-bottom small-mesh sampling trawl used in shrimp surveys. Most jellyfish are probably caught somewhere in the water column when our sampling gear is either set or retrieved, or during periods when jellyfish are swimming near the bottom. However small-mesh sampling gear does retain significant jellyfish and data collected over a long temporal scale since the early 1970s does provide a rough index of the relative abundance of these organisms in our survey areas. Jellyfish in three generic groups are

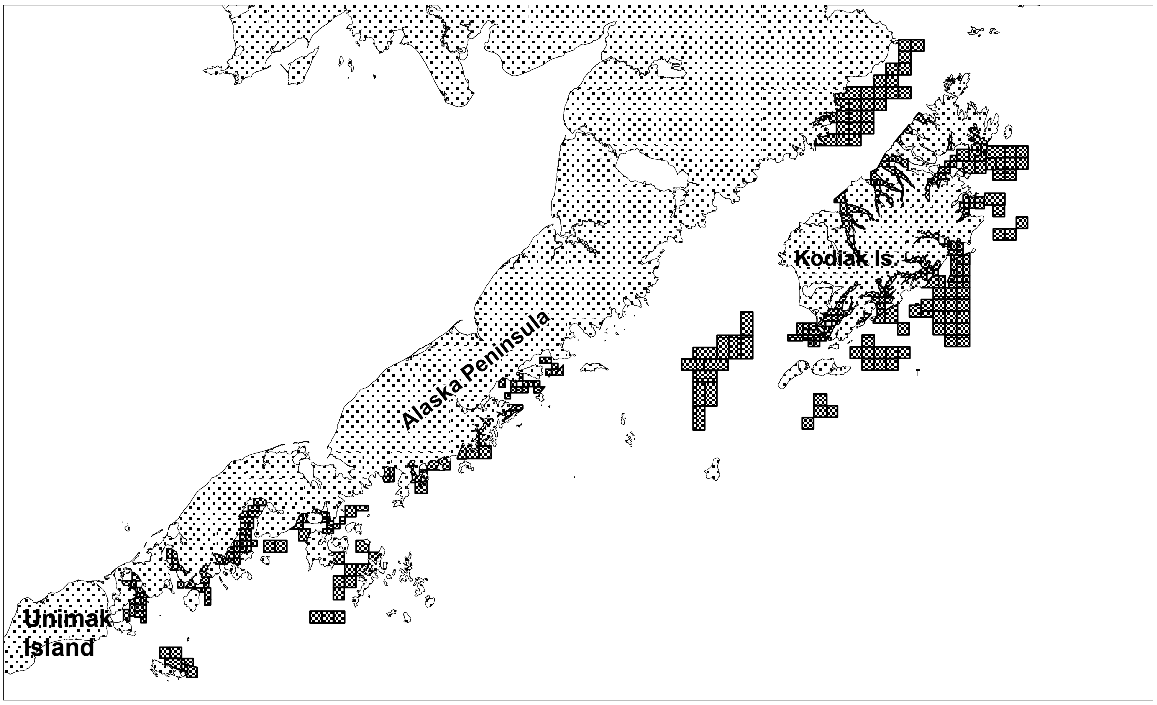


present in small-mesh trawl catches, *Cyanea, Aurelia*, and *Aequorea*. *Cyanea* appears to dominate in most of the catches along the south side of the Alaska peninsula. Average catches were 2.3 kg/km prior to 1980. In 1980 the highest average catch of total jellyfish biomass was observed in small-mesh survey samples averaging 58.2 kg/km (n=548), for that year. In the years 1981-97 catches have averaged 7.1 kg/km (3 year running average), well above the overall average for years prior to 1980 (see fig.). It appears that 1980 was a pivotal year in jellyfish abundance in the GOA. In 1999 a catch of 0.5 kg/km may signal another lower trophic level change is underway in the GOA ecsystem. High jellyfish biomass possibly impacts lower trophic level productivity through predation. Brodeur et al. (1999) reported a dramatic jellyfish increase in the Bering Sea during the 1990s. These observations support the notion that jellyfish may signal significant changes in the low trophic production in the North Pacific. Future research should concentrate on the relationship between jellyfish, primary productivity of the ecosystem, and what their high abundance might mean in impacting year-class strength of commercial and non commercial species.

ADF&G Gulf of Alaska Trawl Survey

Contributed by Dan Urban

In 1980, ADF&G began to switch from pot gear to the 400 Eastern trawl for its surveys of crab stocks. By 1988 the changeover was complete; trawl stations around Kodiak Island, Chignik, and Sand Point had been defined and were being surveyed on an annual basis. These surveys are restricted to soft bottoms only due to the configuration of the footrope.



Stations surveyed in 1999 during the ADF&G trawl survey. One tow per station.

Our survey use of trawl gear began about the same time as large scale climatic and oceanographic changes occurred in the North Pacific. The ecosystem shift from a community dominated by crab, shrimp, and small forage fishes to one dominated by large piscivorous gadid and flatfish species is well reported (e.g., Mueter and Norcross 2000, Anderson et al. 1997). Our survey results confirm this shift: walleye pollock (*Theragra chalcogramma*), arrowtooth flounder (*Atheresthes stomias*) and flathead sole (*Hippoglossoides elassodon*) have consistently been the top three species by weight encountered. Results from Kiliuda and Ugak Bays and the immediately contiguous offshore Barnabas Gully (Figure 1) can be taken as broadly representative of survey results across the region.

Despite their proximity, several important differences between the two areas are obvious from Figure 1. Arrowtooth flounder dominate the catch in the ocean stations while flathead sole are dominate in nearby bays. Skates (*Raja* and *Bathyraja* sp.)and Tanner crab (*Chionecetes bairdi*) have maintained a higher relative proportion of the catch and higher absolute biomass in the bays than in the ocean stations. Trawl survey Tanner crab results contrast with the period before the regime shift when crab CPUE in pot surveys was 1/3 higher in Barnabas Gully stations than in stations in Kiliuda and Ugak bays. Starfish appear to be gradually increasing in relative abundance in both systems, a phenomenon that may be related to the near total disappearance of red king crab, a predator of sea stars (Feder and Paul 1980, Jewett and Feder 1982).

Since 1992, a number of pleuronectids appear to be increasing their ranges as measured by the proportion of stations where they have been captured (Figure 2), although more data is needed to confirm this trend.

Efforts to use this trawl survey data to measure changes in biodiversity are confounded by the fact that more taxa are currently being identified to the species level than when the trawl survey was initiated, these include snails, starfish, skates, and sculpins. Better species identification and increased intensity of catch sampling should position this survey to document future changes to the ecosystem.

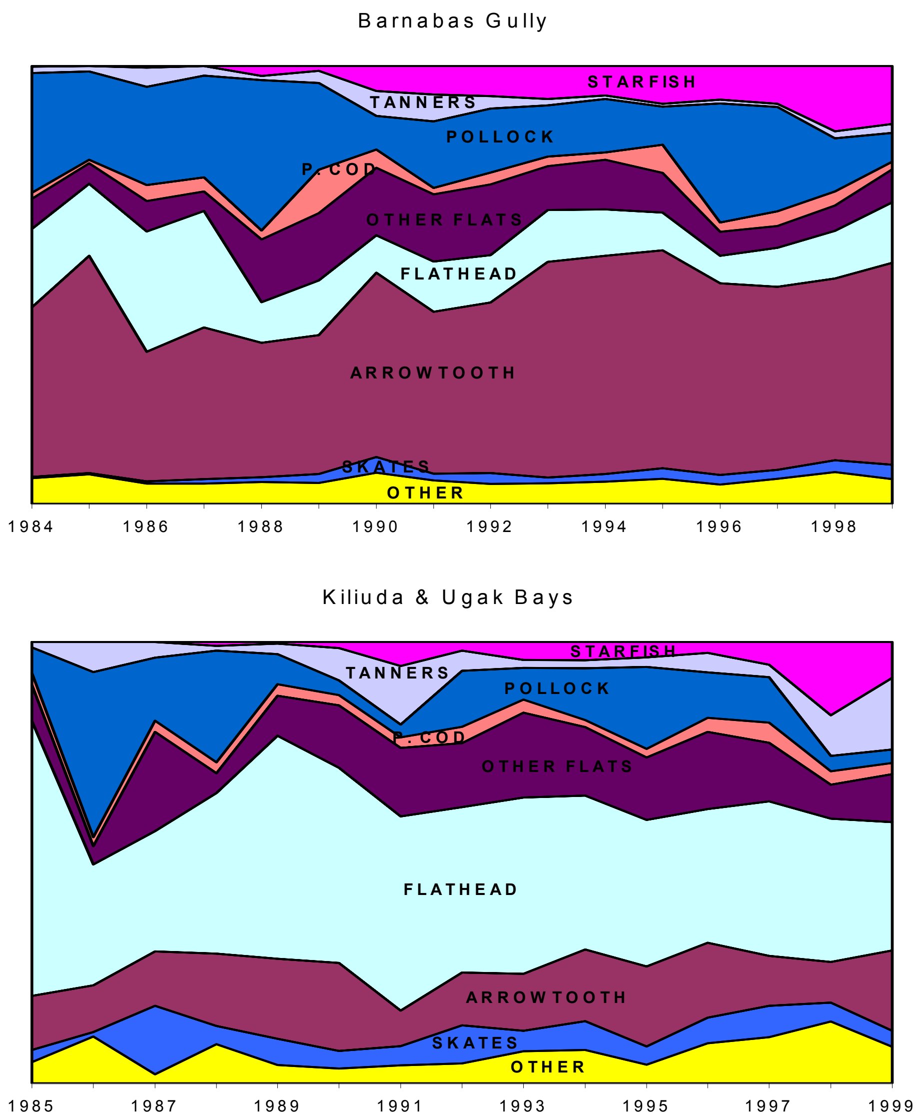


Figure 1. Relative catch of selected species from adjacent bay and offshore areas on the east side of Kodiak Island.

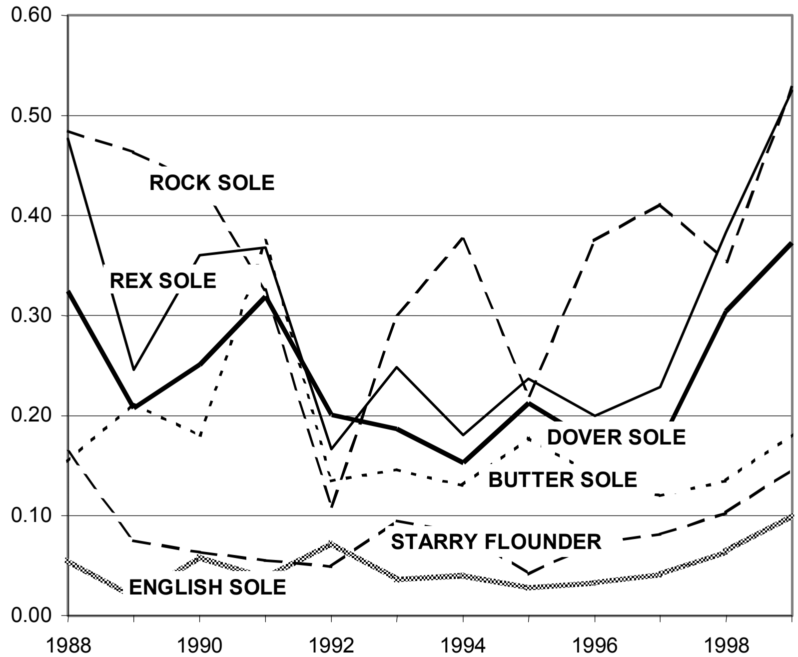


Figure 2. Frequency of occurrence of selected pleuronectids during recent ADF&G trawl surveys in the Gulf of Alaska.

Non-target species in the BSAI and GOA: Case studies on Skates, Grenadiers, and Squid

Contributed by Sarah Gaichas, AFSC

Review of non-target species catch in groundfish fisheries and information for management

We examined catches from groundfish fisheries between 1997 and 1999 to determine the proportion and composition of non-target species groups caught. In addition, we provide information on selected non-target species groups which may inform future management.

The FMPs define four management categories: Target species, Other species, Prohibited species, and Forage fish. All animals not listed in one of these categories are placed by default into a fifth category called Non-specified species.

Under present management, the catch of all non-target species groups combined is very low relative to the catch of the more intensively managed Target species (Figure 1). Our best estimate of non-target species catch over the most recent period of complete data (1997-1999) represents approximately 3% of total catch of all species in the BSAI and 10% of total catch in the GOA. Even when viewed by individual gear type or target fishery, recent observed catches in the BSAI and GOA have been overwhelmingly composed of target species. One exception to this generality appears to be in deepwater longline fisheries, where the catch of Non-specified species may approach that of Target species. We attribute this phenomenon to bycatch of grenadiers, which is discussed in detail below. Note that only Prohibited species catches are limited by current management of non-target species; there are no constraints on overall catch of Non-specified or Forage species, and Other species TACs have never been constraining.

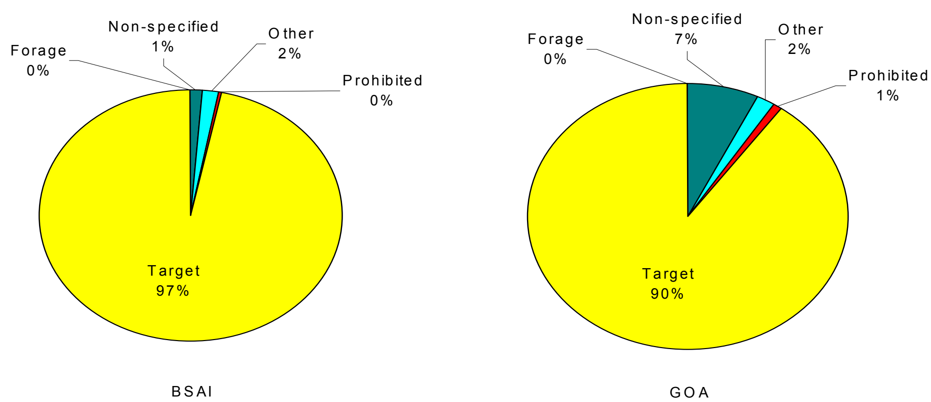


Figure 1 All catch (retained and discarded) by FMP species category in each area, 1997-1999. Proportions are based on weight. Non-target species include the Forage, Non-specified, Other, and Prohibited categories.

Despite the relatively small proportion of non-target species in overall catch, they do receive management attention. Prohibited species catch determines whether the Target species TAC can be taken in major target fisheries. There was no fishery for the ecologically important species in the Forage category, but the category was established recently to prevent future fishing pressure. The highest observed catches of non-target species are within the categories currently under less intensive management: Other and Non-specified. Within these categories, skate (Other) and grenadier (Non-specified) catches are highest (Table 1).

Table 1 Estimated catches (metric tons) of non-target species groups, 1997-1999 with average.

		Bering Sea and Aleutian Islands				Gulf of Alaska			
FMP Category	**Species group**	**1997**	**1998**	**1999**	**average**	**1997**	**1998**	**1999**	**average**
Forage	gunnels	0	0	0	0	0	0	0	0
Forage	lanternfishes	0	0	0	0	0	0	0	0
Forage	sandfish	1	0	3	2	4	2	1	2
Forage	sandlance	0	0	0	0	0	0	0	0
Forage	smelts	30	37	45	37	23	123	26	57
Forage	sticheidae	0	0	0	0	0	0	4	1
Non-specified	anemones	183	114	172	156	18	16	17	17
Non-specified	benthic invets	673	531	226	477	25	31	25	27
Non-specified	birds	29	43	24	32	2	6	6	5
Non-specified	corals	39	28	52	40	4	8	1	4
Non-specified	crabs	304	186	109	200	15	25	11	17
Non-specified	echinoderms	45	24	30	33	23	32	8	21
Non-specified	grenadiers	5,852	6,589	7,388	6,610	12,029	14,683	11,388	12,700
Non-specified	invert unident	1,609	638	140	796	8	43	1	17
Non-specified	jellyfish	8,849	7,148	7,153	7,717	36	167	107	103
Non-specified	other fish spp	1,569	1,363	1,327	1,420	576	8,400	819	3,265
Non-specified	seapen seawhip	3	2	5	3	1	3	3	2
Non-specified	shrimps	3	2	1	2	4	2	1	2
Non-specified	sponges	530	501	322	451	4	4	13	7
Non-specified	starfish	6,191	3,287	3,051	4,177	987	1,245	1,510	1,247
Non-specified	tunicates	1,794	728	372	965	2	1	0	1
Other	dogfish	4	6	5	5	657	865	314	612
Other	octopus	248	190	326	255	232	112	166	170
Other	salmon shark	7	18	30	18	124	71	132	109
Other	sculpins	7,478	6,285	5,470	6,411	907	541	544	664
Other	shark unident	53	136	176	122	123	1,380	33	512
Other	skates	17,747	19,318	14,080	17,048	3,120	4,476	2,000	3,199
Other	sleeper shark	304	336	319	320	136	74	558	256
Other	squids	1,573	1,256	502	1,110	97	59	41	66

Historically, non-target species have been given relatively low priority in both fishery-dependent and fishery-independent data collection programs. Although this has changed in recent years in the North Pacific, data limitation remains the primary assessment and management problem for most non-target species in the Forage, Other, and Non-specified categories. To provide a baseline for future management, we characterize available data for skates, grenadiers and squids.

Skates

At least 11 species of skates have been identified in the BSAI and GOA (Table 2). Skate species are distributed throughout the North Pacific and are common from shallow inshore waters to very deep benthic habitats (Eschmeyer et al., 1983). Skate species are part of the Other species FMP management category. This means that their catch is reported in aggregate as "other" along with the catch of sharks, sculpins, and octopus (BSAI) and squid (GOA). In the BSAI, catch of other species is limited by a TAC which is based on an ABC estimated by the average catch of all other species combined from 1977-present (Fritz, 1999). In the GOA, the TAC of other species has been established as 5% of the sum of the TACs for all other assessed target species in the GOA (Gaichas et al., 1999). The other species TAC has never been exceeded in the BSAI or the GOA with the current composition of the category. Right now, skates are taken only as bycatch in fisheries directed at Target species, so future catches of skates are more dependent on the distribution and limitations placed on target fisheries than on any harvest level established for this category. An FMP amendment (EA/RIR) was initiated by the NPFMC in 1999 to remove both skates and sharks from the Other species category to increase the level of management attention and control for these potentially vulnerable species groups; this action is still in the process of revision and review.

Table 2 Skate species identified during recent and previous AFSC bottom trawl surveys.

Species	Common	BS 99	AI 97	GOA 99	other records
Raja binoculata	big skate	X	X	X	
Raja rhina	longnose skate		X	X	
Raja stellulata	starry skate				all pre-1990
Bathyraja interrupta	Bering skate	X	X	X	
Bathyraja tanaretzi	mud skate	X	X	X	
Bathyraja trachura	black skate		X	X	
Bathyraja parmifera	Alaska skate	X	X	X	
Bathyraja aleutica	Aleutian skate	X	X	X	
Bathyraja lindberghi	commander skate		X	X	
Bathyraja maculata	whiteblotched skate	X	X	X	
Bathyraja minispinosa	whitebrow skate	X	X		
Bathyraja violacea	Okhotsk skate	X			
Bathyraja smirnovi	golden skate				1983 BSAI
Bathyraja spinosissima	white skate				1983 AI
Bathyraja abyssicola	deepsea skate				all pre-1995

Although there are no directed skate fisheries in the North Pacific at present, skates support directed fisheries in other parts of the world (Agnew et al 2000, Martin and Zorzi 1993), so they could be a potentially important fishery resource in the future. However, skate life cycles are similar to those of sharks, with relatively low fecundity, slow growth to large body sizes, and the dependence of population size on high survival rates of a few well developed offspring. Although little specific life history information exists for most skate species, they are generally thought to have limited reproductive capacity relative to gadids, pleuronectids and other exploited groundfish, and thus be vulnerable to overfishing. Large skate species with late maturation (11+ years) are most vulnerable to heavy fishing pressure, with cases of near-extinction reported in the North Atlantic for the common skate *Raja batis* and the barndoor skate *Raja laevis* (Brander, 1981; Casey and Myers, 1998). The management of skate species within aggregate complexes coupled with the apparent population stability for skate species in aggregate has masked the decline of individual skate species in European fisheries (Dulvy et al, 2000). In the North Atlantic, declines in barndoor skate abundance were concurrent with an increase in the biomass of skates as a group. Although we cannot determine if any skate species have declined in the North Pacific during the timeframe of the FMPs (see discussion of available data below), we feel there is adequate evidence that fisheries can have an impact on skate populations, and that stable or rising aggregate skate biomass does not necessarily indicate that no impact is occurring at the species level. Skates are currently the highest non-target catch biomass in the EBS (Table 1 above). Therefore, skates should be given highest priority for improved management of non-target species.

Because observers are not trained to identify individual species of skates, the majority (99.6%) of skate catch is reported as skate unidentified. Therefore, all available catch information is for aggregated skate species, including annual catch and location of catch. We examined fishery data from 1997-1999 to determine total skate catch, catch in different gear types and target fishery (Table 3), and observed location and seasonality of skate catch (see spatial analysis below). We note that catch in the fishery does not necessarily imply mortality for skates; like halibut, skates may survive catch and discard depending on how they are handled. However, for the purposes of management under this alternative we assume that any skate caught dies.

Table 3 Estimated catch (t) of all skate species combined by gear and target fishery.

Bering Sea Aleutian Islands skates					**Gulf of Alaska skates**				
Gear	**1997**	**1998**	**1999**	**average**	**Gear**	**1997**	**1998**	**1999**	**average**
bottom trawl	**3,619**	**5,169**	**3,601**	**4,130**	**bottom trawl**	**2,247**	**1,166**	**926**	**1,446**
pelagic trawl	**311**	**204**	**359**	**291**	**pelagic trawl**	**5**	**15**	**20**	**14**
pot	**1**	**0**	**1**	**1**	**pot**	**1**	**0**	**0**	**0**
longline	**13,816**	**13,945**	**10,118**	**12,627**	**longline**	**867**	**3,295**	**1,054**	**1,738**
Total	**17,747**	**19,318**	**14,080**	**17,048**	**Total**	**3,120**	**4,476**	**2,000**	**3,199**
Target species	**1997**	**1998**	**1999**	**average**	**Target species**	**1997**	**1998**	**1999**	**average**
Arrowtooth	**2**	**118**	**27**	**49**	**Arrowtooth**	**133**	**21**	**49**	**67**
Atka	**111**	**131**	**127**	**123**	**Cod**	**954**	**873**	**1,174**	**1,000**
Cod	**14,016**	**14,305**	**10,636**	**12,985**	**Deepwater flats**	**42**	**31**	**17**	**30**
Flathead	**777**	**1,868**	**1,215**	**1,287**	**Demersal shelf rockfish**	**200**		**22**	**111**
Other flats	**39**	**103**	**69**	**71**	**Flathead sole**	**139**	**130**		**134**
Other rockfish	**110**	**1**	**1**	**37**	**Northern rockfish**	**4**	**9**	**15**	**9**
Other species		**10**	**26**	**18**	**Other species**	**446**	**138**	**0**	**195**
Other targets	**0**	**3**	**1**	**1**	**Pelagic shelf rockfish**	**8**	**15**	**11**	**11**
Pollock B	**52**	**205**	**28**	**95**	**Pollock B**	**29**	**41**	**19**	**30**
Pollock P	**298**	**200**	**347**	**282**	**Pollock P**	**2**	**11**	**5**	**6**
POP	**30**	**40**	**54**	**41**	**POP**	**52**	**15**	**44**	**37**
Rock sole	**679**	**559**	**322**	**520**	**Rex sole**	**489**	**172**	**331**	**331**
Sablefish	**266**	**110**	**110**	**162**	**Sablefish**	**166**	**2,834**	**243**	**1,081**
Shortraker / rougheye		**6**	**0**	**3**	**Shallow water flats**	**427**	**186**	**70**	**228**
Turbot	**157**	**300**	**338**	**265**	**Shortraker / rougheye**	**28**		**1**	**14**
Yellowfin sole	**1,211**	**1,359**	**778**	**1,116**	**Thornyheads**	**1**			**1**
Total	**17,747**	**19,318**	**14,080**	**17,048**	**Total**	**3,120**	**4,476**	**2,000**	**3,199**

Survey biomass in aggregate and by species

Bottom trawl surveys conducted by the AFSC provide reliable estimates of aggregate skate biomass within the timeframe of the FMPs (Table 4).

Table 4 Estimated aggregate biomass (t) of skate species complex from bottom trawl surveys.

Year	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska
1979	74,400		
1980	123,100	10,100	
1981	127,400		
1982	173,200		
1983	166,000	16,300	
1984	190,500		38,800
1985	154,000		
1986	258,000	19,500	
1987	350,800		36,400
1988	452,100		
1989	414,000		
1990	583,800		38,500
1991	467,300	16,500	
1992	377,500		
1993	375,000		63,200
1994	414,200	26,200	
1995	391,800		
1996	423,900		81,200
1997	393,700	30,600	
1998	354,200		
1999	370,500		112,900

As opposed to aggregate skate biomass, biomass for each individual skate species is more difficult to assess. Our knowledge of the number and identity of skate species in our area is developing concurrently with research. Skates as a group have been described as "unique among Chondrichthyes for their relatively high species diversity combined with morphological conservatism"; in other words, there are lots of species that look alike. For this reason, species identification was variable over the course of surveys, ranging from "skate unidentified" to identification of over 10 different species in each area. In addition, skate taxonomy has changed over the course of surveys, with new species described in the North Pacific. Therefore, any apparent trends in species abundance within the skate complex over the period of the surveys are not likely to be reliable. In recent years (~1996 to present) training with increased emphasis on consistent skate species identification has improved this situation dramatically, so that individual skate species may be assessed in the future. Distributional data is also affected by species identification issues. For these reasons, we evaluate biomass and distribution of individual skate species only for recent years where survey scientists are confident of species identification.

The EBS skate complex is dominated by a single species, the Alaska skate (*Bathyraja parmifera)* (Table 5). This species accounts for about 91% of the aggregate skate biomass estimated in 1999. The Bering or sandpaper skate *(Bathyraja interrupta*) was the next most common species in the EBS, making up about 6% of aggregate skate biomass. The other six skate species identified on the survey (see Table 2) made up less than 3% of the aggregate skate complex biomass.

The GOA skate complex is more diverse than that found on the Bering Sea shelf. Four skate species were considered common, with an additional five uncommon species. The big skate (*Raja binoculata*) composed nearly half of the aggregate skate biomass, followed by the longnose skate (*Raja rhina*) at about a third of aggregate biomass. Two *Bathyraja* species, the Aleutian skate *(B. aleutica)* and the Bering skate *(B. interrupta)* were next in abundance, representing about 10%, and 3% of the aggregate biomass, respectively. All five other skate species identified on the 1999 GOA survey made up about 3% of aggregate skate complex biomass.

The skate community in the AI appears to be different from that described for both the EBS and the GOA. In the AI, the most common species on the 1997 survey was the whiteblotched skate, *Bathyraja maculata* (45% of aggregate biomass). Alaska and Aleutian skates were also common, composing about 30% and 15% of aggregate biomass, respectively. All seven other skate species identified on the 1997 AI survey made up about 10% of aggregate skate complex biomass.

Table 5 Estimated biomass (t) for common skate species from recent bottom trawl surveys.

Year	Area	Species	Biomass estimate
1999	**Eastern Bering Sea**	***Bathyraja parmifera***	**337,998**
1999	**Eastern Bering Sea**	***Bathyraja interrupta***	**23,694**
1999	**Eastern Bering Sea**	**All (6) other skate**	**8,580**
1999	**Gulf of Alaska**	***Raja binoculata***	***54,856***
1999	**Gulf of Alaska**	***Raja rhina***	***38,939***
1999	**Gulf of Alaska**	***Bathyraja aleutica***	***11,466***
1999	**Gulf of Alaska**	***Bathyraja interrupta***	***3,899***
1999	**Gulf of Alaska**	**All (5) other skate**	***3,748***
1997	**Aleutian Islands**	***Bathyraja maculata***	***13,750***
1997	**Aleutian Islands**	***Bathyraja parmifera***	***8,649***
1997	**Aleutian Islands**	***Bathyraja aleutica***	***4,543***
1997	**Aleutian Islands**	**All (7) other skate**	***3,623***

Spatial aspects of Fishery catch and Survey distribution by species

Because skate catch is not identified to species, we combined the most recent survey information on species distributions with 1997-1999 observed fishery catch locations in an attempt to determine which species are caught in the fisheries. Although surveys occur in the summer months and fishery catch of skates happens year round, we feel that this approach can at least generate basic information useful for management.

In the Eastern Bering Sea, the results of this analysis indicates that both common skate species are likely to be caught in both longline and trawl fisheries. The more common Alaska skate, *B. parmifera*, is distributed widely throughout the EBS, while the less common Bering skate, *B. interrupta*, appears to be more common in deeper areas of the shelf. Because most fishery catch of skates between 1997 and 1999 has been in this area where the two common species overlap in distribution, we assume that fisheries catch is composed of both of the common EBS skate species.

There are at least four common skate species in the Gulf of Alaska, and there are no clear patterns of species distribution by area or depth. Fishery information is also more sparse in the GOA than in the EBS due to the differences in observer coverage, sothere is little informative overlap between fishery catch of skates and survey observations of skate species distributions. Because we can discern no clear patterns, we must assume that any fishery could be catching any of the skate species identified in the GOA.

While skate diversity in the AI is also high, there are clearer patterns of species distribution, giving some indication that fishing in a certain area is likely to catch a certain species, especially the whiteblotched skate *B. maculata*.

Life History Information

As stated above, skate life cycles are similar to those of sharks, with relatively low fecundity, slow growth to large body sizes, and the dependence of population size on high survival rates of a few well developed offspring. All skate species are oviparous (lay eggs), with one to seven embryos per egg case in locally occurring *Raja* species (Eschmeyer et al., 1983). Available life history information for skate species identified in recent AFSC bottom trawl surveys is summarized in Table 6. The big skate, *Raja binoculata*, is the largest skate in the Gulf of Alaska, but all information reported below was collected for California big skates. Maximum size is 2.4 m, with 1.8m and 90 kg common (Martin and Zorzi, 1993). The longnose skate, *Raja rhina*, achieves a smaller maximum length of about 1.4 m in California. Maximum age reported for the longnose skate was 13 years, although there are many difficulties with ageing skates (Zeiner and Wolf, 1993) and this age is only slightly higher than the age at maturity. Little information is available on on any *Bathyraja* species life history.

Table 6Life history information available for BSAI and GOA skate species.

Species	Common	Max Length (cm)[1]	Max Age	Age Length Mature2	Feeding mode3	n / egg case1	Depth range (m)4	Est. of M
Raja binoculata	big skate	180-240	?	8-12 yrs 109-130 cm	predatory?1	1-7	3-800[5]	0.10
Raja rhina	longnose skate	137	?	7-10 yrs 74-100	?	1	25-675[5]	0.10
Bathyraja interrupta	Bering skate	86	?	?	benthophagic	1	50-1380	0.10
Bathyraja tanaretzi	mud skate	70*	?	?	?	1		0.10
Bathyraja trachura	black skate	89	?	?	?	1	800-2050	0.10
Bathyraja parmifera	Alaska skate	61-91, 113*	?	?	predatory	1	25-300	0.10
Bathyraja aleutica	Aleutian skate	120-150	?	?	predatory	1	300-950	0.10
Bathyraja lindberghi	commander skate	93*	?	?	?	1	175-950	0.10
Bathyraja maculata	whiteblotched skate	120*	?	?	predatory	1	175-550	0.10
Bathyraja minispinos	whitebrow skate	82*	?	?	benthophagic	1	100-1400	0.10
Bathyraja violacea	Okhotsk skate	150*	?	?	benthophagic	1	25-500	0.10

[1]Eschemeyer, 1983 (assuming that *B. kincaidii = B. interrupta*) and *species id notes by Jay Orr (AFSC)
[2]Zeiner and Wolf, 1993.
[3]Orlov, 1998 & 1999 (benthophagic eats mainly amphipods, worms. Predatory diet primarily fish, cephalopods)
[4]McEachran and Miyake, 1990b
[5]Allen and Smith, 1988

The most important life history parameter for our purposes is the natural mortality rate (M). Natural mortality provides an approximation of the amount of fishing mortality a stock can withstand, so that fractions of M are often used to set upper limits on F (Clark 1991). The natural mortality rate can be estimated from information on the maximum age attained by a species (in the absence of fishing mortality). We used a relationship developed from data on many marine species including fish, molluscs and marine mammals to estimate M for skates using all the information available to us. Admittedly, little is known about the life span of many shark and skate species, but some ichthyologists speculate that in larger chondrichhyan fish "maximum ages of 70-100 years or more are likely". We chose to estimate M conservatively at 0.10, a low but reasonable number for larger skates (reflecting a potential maximum age of 40 years), in an attempt to account for the longer-lived species within the complex. We must assume the same natural mortality rate for all skate species in our area until better information is available.

Grenadiers

There are at least 3 common species in the BSAI and GOA; the giant grenadier *Albatrossia pectoralis*, the Pacific grenadier *Coryphaenoides acrolepis*, and the popeye grenadier *Coryphaenoides cinereus*. An additional 8 species are known from the Pacific Ocean, and may be present in the North Pacific. Grenadiers dominate the fish fauna of continental slopes worldwide, and may be pelagic or demersal, but are found only in deep waters (Eschmeyer et al. 1983).

The original GOA FMP (1978) had three management categories: Target, Prohibited, and Other. The Other category contained all species that are in the current Other category plus all that are now in the Non-specified category. Each category had an MSY/OY cap, including Other. It became clear that the inclusion of grenadiers within the Other category could cause the Other MSY/OY cap to be reached before (foreign) fisheries had caught their allocations of target species, because bycatch of grenadiers was high even then. In 1979, GOA FMP plan amendment 5 established a separate management category and TAC of 13,200 t for grenadiers to avoid premature closure of target fisheries due to grenadier bycatch. However, they were removed to the Non-specified FMP category in 1980 (Amendment 8), where they have remained ever since. Within the Non-specified FMP category, there are no requirements for reporting catch of grenadiers, and their catch is not monitored, but retention of grenadiers is permitted. Right now, grenadiers are taken only as bycatch in fisheries directed at Target species, so catches of grenadiers are dependent on the distribution and limitations placed on target fisheries. At the November 1999 Gulf of Alaska Plan Team meeting, GOA grenadier catches were reviewed and there was interest in initiating management for grenadier species, at least as part of the Other species category. This action is being considered within the revision of the proposed FMP amendment to change the management of sharks, skates, and the rest of the Other species category (NPFMC 1999).

Although there are no directed grenadier fisheries in the North Pacific at present, grenadier species support directed fisheries in other parts of the world. The Pacific grenadier is fished commercially in California (Andrews et al. 1999) and its fillets compared favorably with those of Atlantic cod, *Gadus morhua*. Markets are very limited at present for the giant grenadier *A. pectoralis*, but research to develop profitable products from this common North Pacific species is ongoing. Despite the fishery potential of grenadiers, the life history of these particular grenadier species may render them susceptible to overfishing, even as bycatch. Both giant and Pacific grenadiers are very slow growing species which live at least 30 to 50 years, and may reach ages as high as 73 years (Andrews et al. 1999). This life history indicates that grenadier populations may be more vulnerable to and slower to recover from heavy fishing pressure, similar to rockfish and elasmobranch populations. We feel that observed catches of grenadiers are sufficiently high (Table 1 above) to warrant further investigation and management attention, given the general life history of these species and our limited knowledge of their role in deepwater communities. We would prioritize grenadiers next after skates to receive increased protection under the non-target species group.

Because observers are not trained to identify individual species of grenadiers, the majority (100% in 1997-98, 90% in 1999) of grenadier catch is reported as "grenadier unidentified". The other 10% of grenadier catch from 1999 was identified as giant grenadier, *A. pectoralis*. We summarize all available catch information for aggregated grenadier species, including annual catch and location of catch. We examined fishery data from 1997-1999 to determine total grenadier catch, catch in different gear types and target fisheries (Table 7), and observed location and depth of grenadier catch (see spatial analysis below). Unlike skates, grenadiers are almost certainly all killed in the process of being caught and brought to the surface from the depths they inhabit.

Table 7 Estimated catch (t) of all grenadier species combined by gear and target fishery.

Bering Sea Aleutian Islands Grenadiers					**Gulf of Alaska Grenadiers**				
Gear	**1997**	**1998**	**1999**	**average**	**Gear**	**1997**	**1998**	**1999**	**average**
bottom trawl	**214**	**241**	**132**	**195**	**bottom trawl**	**965**	**655**	**529**	**716**
pelagic trawl	**36**	**41**	**79**	**52**	**pelagic trawl**	**28**	**5**	**81**	**38**
pot	**0**	**0**	**0**	**0**	**pot**	**0**	**0**	**0**	**0**
longline	**5,602**	**6,307**	**7,177**	**6,362**	**longline**	**11,037**	**14,023**	**10,777**	**11,946**
Total	**5,852**	**6,589**	**7,388**	**6,610**	**Total**	**12,029**	**14,683**	**11,388**	**12,700**

Target	**1997**	**1998**	**1999**	**average**	**Target**	**1997**	**1998**	**1999**	**average**
Arrowtooth	**0**	**1**	**43**	**15**	**Arrowtooth**	**102**	**28**	**140**	**90**
Atka mackerel	**10**	**92**	**1**	**34**	**Cod**	**191**	**1**	**439**	**211**
Cod	**835**	**693**	**571**	**700**	**Deepwater flats**	**318**	**232**	**285**	**278**
Flathead	**3**	**11**	**3**	**6**	**Demersal shelf rockfish**	**0**		**0**	**0**
Other flats	**0**	**0**	**6**	**2**	**Flathead sole**	**46**	**6**		**26**
Other rockfish	**232**	**1**	**4**	**79**	**Northern rockfish**	**44**	**149**	**2**	**65**
Other species		**0**	**59**	**29**	**Other species**	**0**	**0**	**0**	**0**
Other targets	**0**	**0**	**0**	**0**	**Pelagic shelf rockfish**	**83**	**7**	**26**	**39**
Pollock B	**0**	**0**	**0**	**0**	**Pollock B**	**0**	**2**	**29**	**10**
Pollock P	**36**	**41**	**79**	**52**	**Pollock P**	**28**	**0**	**52**	**27**
POP	**149**	**104**	**115**	**123**	**POP**	**185**	**136**	**29**	**117**
Rock sole	**0**	**0**	**0**	**0**	**Rex sole**	**166**	**77**	**26**	**90**
Sablefish	**2,309**	**881**	**2,008**	**1,732**	**Sablefish**	**10,806**	**14,023**	**10,351**	**11,727**
Shortraker / rougheye		**49**	**0**	**24**	**Shallow water flats**	**20**	**21**	**0**	**14**
Turbot	**2,276**	**4,713**	**4,499**	**3,830**	**Shortraker / rougheye**	**2**		**8**	**5**
Yellowfin sole	**1**	**3**	**0**	**1**	**Thornyheads**	**38**			**38**
Total	**5,852**	**6,589**	**7,388**	**6,610**	**Total**	**12,029**	**14,683**	**11,388**	**12,700**

Survey biomass in aggregate and by species

The reliability of grenadier biomass estimates depends on whether AFSC bottom trawl surveys included sampling of deepwater strata. Deep strata were sampled in 1979, 1981-82, 1985, 1988, and 1991 in the EBS, in 1980, 1983, and 1986 in the AI, and in 1984, 1987, and 1999 in the GOA. We report aggregate biomass estimates from these bottom trawl surveys only, as others may severely underestimate the biomass of these deepwater species (Table 8). Longline surveys directed at sablefish may provide additional information on grenadier biomass as well, at least for giant grenadiers. However, we are not using this information in the present comprehensive analysis, because there are indications that these longline surveys may not extend deep enough to adequately assess the other two common grenadier species. We are fortunate to have very recent biomass estimates for all three common grenadier species from the 1999 GOA bottom trawl survey, but there have been no slope surveys in the EBS since 1991, or in the AI since 1986. This year (2000), a slope survey is being conducted in the EBS; although this information will not be available in time for this analysis, it will be extremely useful in further analyses of grenadiers. We will proceed with our grenadier analysis using only the 1999 GOA bottom trawl survey data, and will defer any analysis in the BSAI until up-to-date information is available. We feel this is justified given the high catch of grenadiers in the GOA relative to the BSAI, and the impending new information from the 2000 BSAI surveys. This also eliminates any questions with species identification on the previous surveys, since survey scientists are confident of species identifications at present. Table 9 lists 1999 trawl survey biomass estimates for the three common grenadier species in the GOA.

Table 8 Estimated aggregate biomass (t) of grenadier species complex from trawl surveys.

Year	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska
1979	91,500		
1980		322,400	
1981	90,500		
1982	104,700		
1983		364,100	
1984			169,800
1985	107,600		
1986		618,100	
1987			136,000
1988	61,400		
1989			
1990			
1991	38,100		
1992			
1993			
1994			
1995			
1996			
1997			
1998			
1999			410,810

Table 9 Estimated biomass (t) for common grenadier species in the GOA, 1999.

Year	Area	Species	Biomass estimate
1999	Gulf of Alaska	*Albatrossia pectoralis*	386,312
1999	Gulf of Alaska	*Coryphaenoides acrolepis*	8,241
1999	Gulf of Alaska	*Coryphaenoides cinereus*	16,260

Spatial aspects of Fishery catch and Survey distribution by species

As with skate catch, we attempted to resolve which species are likely to be caught in the fisheries by combining species distribution information from surveys with the observed fishery catch information from 1997-1999. In this case, information on depth distribution of grenadier species from surveys separated species more clearly than location of catch, because all three species appear to be distributed all along the GOA slope. This depth distribution information is only useful if we also know the depths where fisheries catch grenadiers. Fortunately, we have average depth information associated with each observed catch location which may tell us which species are caught.

According to the observed depth distribution of biomass from the 1999 GOA survey, almost all grenadiers caught shallower than 700 m are giant grenadiers (Figure 2). This depth distribution also suggests that our surveys still do not sample deep enough to fully assess all three common grenadier species found in the GOA; for example, there are indications that the maximum density of Pacific grenadiers occurs around 1500 m depth (Andrews et al, 1999). Catch by average depth and gear type indicates that all three species may be caught in longline fisheries, but the predominant catch in trawl fisheries in the GOA is most likely the giant grenadier, *Albatrossia pectoralis* (Table 10). The depth distribution of longline catch suggests that much of this catch may also be giant grenadiers, but the interpretation of the longline depth data is complicated by the use of an average depth without any indication of the potential depth range. It is possible for a longline set at an average depth of 400-500 m to extend into waters deep enough to catch species other than giant grenadiers.

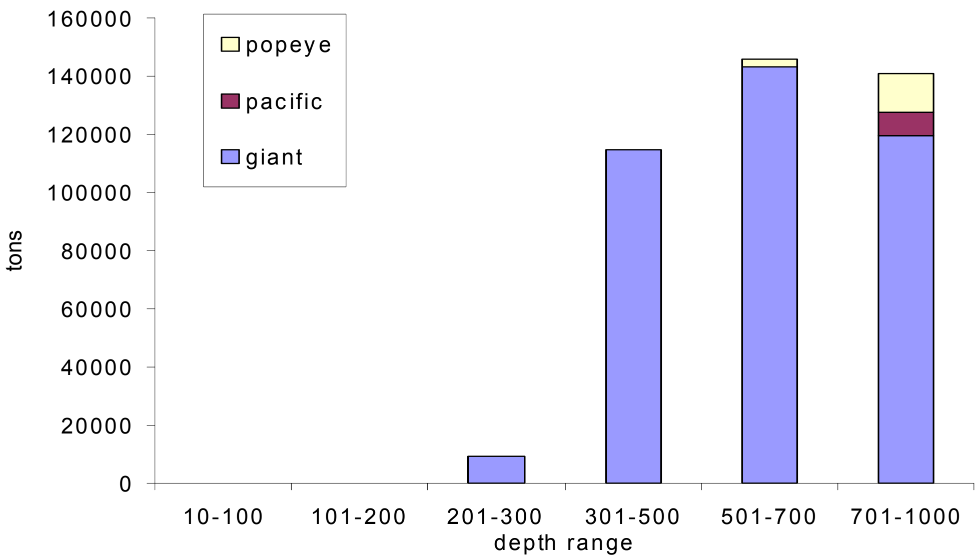


Figure 2. Depth distribution of grenadier biomass on the 1999 GOA survey.

Table 12 Observed GOA fishery catch (t) of grenadiers by average depth and gear type, 1999. These data are from observed sampled sets and hauls only in each year, which is why they total to substantially less than the overall estimated catch of grenadiers in each year. This in part reflects the lower level of observer coverage in the GOA.

observed longline catch						observed bottom trawl catch					
depth range	1997	1998	1999	avg	%by depth	depth range	1997	1998	1999	avg	% by depth
10-100	0	3	5	3	0.10%	10-100	3	1	1	2	0.64%
101-200	81	48	48	59	2.00%	101-200	87	111	23	74	24.70%
201-300	1,080	1,876	958	1,305	44.37%	201-300	190	141	117	149	50.03%
301-500	1,860	1,549	1,284	1,564	53.19%	301-500	66	81	74	74	24.63%
501-700	1	8	0	3	0.10%	501-700	0	0	0	0	0%
701-1000	0	0	12	4	0.14%	701-1000	0	0	0	0	0%
1000+	0	0	10	3	0.11%	1000+	0	0	0	0	0%
Total	3,022	3,484	2,317	2,941	100.00%	Total	346	335	216	299	100.00%

Life history information

As stated above, the grenadiers found in the GOA are very long-lived animals, despite the fact that some do not grow large (Table 11). Giant grenadiers are appropriately named, as they are the largest of all macrourid species. According to research in Russian waters, giant grenadiers form sex-specific aggregations with females found shallower than males, and they migrate seasonally between shallower and deeper waters according to the timing of ovarian maturation and spawning (Novikov 1970). Concentrations of giant grenadiers peak during the summer months in Russian. Giant grenadier have a pelagic juvenile stage, with settlement to benthic habitats thought to coincide with the onset of maturity (Novikov 1970). This life history strategy may protect immature giant grenadiers from fishing pressure. Because grenadiers dominate the biomass in many deep-sea habitats, they are suspected to play an important ecological role in energy transfer, either as pelagic predators, benthic predators, and/or as scavengers on detritus. We have much to learn about grenadier ecology.

Table 11 Life history information available for common GOA grenadier species.

Species	Common	Max Length (cm)	Max Age	Age Length Mature	Feeding mode, Fecundity	Depth range (m)	estimate of M
Albatrossia pectoralis[1]	giant grenadier	150 TL	56	10-16 yrs 50-56 cm TL	?	140-1200	0.074
Coryphaenoides acrolepis2	Pacific grenadier	84 TL	73	20-40 yrs 46-65 cm TL	?	600-2500	0.057
Coryphaenoides cinereus3	popeye grenadier	56 TL	?	?	?	225-2832	0.074

[1]Burton 1999, and references therein.
[2]Andrews et al. 1999, and references therein.
[3]Macrourid life history project notes provided by Jerry Hoff (AFSC)

As we discussed above for skates, the most important life history parameter for our purposes is the natural mortality rate (M). Natural mortality provides an approximation of the amount of fishing mortality a stock can withstand, so that fractions of M are often used to set upper limits on F (Clark 1991). We are fortunate to have the results of recent research to suggest maximum ages for two of the three species, so our estimates of the natural mortality rate M are more species-specific for grenadiers than they were for skates. We estimated M for giant and Pacific grenadier using a regression equation and the maximum reported age for these species derived from otolith readings. Because we have no age and growth information right now for the popeye grenadier, we are assuming that it has a similar lifespan to the giant grenadier, based on preliminary information (Jerry Hoff, AFSC, personal communication).

Squids

The 18 squid species found in the mesopelagic regions of the Bering Sea represent 7 families and 10 genera (Sinclair et al. 1999). Less is known about which squid species inhabit the GOA, but the species are likely to represent both EBS species and more temperate species in the family Loligo, which are regularly found on the U.S. West Coast and in British Columbia, Canada, especially in warmer years (BC squid fishery thing). Squid are distributed throughout the North Pacific, but are common in large schools in pelagic waters surrounding the outer continental shelf and slope (Sinclair et al, 1999). The most common squid species in the Eastern Bering Sea are all in the family Gonatidae. Near the continental shelf, the more common species are *Berryteuthis anonychus* and *Berryteuthis magister*. Further offshore, the likely common species are *Gonatopsis borealis*, *Gonatus middendorfi* and several other *Gonatus* species, according to survey information collected in the late 1980's (Sinclair et al. 1999). In addition, marine mammal food habits data and recent pilot studies indicate that *Ommastrephes bartrami* may also be common, in addition to *Berryteuthis magister* and *Gonatopsis borealis* (B. Sinclair, ASFC, personal communication). Much more research is necessary to determine exactly which species and life stages are present seasonally in the BSAI and GOA.

Squids are part of the Other species FMP category. In the BSAI, catch of all squid species in aggregate is limited by a TAC, which is based on the average catch of squid between 1978 and 1995 (Fritz, 1999). In the GOA, catch of squids is reported within the category “other” along with skates, sharks, sculpins, and octopus, and is limited by a TAC set for the entire complex. This GOA TAC for other species has been established as 5% of the sum of the TACs for all other assessed target species in the GOA (Gaichas et al., 1999). The squid TAC in the BSAI and the other species TAC in the GOA have never been exceeded. However, squid catch in the BSAI became a potential problem within the management of the Community Development Quota (CDQ) program. Because each CDQ group receives an allocation of groundfish which is 7.5% of the TAC set for each species, the groups would be required to restrict squid catch to a low level, potentially constraining target fisheries. This is more an example of the difficulties with managing very small TACs than with managing squid in particular, because the squid TAC is one of the smallest TACs in the BSAI (ref 2000 harvest specifications for BSAI groundfish). The NPFMC approved BSAI FMP amendment 66 to remove squid from the CDQ program in June 1999, and the Final Rule is pending (Federal Register, May 30, 2000). Under this rule, the catch of squid within the CDQ program is still monitored, and still counts against overall BSAI squid TAC, but CDQ groups will not be restricted to 7.5% of the squid TAC.

Although there are no directed squid fisheries in the Eastern North Pacific, there are many fisheries directed at squid species worldwide, although most focus on temperate squids in the genera *Ilex* and *Loligo* (Agnew et al. 1998, Lipinski 1998). There are fisheries for *Berryteuthis magister* in the Western Pacific, including Russian trawl fisheries with annual catches of 30,000 - 60,000 metric tons (Arkhipkin et al., 1995), and coastal Japanese fisheries with catches of 5,000 to 9,000 t in the late 1970's-early. In addition to the fishery potential of North Pacific squids, they were selected for analysis because of the crucial role they play in marine ecosystems. Squid are important components in the diets of many seabirds, fish, and marine mammals, as well as voracious predators themselves on zooplankton and larval fish (Caddy 1983, Sinclair et al. 1999). Many squid populations are composed of spatially segregated schools of similarly sized (and possibly related) individuals, which may migrate, forage, and spawn at different times of year (Lipinski, 1998). The timing and location of fishery interactions with squid spawning aggregations may affect the availability of squid as prey for other animals as well as the squid populations themselves (Caddy 1983, O’Dor 1998). The essential position of squids within North Pacific pelagic ecosystems combined with our limited knowledge of the abundance, distribution, and biology of squid species in the FMP areas make squids a good case study to illustrate management of an important resource with little information.

Because observers are not trained to identify individual species of squids, the majority (99%) of squid catch is reported as “squid unidentified”. No species codes for the likely common species, *Berryteuthis magister* and *Gonatopsis borealis*, have been established for observers to use even if they did identify these species. We summarize all available catch information for aggregated squid species, including annual catch and location of catch. We examined fishery data from 1997-1999 to determine total squid catch, catch in different gear types and target fisheries (Table 12), and observed location of squid catch (see spatial analysis below). Unlike skates, squids are rather delicate are almost certainly all killed in the process of being caught, regardless of gear type or depth of fishing.

Squid catch in the FMP areas is low relative to the catch of skates and grenadiers, and relative to the reported catches of squid from directed fisheries in the western Bering Sea. The majority of squid catch in all areas occurs in the pelagic trawl fishery directed at pollock in the EBS (Table 12). In the GOA, catches of squid are estimated to be low overall, but most squid catch comes from the pollock fishery in this area as well. Squids are also caught in smaller amounts in bottom trawl fisheries in both areas, while catches are negligible in fixed gear fisheries. We focus on squid catch in EBS pollock pelagic trawl fisheries for the remainder of this case study, since this represents the majority of squid catch in areas covered by the FMPs.

Table 12 Estimated catch (t) of all squid species combined by gear and target fishery.

Bering Sea Aleutian Islands					**Gulf of Alaska**				
Gear	**1997**	**1998**	**1999**	**average**	**Gear**	**1997**	**1998**	**1999**	**average**
bottom trawl	**69**	**23**	**28**	**40**	**bottom trawl**	**17**	**13**	**18**	**16**
pelagic trawl	**1,505**	**1,233**	**473**	**1,070**	**pelagic trawl**	**80**	**46**	**20**	**49**
pot	**0**	**0**	**0**	**0**	**pot**	**0**	**0**	**0**	**0**
longline	**0**	**0**	**0**	**0**	**longline**	**0**	**0**	**2**	**1**
Total	**1,573**	**1,256**	**502**	**1,110**	**Total**	**97**	**59**	**41**	**66**
Target fishery	**1997**	**1998**	**1999**	**average**	**Target fishery**	**1997**	**1998**	**1999**	**average**
Arrowtooth	**0**	**3**	**3**	**2**	**Arrowtooth**	**1**	**3**	**1**	**1**
Atka	**16**	**8**	**5**	**10**	**Cod**	**1**	**1**	**1**	**1**
Cod	**8**	**2**	**0**	**3**	**Deepwater flats**	**5**	**3**	**6**	**5**
Flathead	**1**	**2**	**2**	**2**	**Demersal shelf rockfish**	**0**		**0**	**0**
Other flats	**0**	**1**	**5**	**2**	**Flathead sole**	**1**	**0**		**1**
Other rockfish	**0**	**0**	**0**	**0**	**Northern rockfish**	**1**	**1**	**0**	**1**
Other species		**0**	**0**	**0**	**Other species**	**14**	**0**	**0**	**5**
Pollock B	**92**	**28**	**4**	**41**	**Pelagic shelf rockfish**	**2**	**1**	**2**	**2**
Pollock P	**1,446**	**1,208**	**471**	**1,042**	**Pollock B**	**0**	**0**	**1**	**1**
POP	**7**	**1**	**6**	**4**	**Pollock P**	**66**	**45**	**19**	**43**
Rock sole	**0**	**0**	**0**	**0**	**POP**	**4**	**4**	**5**	**4**
Sablefish	**0**	**0**	**0**	**0**	**Rex sole**	**1**	**1**	**4**	**2**
Shortraker / rougheye		**0**	**0**	**0**	**Sablefish**	**0**	**0**	**2**	**1**
Turbot	**4**	**3**	**4**	**3**	**Shallow flats**	**0**	**0**	**0**	**0**
Yellowfin sole	**0**	**0**	**0**	**0**	**Shortraker / rougheye**	**0**		**0**	**0**
Other targets	**0**	**0**	**0**	**0**	**Thornyheads**	**0**			**0**
Total	**1,573**	**1,256**	**502**	**1,110**	**Total**	**97**	**59**	**41**	**66**

Survey biomass in aggregate and by species

The AFSC bottom trawl surveys are directed at groundfish species, and therefore do not employ the appropriate gear or sample in the appropriate places to provide reliable biomass estimates for the generally pelagic squids. Although midwater acoustic and trawl surveys are conducted in the EBS annually by the AFSC, all sampling on these surveys is directed at pollock. Squid records from these surveys tend to appear at the edges of the continental shelf, which is at the margin of the sampling strata defined for these surveys. The available information from 1988 and 1989 Japanese / U.S. pelagic trawl research surveys in the EBS indicates that the majority of squid biomass is distributed in pelagic waters off the continental shelf (Sinclair et al. 1999), beyond the current scope of the AFSC surveys. These midwater surveys provided the information we have to indicate which species might be found in the EBS, but they were characterized by extreme variability in species abundance between years. The bottom line is, there is no reliable biomass estimate for squids, either in aggregate or by species, for any year in any FMP area at this time.

Spatial aspects of Fishery catch and Survey distribution by species

As with skate and grenadier catch, we attempted to resolve which squid species are likely to be caught in the EBS pollock fishery by combining species distribution information from surveys with the observed fishery catch information from 1997-1999. While the surveys do not cover enough area to provide biomass estimates for squids, they do cover many of the areas where pollock fisheries catch squids. This analysis confirms that *Berryteuthis magister* is likely to be present in at least some fishery catches of squid. As with many other non-target species, identification of squids on past surveys was not always attempted, so records labeled as “other squid” may or may not also represent Berryteuthis magister. Fisheries catch squids mostly along the outer continental shelf, and that catch is concentrated in certain areas, especially around submarine canyons.

Life history information

In contrast with the previous case study species, squids are highly productive, short-lived animals. They have been described as “the marine equivalent of weeds,” displaying rapid growth, patchy distribution and highly variable recruitment (O’Dor 1998). Unlike most fish, squids may spend most of their life in a juvenile phase, maturing late in life, spawning once, and dying shortly thereafter. Whereas many groundfish populations (including skates and grenadiers) maintain stable populations and genetic diversity over time with multiple year classes spawning repeatedly over a variety of annual environmental conditions, squids have no such “reserve” of biomass over time. Instead, it is hypothesized that squids maintain a “reserve” of biomass and genetic diversity in space with multiple cohorts spawning and feeding throughout a year and over a wide geographic area across locally varied environments (O’Dor 1998). Many squid populations are composed of these spatially segregated schools of similarly sized (and possibly related) individuals, which may migrate, forage, and spawn at different times of year (Lipinski 1998). Most information on squids refers to *Illex* and *Loligo* species which support commercial fisheries in temperate and tropical waters. Of North Pacific squids, life history is best described for western Pacific stocks (Arkhipkin et al. 1995).

The most commercially important (and therefore best studied) squid in the western north Pacific is the magistrate armhook squid, *Berryteuthis magister*. This species is distributed from southern Japan throughout the Bering Sea, Aleutian Islands, and Gulf of Alaska to the U.S. West coast as far south as Oregon. The maximum size reported for *B. magister* is 28 cm mantle length. The internal vestigial shell, or gladius, and statoliths (similar to otoliths in fish) were compared for ageing this species (Arkhipkin et al., 1995). *B. magister* from the western Bering Sea are described as slow growing (for squid) and relatively long lived (up to 2 years). Males grew more slowly to earlier maturation than females. *B. magister* were dispersed during summer months in the western Bering sea, but formed large, dense schools over the continental slope between September and October. Stock structure in this species is complex, with three seasonal cohorts identified in the region: summer-hatched, fall-hatched, and winter-hatched. Growth, maturation, and mortality rates varied between seasonal cohorts, with each cohort using the same areas for different portions of the life cycle. For example, the summer-spawned cohort used the continental slope as a spawning ground only during the summer, while the fall-spawned cohort used the same area at the same time primarily as a feeding ground, and only secondarily as a spawning ground (Arkhipkin et al., 1995).

Management implications

TAC setting is currently the preferred management tool to prevent overfishing and maintain healthy stocks of target species in the North Pacific. To implement a TAC for non-target species groups, we need (minimally) a reliable estimate of biomass, a reasonable estimate of natural mortality, and the ability to monitor catch so that we can determine when the TAC is taken. We have enough information (biomass, estimated M) to set aggregate TACs for the skate complex in the BSAI and GOA, and the grenadier complex in the GOA. We also have reasonably good catch estimates for these non-target species groups in aggregate. Setting aggregate biomass TACs for the skate species complex and the grenadier species complex would achieve a higher level of protection for these groups than current management. However, the problem with an aggregate TAC occurs when species within the complex have different levels of productivity and vulnerability to overfishing. Our catch accounting for skates and grenadiers at the aggregate level might still allow the less productive species to be harvested at disproportionally high levels, so that these species might be overfished even within the overall TAC constraint for the skate or grenadier complex. This is an especially important problem for grenadiers, since the Pacific grenadier which is least common according to our surveys has the most commercial potential, and could easily be targeted if the fishery changes depth.

For skates and grenadiers, the most effective application of TAC management would be at the individual species level. We have enough information (species biomass, estimated M) to set an individual species TAC for several skate species in the BSAI and GOA, and at least one grenadier species in the GOA, the giant grenadier. The biggest impediment to effective management using individual species TACs is the lack of identification of grenadiers to species in the fishery. This means that our individual species TACs, once set, cannot be monitored either inseason or post-season, and therefore cannot be used to limit catch by species.

Another option would be to set an aggregate TAC by area/depth or gear strata, corresponding to the distribution of the rare and common species. This could be especially effective for grenadiers, as has been suggested by some researchers. Setting TAC by depth range could not only effectively manage each species in a mixed species fishery, but it could also protect vulnerable life stages for a particular species. Some researchers suggest that restricting fishing to a range of 1200-1800 m would minimize fishing pressure on both juvenile and very large adult Pacific grenadiers in the California fishery.

The rapid dynamics reported for squid species and their subpopulations indicates that the temporal and spatial scales for assessment of squids are different from the annual and basinwide scales we apply to most groundfish. Therefore, even if we had a reliable estimate of biomass, we would have to understand the relative composition of cohorts and their movements and different mortality rates in order to apply TAC management effectively. If we used a previous year's biomass estimate to set a TAC for the following year for squids (as we do for Target species), there would be a significant probability that this TAC would be far too high or low relative to the current year's biomass due to the great interannual variability of squid stocks (Caddy 1983). To avoid this problem, biomass would have to be estimated for a given species and TAC set and taken within a very short time period, potentially less than one year. Even this intensive management scenario would leave open the possibility that an entire seasonal cohort could be eliminated by fishing unless additional temporal or spatial management measures ensured that fishing pressure was distributed between cohorts. Both effort controls and closed areas and seasons have been suggested as more effective management tools than TAC setting for maintaining adequate levels of squid spawning stock biomass (Caddy 1983, O'Dor 1998). An understanding of the biology and dynamics of squid life cycles at the species level is essential for the application of any management tool (Lipinski et al 1998).

Summary

These three non-target species groups illustrate some of the data limitation issues common to the majority of non-target species. While the observed proportion of non-target species catch in the BSAI and GOA is very low compared with target species catch, the most important indirect effect of our current system, which focuses on intensive and detailed target species management, is data limitation for non-target species.

Given this overview of available information, we might be able to apply management tools such as TAC setting or area closures to limit the catch of selected non-target species groups. However, we would be unable to determine whether the catch limitation actually achieved policy objectives similar to those we apply to target species, which are generally to prevent overfishing, maintain healthy stocks, and rebuild depressed stocks. We have inadequate information to assess the status of the skates, grenadiers and squids at this time, and this is likely true of nearly any other non-target stock we could have selected. In general, we lack information on abundance trends by species, recruitment, the size or age distribution in the population or in the catch, and even catch and effort data for most non-target species at a level which is useful to meet the policy objectives--the species or even the stock level. Basic biological information is missing for many non-target species, including adequate species descriptions in some cases. The lack of this information will always make it difficult to apply management tools of any kind in a way that demonstrably achieves the policy objectives for non-target species.

Our inability to achieve the policy objectives due to our current data limitations does not mean that there is no use in applying management tools which limit or reduce catch of non-target species. Taken on a case by case basis, there is merit in monitoring and controlling catches of these species simply as a conservative measure until we have better information. The groups listed above are examples where this type of management may be warranted, especially because catches of some of these groups (skates and grenadiers) are relatively high and their life histories may make them particularly vulnerable to fishing. The ultimate goal for non-target species should be to collect adequate information to assess the effects of fishing (if any) on these stocks so that data limitation does not force us into overly-conservative management.

Alaska Shark Assessment Program

Contributed by Lee Hulbert, AFSC

Fisheries survey data and anecdotal information strongly indicates spiny dogfish sharks (*Squalus acanthias*), Pacific sleeper sharks (*Somniosus pacificus*), and salmon sharks (*Lamna ditropis*) increased in abundance in the northeastern gulf coast of Alaska and Prince William Sound during the 1990's. Increases in shark abundance follows 10-15 years after a warming trend in the north Pacific Ocean that transpired in the winter of 1976-77. The ocean climate regime shift paralleled changes in community structure with the decline of the forage base (pandalid shrimps and capelin) in the late 1970's, followed by increases in high trophic-level groundfish (pollock, cod, and flatfishes) during the 1980's and into the 1990's. Increases in shark species abundance may be due to population increase or shift in range, but is likely a delayed but natural succession of sharks in the apex predator community of the Gulf of Alaska ecosystem. Because of their size and longevity evidence of sharks ascension in the community structure of the region likely indicates that their dominance would persist for a long time.

Is the trend in shark abundance due to population increase or range extension? Are the sharks more affected by climate regime shift or trophic regime shift? The cause and consequences of the trend are unclear. Monitoring shark population trends through better bycatch data records and directed surveys, combined with research describing the sharks' spatial and temporal movements, diet, and demographics, will contribute greatly to the understanding of the role of sharks as indicators of and their effects on trophic community structure.

Few historical indices of shark abundance in the GOA exist because shark species have been identified as "other" or "shark" in historical fisheries survey and observer data records. Therefore, both empirical and anecdotal evidence of dogfish, sleeper, and salmon shark abundance trends will be presented as supporting evidence of temporal changes in shark abundance in the GOA.

Spiny Dogfish Sharks (*Squalus acanthias*)

Spiny dogfish are commonly taken as bycatch in commercial fishing gear in Alaska. They are particularly well represented in the pelagic trawl Pollock fishery and in longline fisheries for sablefish *(Anoplopoma fimbria*), halibut (*Hippoglossus stenolepis*), Greenland turbot (*Reinhardtius hippoglossoides*), Pacific cod (*Gadus macrocephalus*) and rockfish (*Sebastes spp.*). Large aggregations of dogfish along the eastern GOA from Yakutat to the Copper River in the late 1990's appear to be unprecedented in recent memory and have recently caused damage to fishing gear and loss of fishing time to commercial salmon drift net fishermen. Fishermen in these areas reported few problems with dogfish prior to the 1990's.

International Pacific Halibut Commission (IPHC) longline grid surveys expanded in 1996 to include statistical areas from Cape Spencer to Hinchinbrook Entrance. The survey data indicate an increasing trend in relative abundance of dogfish along the eastern and central gulf coast of Alaska in the 1990's (Fig. 1). The downturn in this trend in 1999 corresponds to a virtual no-show for eulachon in the Copper River, although fishermen in the Yakutat area continued to have problems with dogfish swamping salmon gill-nets. Dogfish bycatch have presented a formidable problem for IPHC statistical analyses of halibut abundance in recent years, a problem that has not been resolved (Dan Randolph 1999 pers.comm.).

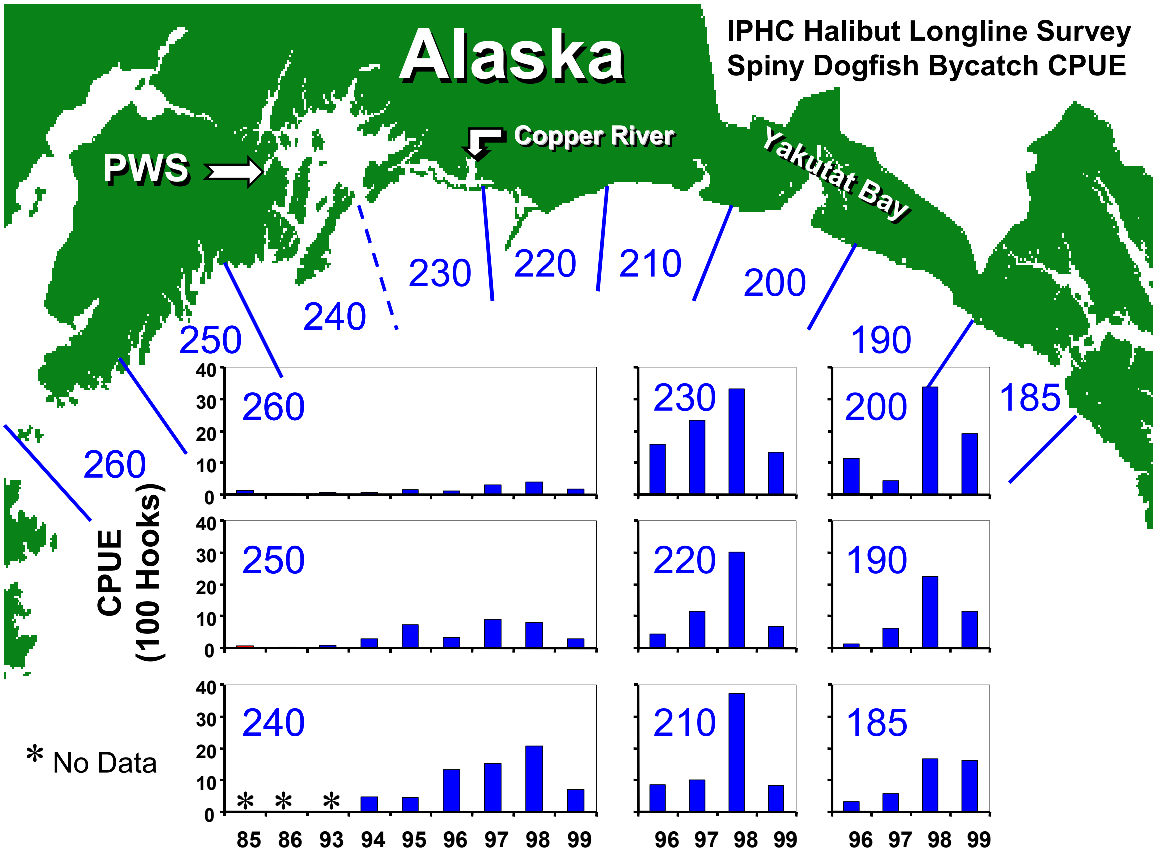


Figure 1. Spiny dogfish catch per standardized skate (100 hooks) averaged across stations within International Pacific Halibut Commission statistical areas (Dan Randolph, International Pacific Halibut Commission, unpublished data).

The trend is supported by data from Paul Anderson and Jim Blackburn with the NMFS lab in Kodiak who conduct standardized small mesh trawl surveys in the Kodiak Island region (Fig. 2).

Occurrence of Dogfish in Kodiak Area,

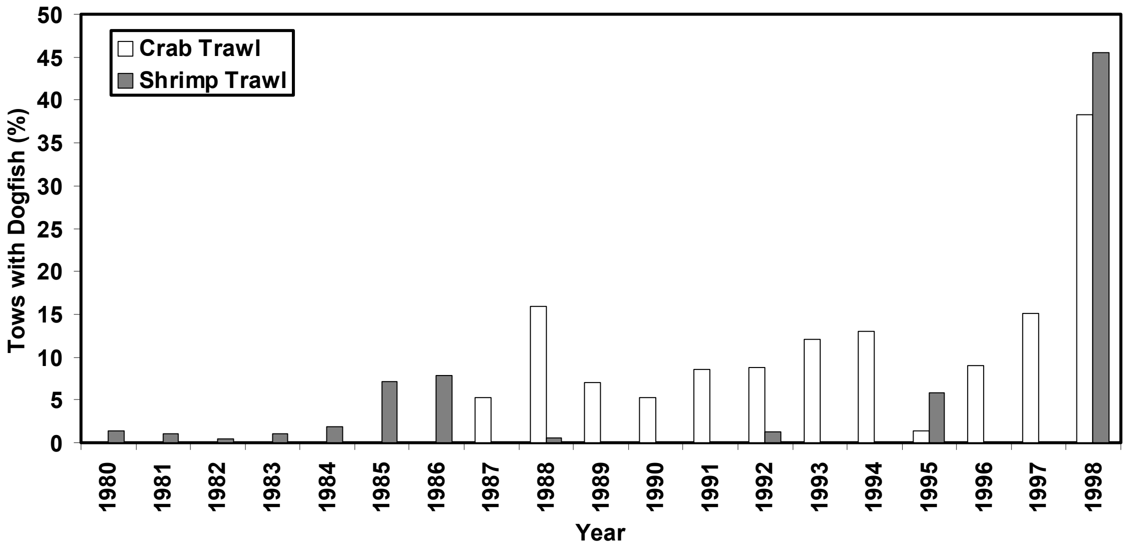


Figure 2. Percent of small-mesh trawl tows with dogfish in the northern Gulf of Alaska (GOA) between 1980 and 1998 (Jim Blackburn and Paul Anderson, NMFS Alaska Fisheries Science Center, Kodiak, Alaska, unpublished Data).

The data are percent of tows with dogfish from 1980 to 1998, and clearly shows the spike in relative abundance of dogfish we saw in the Halibut Commission data. Only one tow in more than 1500 shrimp tows from 1975 through 1979 contained dogfish.

Pacific Sleeper Shark (*Somniosus pacificus*)

Pacific sleeper sharks are often caught on commercial longline gear targeting halibut and sablefish in Alaska. They are one of the few sharks found in polar waters year-round. Sleeper sharks range from the Chukchi Sea, and possibly the East Siberian and Beaufort seas, to the Bering Sea and in the Pacific Ocean to Baja California and off Japan including the Okhotsk Sea. Noted for its lethargic nature, the sleeper shark is a large demersal species generally inhabiting deep water from 238-2,000m (780- 6,562 feet). At high latitudes however, they venture into the littoral and intertidal zones and occasionally come to the surface (Eschmeyer et al. 1983). They are reported to reach lengths to 7.6 m, although average length and weight are 3.6 m and 320-365kg. A specimen in Kachemak Bay measured 3.93m (12.9ft) total length.

NMFS and Halibut Commission researchers in Alaska have caught specimens in the 6 meter range although they average 1.8-2.4 meters in length in PWS sablefish surveys (Lee Hulbert 1999 unpublished data). Sleeper sharks are opportunistic predators whose diet consists primarily of groundfish, squid, and salmon. They are also known to prey on marine mammals, including harbor seals and southern right whale dolphins.

The International Pacific Halibut Commission expanded their survey into Prince William Sound in 1998 (Figure 3). Six of the 12 stations had catches of 60 or more sharks per 700 hooks in 1998.

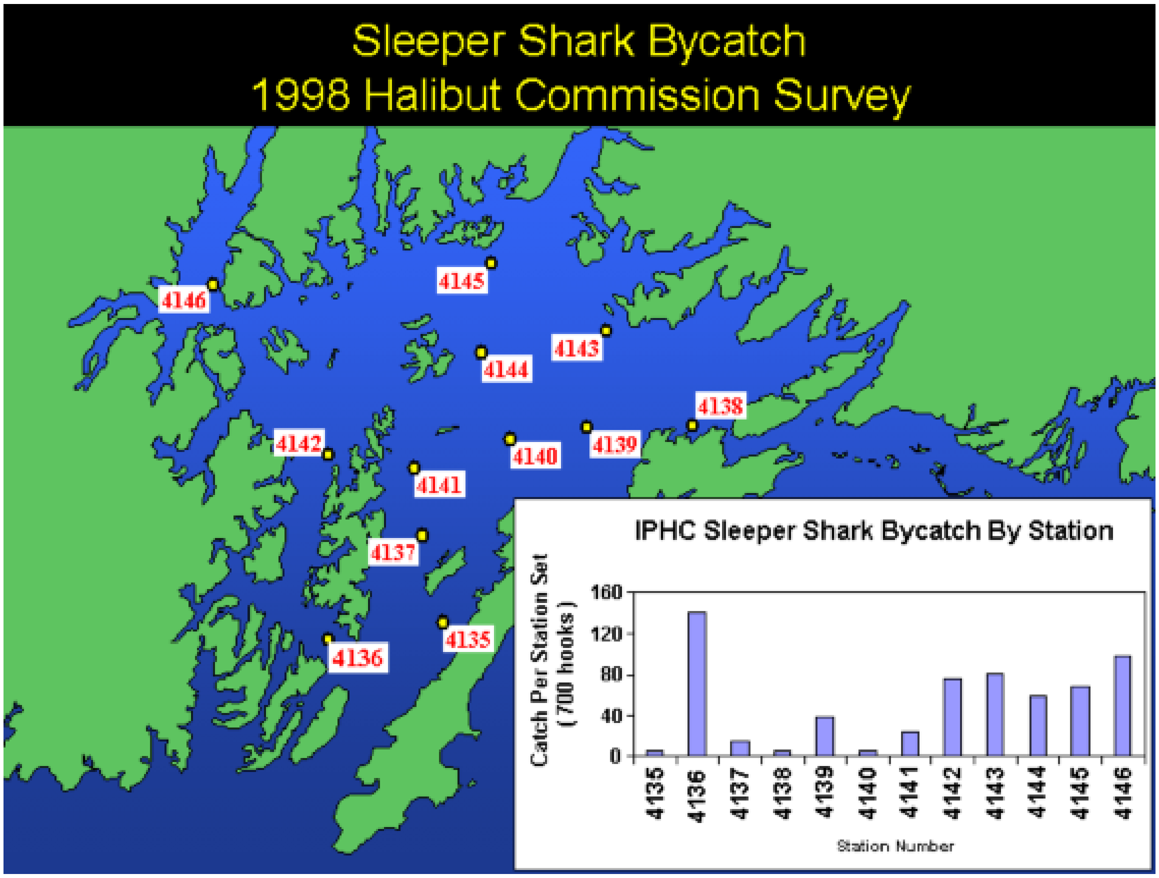


Figure 3. International Pacific Halibut Commission Pacific sleeper shark bycatch per station set (700 hooks) in Prince William Sound in 1998 (Dan Randolph, International Pacific Halibut Commission, unpublished data)

Alaska Department of Fish and Game sablefish survey data indicates an increasing trend in sleeper shark abundance since the survey began in 1996 (Figure 4).

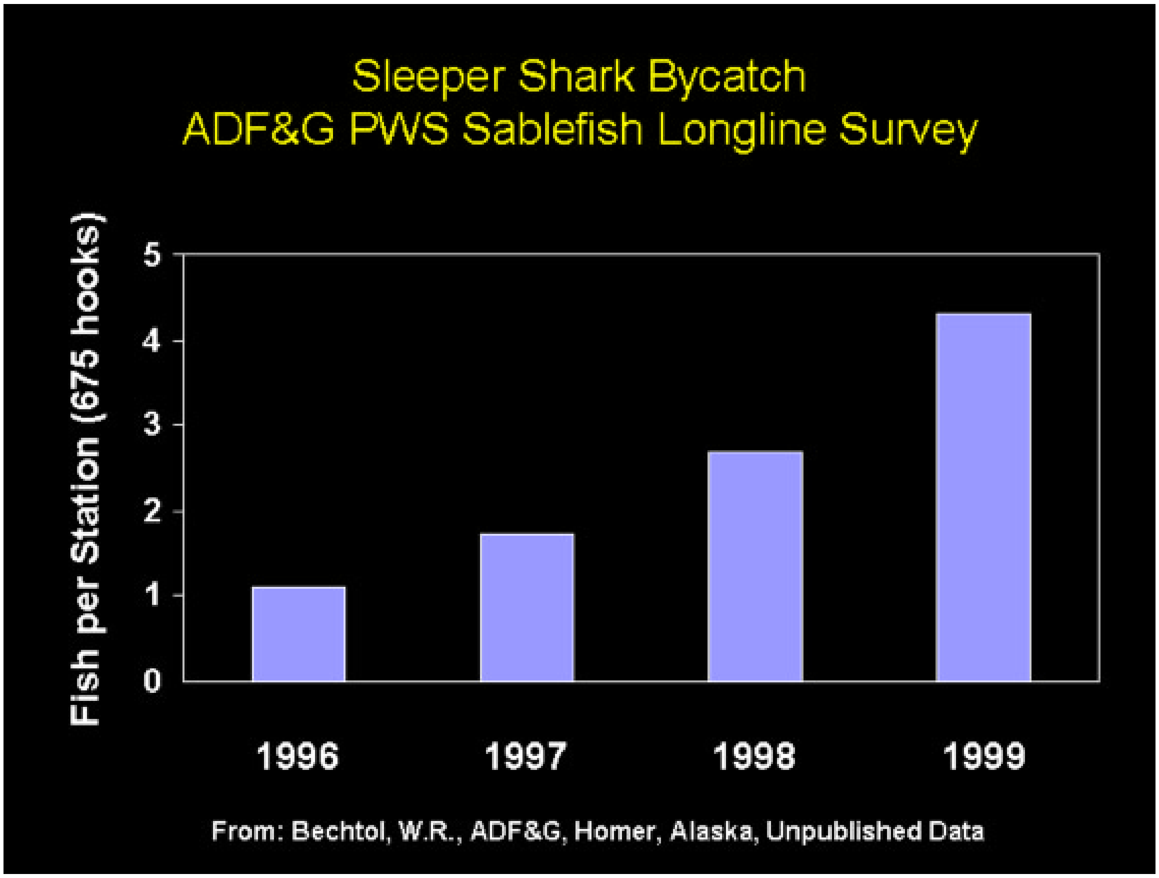


Figure 4. Grand averages of Pacific sleeper shark bycatch by year taken in the Alaska Department of Fish and Game sablefish longline survey in Prince William Sound. (Bill Bechtol, ADF&G, Homer, Alaska, unpublished data)

Salmon Sharks (*Lamna ditropis*)

Salmon sharks are rarely caught in commercial gear and information on trends in abundance is largely anecdotal. Salmon sharks are the predominant large predatory pelagic fish in the coastal GOA. A member of the family Lamnidae, they are the Pacific congener of the porbeagle shark in the Atlantic and are closely related to white and mako sharks. Abundant anecdotal evidence suggests a dramatic increase in salmon shark abundance in the northern GOA throughout the 1990's.

The vast majority of salmon sharks aggregating in surface waters of the GOA are adult females. They have been reported to reach 3m in length, although normal size range appears to be between 1.8 and 2.4m. Salmon sharks maintain an elevated body temperature and studies have shown that they may have the highest body temperature of any shark, as much as 13.6°C above ambient water temperatures. Because of this, they likely possess a relatively high metabolic rate and daily ration. Their diet consists primarily of salmon, squid, and groundfish.

Discussion

Is the trend in shark abundance in the GOA following shifts in ocean climate and trophic structure due to increases in abundance or range extension? The forage base responds quickly to changes in climate regimes and is further impacted by predation as groundfish biomass increases. It may be that shark succession in trophic community structure is a natural response to the regime shifts, but delayed due to low intrinsic rates of population increase.

Has enough time elapsed following the trophic regime shift to justify an explanation of the trend to an increase in shark numbers? Little is known of salmon shark and sleeper shark life history parameters and dogfish age at maturity appears to vary greatly with region and environmental stressors. Considering low intrinsic rates of population increase for sharks in general, it may seem unlikely that the trend follows an increase in numbers. However, changes in reproductive potential due to favorable conditions is a factor that should not be ruled out. Unfortunately, historical shark length data do not exist to support the hypothesis. Until demographic parameters of these sharks in the GOA are described, the answer is highly speculative. We hypothesize that there would have been more sharks in the region earlier if the increase in shark abundance were due to a shift in optimal range due to warmer temperatures and increases in prey abundance.

Are the sharks more affected by climate regime shift or trophic regime shift? In other words, is it food, or is it temperature? It is probably both. Both temperature and prey abundance can influence reproductive potential, and optimal range. Because of the size and longevity of the salmon sharks and sleeper sharks in particular, evidence of their ascension in the community structure of the region would likely indicate that their dominance would persist for a long time.

Environmental variables affect population and community dynamics strongly and, over time, community structure (McGowan et al. 1998). We believe that evidence of increasing shark abundance following ocean climate and trophic regime shifts indicates that sharks are succeeding pinnipeds as the predominant apex predators in the GOA.

Marine Mammals

Contributed by NMFS National Marine Mammal Lab Staff, AFSC

The Bering Sea and Gulf of Alaska support one of the richest assemblages of marine mammals in the world. Twenty-six species are present from the orders Pinnipedia (seals, sea lion, and walrus), Carnivora (sea otter and polar bear), and Cetacea (whales, dolphins, and porpoises) in areas fished by commercial groundfish fleets (Lowry and Frost 1985, Springer et al. 1999). Most species are resident throughout the year, while others migrate into or out of the management areas seasonally. Marine mammals occur in diverse habitats, including deep oceanic waters, the continental slope, and the continental shelf (Lowry et al. 1982). Below are brief descriptions of the range, habitat, diet, abundance, and population status for species thought to potentially have the most significant interactions with commercial fisheries because of direct takes or diet overlap. Incidental take estimates (where available) and management measures taken to address interactions with commercial fisheries are included where applicable.

Pinnipedia

Three families of pinnipeds are represented in the management areas: Otariidae, the eared seals (Steller sea lion and northern fur seals), Odobenidae, the Pacific walrus, and Phocidae, the true seals (harbor, spotted, bearded, ringed, ribbon and northern elephant seals).

Steller sea lion

The Steller sea lion (*Eumetopius jubatus*) ranges along the North Pacific Ocean rim from northern Japan to California (Loughlin et al. 1984), with centers of abundance and distribution in the GOA and Aleutian Islands, respectively. The northernmost breeding colony in the Bering Sea is on Walrus Island in the Pribilof Islands and in the Gulf of Alaska on Seal Rocks in Prince William Sound (Kenyon and Rice 1961).

Habitat includes both marine waters and terrestrial rookeries (breeding sites) and haulouts (resting sites). Pupping and breeding occur during June and July in rookeries on relatively remote islands, rocks, and reefs. Females generally return to rookeries where they were born to give birth and mate (Alaska Sea Grant 1993, Calkins and Pitcher 1982, Loughlin et al. 1984). Although most often within the continental shelf region, they may be found in pelagic waters as well (Bonnell et al. 1983, Fiscus and Baines 1966, Fiscus et al. 1976, Kenyon and Rice 1961). Although most often within the continental shelf region, they may be found in pelagic waters as well (Bonnell et al. 1983, Fiscus et al. 1976, Kajimura and Loughlin 1988, Kenyon and Rice 1961, Merrick and Loughlin 1997).

Observations of Steller's sea lions at sea suggest that large groups usually consist of females of all ages and subadult males; adult males sometimes occur in those groups but are usually found individually. On land, all ages and both sexes occur in large aggregations during the nonbreeding season. Breeding season aggregations are segregated by sexual/territorial status. Steller's sea lions are not known to migrate, but they do disperse widely at times of the year other than the breeding season. For example, sea lions marked as pups in the Kuril Islands (Russia) have been sighted near Yokohama, Japan (more than 350 km away) and in China's Yellow Sea (over 750 km away), and pups marked near Kodiak, Alaska, have been sighted in British Columbia, Canada (about 1,700 km distant). Generally, animals up to about 4 years-of-age tend to disperse farther than adults. As they approach breeding age, they have a propensity to stay in the general vicinity of the breeding islands, and, as a general rule, return to their island of birth to breed as adults.

The foraging patterns of adult females varies seasonally. Trip duration for females with young pups in summer is approximately 18 to 25 hours, trip length averages 17 km, and they dive approximately 4.7 hours per day. In winter, females may still have a dependent pup, but a mean trip duration is about 200 hours, with a mean trip length of about 130 km, and they dive about 5.3 hours per day (Merrick and Loughlin 1997). Yearling sea lions in winter exhibit foraging patterns intermediate between summer and winter females in trip distance (mean of 30 km), but shorter in duration (mean of 15 hours), and with less effort devoted to diving (mean of 1.9 hours per day). Estimated home ranges are 320 km^2 for adult females in summer, about 47,600 km^2 (with large variation) for adult females, and 9,200 km^2 for winter yearlings in winter (Merrick and Loughlin 1997).

Compared to some other pinnipeds, Steller sea lion tends to make relatively shallow dives, with few dives recorded to depths greater than 250 m. Maximum depths recorded for individual adult females in summer are in the range from 100 to 250 m; maximum depth in winter is greater than 250 m. The maximum depth measured for yearlings in winter was 72 m (Merrick and Loughlin 1997; Swain and Calkins 1997)

Steller sea lions give birth to a single pup each year; twinning is rare. Males establish territories in May in anticipation of the arrival of females (Pitcher and Calkins 1981). Viable births begin in late May and continue through early July and the sex ratio at birth is slightly in favor of males. Females breed about two weeks after giving birth. Copulations may occur in the water but most are on land (Pitcher and Calkins 1981; Gentry 1970; Gisiner 1985). The mother nurses the pup during the day and after staying with her pup for the first week she goes to sea on nightly feeding trips. Pups generally are weaned before the next breeding season but it is not unusual for a female to nurse her offspring for a year or more. Females reach sexual maturity between 3 and 8 years of age and may breed into their early 20s. Females can have a pup every year but may skip years as they get older or when nutritionally stressed. Males also reach sexual maturity at about the same ages but do not have the physical size or skill to obtain and keep a breeding territory until they are 9 years of age or older. Males may return to the same territory from 1 to 7 years, but rarely more than 3 years (Gisiner 1985). While on the territory during the breeding season males may not eat for 1-2 months. The rigors of fighting to obtain and hold a territory and the physiological stress over time during the mating season reduce the life expectancy of these animals. They rarely live beyond their mid-teens while females may live as long as 30 years.

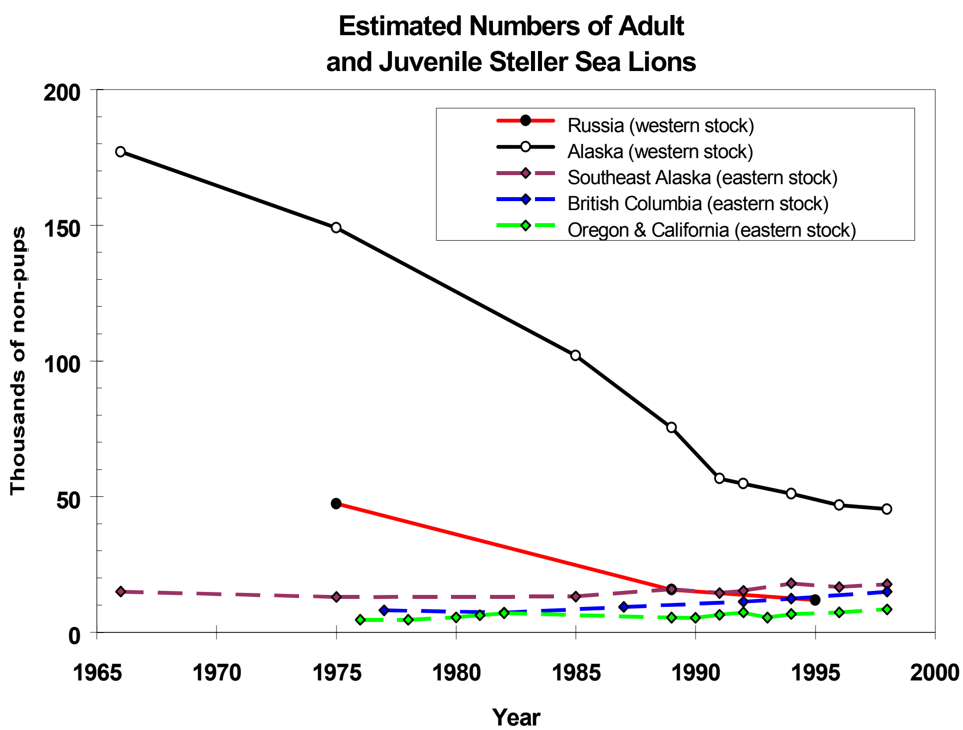
In the Bering Sea and GOA, the Steller sea lion diet consists of a variety of schooling fishes (e.g., walleye pollock, Atka mackerel, Pacific cod, flatfishes, sculpins, capelin, Pacific sand lance, rockfishes, Pacific herring, and salmon), as well as cephalopods (e.g., octopus and squid) (Calkins and Goodwin 1988, Lowry et al. 1982, Merrick and Calkins 1995, Perez 1990). Recent analyses of fecal samples collected on Steller sea lion haulouts and rookeries in the GOA and Aleutian Islands suggest particular importance of Atka mackerel in the central and western Aleutian Islands. Over 70% of the Steller sea lion summer diet is composed of Atka mackerel in this area. Pollock represented over 60% of their diet in the central GOA, 29% in the western GOA and eastern Aleutian Islands, and over 35% in parts of the central Aleutian Islands (Merrick and Calkins 1995). Small pollock (those less than 20 cm) appear to be more commonly eaten by juvenile sea lions than by older animals (Merrick and Calkins 1995).

The total estimated annual food consumption by the Steller sea lion population in the eastern Bering Sea is 185.2 x 10^3 mt, of which 140.7 x 10^3 mt (76%) is fish. Of the total annual fish consumption, commercial groundfish comprise 69%. The groundfish consumption by Steller sea lions represents 0.4% of the standing biomass consumed annually by all predators combined in the EBS (Perez and McAlister 1993).

Merrick and Loughlin (1997) documented Steller sea lion's relative consumption of seven prey categories in the GOA: 66.5% are gadids (walleye pollock, Pacific cod, Pacific hake and unidentified gadids), 20.3% Pacific salmon, 6.1% small schooling fish, 3.9% flatfish, 2.9% squid or octopus, and 0.3% Atka mackerel. Merrick and Calkins (1996) determined 70% of stomachs collected from animals in the GOA during the 1970s and 1980s also contained gadids.

Daily consumption rates of herring by captive sea lions was estimated by Rosen and Trites (1998) between 5.61 and 8.07 kg. In an attempt to predict the nutritional importance of pollock versus herring in the diet of the Steller sea lion, Fadley et al. (1994) reported daily consumption rates of these two prey items by captive California sea lions (*Zalophus californianus*). The daily food intake of herring was 5.2-8.2 kg; intake of pollock was from 7.8 to 12.0 kg.

The count of adult and juvenile Steller sea lions in Alaska during 1996/98 was 40,565 (Alaskan western stock = 29,658), with a total for the state of 52,602 if pups are included (Sease and Loughlin 1999). In the late 1950s and early 1960s, the total population in the North Pacific was estimated to be about 240,000 to 300,000 (Kenyon and Rice 1961). Steller sea lions are currently managed as two distinct stocks (i.e., eastern and western) (Loughlin 1997). Abundance of the U.S. eastern stock remained relatively stable from the 1960s to 1985 at around 13-15,000 nonpups, and has since increased to nearly 19,000 nonpups. The U.S. western stocks on the other hand have declined continuously since the 1960s, from around 177,000 nonpups in the 1960s to 33,600 nonpups in 1994. In the 1960s, the western stock included 92% of the U.S. population, but by 1994 this proportion had declined to 64% (Loughlin et al. 1992, Merrick et al. 1987). Historical trends of various regional components of the western and eastern stocks are shown below.



In 1990, Steller sea lions were listed as threatened under the Endangered Species Act (ESA) throughout its range (55 FR 12645, 55 FR 13488, 55 FR 49204, 55 FR 50005). A recovery plan was completed in 1992. In 1997 NMFS reclassified Steller sea lions as two distinct population segments under the ESA (62 FR 24345). The population segment west of 144□W, or approximately at Cape Suckling, was reclassified as endangered. The eastern stock remains listed as threatened. A recovery plan for Steller sea lions has been written (NMFS 1992a).

The NMFS observers monitored incidental take in the BSAI and GOA groundfish trawl, longline, and pot fisheries during 1990-1995. The minimum estimated mortality rate incidental to commercial fisheries is 30 sea lions per year, based on observer data (23.7) and self-reported fisheries information (5.7) or stranding data (0.2) where observer data were not available. No sea lion mortality was observed by NMFS in either pot fishery (Hill and DeMaster 1999).

The NMFS has implemented several management measures for Steller sea lions. In 1990, coincident with the ESA listing of Steller sea lion, NMFS: (1) Prohibited entry within three nautical miles of listed Steller sea lion rookeries west of 150º W; (2) prohibited shooting at or near Steller sea lions; and (3) reduced the allowable level of take incidental to commercial fisheries in Alaskan waters (50 CFR 227.12) (Fritz et al. 1995). As a result of ESA Section 7 consultations on the effects of the North Pacific federally-managed groundfish fisheries, NMFS implemented additional protective measures in 1991, 1992, and 1993 to reduce the effects of certain commercial groundfish fisheries on Steller sea lion foraging [50 CFR 679.20(a)(5)(ii), 679.22(a)(7) and (a)(8), and 679.22(b)(2))(1994)]. No additional management actions accompanied the 1997 change in ESA listing. However, since 1998 several additional management measures have been implemented in Alaskan groundfish fisheries. The Atka mackerel fishery in the Aleutian Islands was modified to restrict removals from inside critical habitat and seasonal apportionments were established. In December 1998, NMFS developed a set of management actions for the BSAI and GOA pollock fisheries after reaching a jeopardy finding under the ESA. The actions included further temporal/spatial distribution of the fisheries, establishment of additional pollock trawl closure zones around haulouts and closure of the Aleutian Islands to pollock trawling.

Steller Sea Lion Survey Results, June and July 2000

The National Marine Fisheries Service (NMFS) and the Alaska Department of Fish and Game (ADF&G) conducted surveys of Steller sea lion pups and non-pups during June and July 2000 from Southeast Alaska to the western Aleutian Islands. The NMFS aerial survey occurred during 11-20 June and covered Cape St. Elias in the eastern Gulf of Alaska to Attu Island in the western Aleutian Islands. This includes almost the entire western stock of Steller sea lions in Alaska. Aerial survey counts, which are made from photographs, are of all adult and juvenile sea lions, animals 1 or more years old. The NMFS counted pups at selected rookeries during ship-based field work from 20 June to 6 July. At the time of this memorandum, results from ADF&G for Southeast Alaska are not available.

Aerial Survey for Adult and Juvenile Sea Lions

Numbers of adult and juvenile sea lions in the western stock in Alaska (west of 144□W long.) continued to decline from 1998 to 2000 (Figure 1). Counts at 30 **Trend Rookeries** (13,271 non-pups) declined by 7.6% since 1998 (14,368) and 18.9% since 1996 (16,358). The estimated annual decline from 1990 to 2000 was 5.2%. At 82 **Rookery and Haul-out Trend Sites** (18,193: Table 1), the decline was 9.8% since 1998 (20,180) and 18.1% since 1996 (22,223), with an average annual decline of 5.2% since 1990. Trend sites are those consistently surveyed since the 1970s, thus allowing analysis of trends over relatively long periods of time. The aerial survey includes many sites (primarily haulouts) and 35-40% more animals than those at the Trend Sites alone. Consistent survey coverage of these non-trend sites allows meaningful comparison of all surveyed sites beginning in 1991. The count of 25,227 non-pups at **All Surveyed Sites** (n=264) represented declines of 13.8% from 1998 (29,257) and 17.6% from 1996 (30,622) with an average annual rate of decline since 1991 of 4.0%. Totals for **All Surveyed Sites** and **Rookery and Haul-out Trend Sites** include 1999 counts for the eastern Gulf of Alaska, which was not surveyed completely in 1998.

The Kenai to Kiska subarea is another geographical region used as a population index. For 26 **Trend Rookeries**, the June 2000 count (11,678) was a decline of 2.6% from 1998 (11,994) and 16.0% from 1996 (13,905). The average annual decline at Trend Rookeries in the Kenai to Kiska region was 4.8% for 1990 to 2000. Non-pup numbers at 69 **Rookery and Haul-out Trend Sites** (15,228) decreased by 6.7% from 1998 (16,315) and 14.9% from 1996 (17,900). The average annual decline at all Trend Sites was 4.0% for 1990 to 2000. For **All Surveyed Sites** (n=227) from Kenai to Kiska, the June 2000 count (21,301) declined 12.4% from 1998 (24,318) and 13.5% from 1996 (24,625), or approximately 2.5% per year from 1991 to 2000.

The relatively greater decline for the western stock as a whole compared to the Kenai to Kiska index area was driven by the declines in the western Aleutian Islands (Buldir and the Near Islands): 44% at **Trend Sites** and 42% at **All Surveyed Sites**. Trends have been variable in other regions, as illustrated by the regional counts at **Rookery and Haul-out Trend Sites** (Table 1, Figure 2). The western Gulf of Alaska and eastern Aleutian

Islands, despite declines during recent surveys, are at or near their numbers from the early 1990s. The average rates of change for these regions during the decade has been below 3% for **Rookery and Haul-out Trend Sites** and **Trend Rookeries** and zero [non-significant regression of ln(count) x year] for **All Surveyed Sites**. Although the June 2000 counts for Southeast Alaska are not available at this time, counts for this region have been increasing by approximately 2% per year.

Pup Counts

The NMFS counted Steller sea lion pups at four rookeries in the eastern Aleutian Islands (Yunaska, Adugak, Bogoslof, Akun) and five rookeries in the Gulf of Alaska (Pinnacle, Atkins, Chirikof, Outer I., and Fish I.) during 20 June to 6 July 2000. From 1998 to 2000, three rookeries decreased by a combined loss of 125 pups, two rookeries increased by a combined total of 47 pups, and four rookeries showed no change. Our overall impression was of no appreciable change in pup counts at these sites over the past two years. Importantly, pups and rookeries looked Ahealthy.@ The NMFS also counted pups at three haul-out sites: The Whaleback (12 pups), Lighthouse Rocks (5), and the Chiswell Islands (58). The NMFS also branded pups at Marmot I. (107) and Sugarloaf I. (151).

Table 1.--Counts of adult and juvenile (non-pup) Steller sea lions observed at **ROOKERY AND HAUL-OUT TREND SITES** in seven subareas of Alaska during June and July aerial surveys from 1990 to 2000, including overall percent change between the count for each year and the count for 2000. Results from the ADF&G survey in Southeast Alaska were not available when this report was prepared.

	Gulf of Alaska			Aleutian Islands				
Year	Eastern (n=9)	Central (n=15)	Western (n=9)	Eastern (n=11)	Central (n=34)	Western (n=4)	Kenai to Kiska (n=69)	Western stock (n=82)
1990	5,444 (-65%)	7,050 (-56%)	3,915 (-27%)	3,801 (+ 1%)	7,988 (-32%)	2,327 (-54%)	22,754 (-33.1%)	30,525 (-40.4%)
1991	4,596 (-59%)	6,273 (-50%)	3,734 (-24%)	4,231 (- 9%)	7,499 (-28%)	3,085 (-65%)	21,737 (-29.9%)	29,418 (-38.2%)
1992	3,738 (-49%)	5,721 (-46%)	3,720 (-24%)	4,839 (-21%)	6,399 (-15%)	2,869 (-63%)	20,679 (-26.4%)	27,286 (-33.3%)
1994	3,369 (-44%)	4,520 (-31%)	3,982 (-29%)	4,421 (-13%)	5,790 (- 6%)	2,037 (-47%)	18,713 (-18.6%)	24,119 (-24.6%)
1996	2,133 (-11%)	3,915 (-20%)	3,741 (-24%)	4,716 (-19%)	5,528 (- 2%)	2,190 (-51%)	17,900 (-14.9%)	22,223 (-18.1%)
1998	1,952[1] (- 3%)	3,346 (- 7%)	3,361 (-15%)	3,847 (<1%)	5,761 (- 6%)	1,913 (-44%)	16,315 (- 6.7%)	20,180 (- 9.8%)
2000	1,894	3,117	2,842	3,842	5,427	1,071	15,228	18,193

[1] 1999 counts for the eastern Gulf of Alaska.

Table 2.--Counts of adult and juvenile (non-pup) Steller sea lions observed at **ALL SURVEYED ROOKERY AND HAUL-OUT SITES** in seven subareas of Alaska during June and July aerial surveys from 1991 to 2000, including overall percent change between the count for each year and the count for 2000. Results from the ADF&G survey in Southeast Alaska were not available when this report was prepared.

	Gulf of Alaska			Aleutian Islands				
Year	Eastern (n=25)	Central (n=55)	Western (n=37)	Eastern (n=54)	Central (n=81)	Western (n=12)	Kenai to Kiska (n=227)	Western stock (n=264)
1991	4,812 (-53%)	7,715 (-39%)	5,341 (-14%)	5,291 (- 6%)	8,966 (-22%)	4,923 (-66%)	27,313 (-22.0%)	37,048 (-31.9%)
1992	4,360 (-48%)	7,330 (-36%)	5,502 (-17%)	5,715 (-13%)	8,307 (-16%)	4,533 (-64%)	26,854 (-20.7%)	35,747 (-29.4%)
1994	3,997 (-43%)	6,795 (-31%)	5,719 (-20%)	6,055 (-17%)	7,426 (- 6%)	3,369 (-51%)	25,995 (-18.1%)	33,361 (-24.4%)
1996	2,586 (-12%)	5,751 (-18%)	5,724 (-20%)	5,969 (-16%)	7,181 (- 2%)	3,411 (-52%)	24,625 (-13.5%)	30,622 (-17.6%)
1998	2,072[1] (+10%)	4,971 (- 5%)	5,855 (-22%)	5,803 (-14%)	7,689 (- 9%)	2,867 (-42%)	24,318 (-12.4%)	29,257 (-13.8%)
2000	2,274	4,711	4,577	5,000	7,013	1,652	21,301	25,227

[1] 1999 counts for the eastern Gulf of Alaska.

Northern fur seal

The northern fur seal (*Callorhinus ursinus*) ranges throughout the North Pacific Ocean from southern California north to the Bering Sea and west to the Okhotsk Sea and Honshu Island, Japan. Breeding is restricted to only a few sites (i.e., the Commander and Pribilof Islands, Bogoslof Island, and the Channel Islands)(NMFS 1993a).

Pupping, mating, and weaning occur on land in isolated rookeries; the remainder of their lives is spent at sea. Lactating females at the Pribilof Islands usually forage within 160 km of the rookeries, but occasionally as far away as 430 km (Goebel et al. 1991). Pups are weaned in October and November, about 125 days after birth, and go to sea soon afterward (Gentry and Kooyman 1986). Most females, pups, and juveniles leave the Bering Sea by late November and migrate south as far as southern California in the eastern North Pacific and Japan in the western North Pacific. They remain pelagic offshore and along the continental shelf until March, when they begin returning to the rookeries. Adult males are believed to migrate only as far south as the GOA.

Studies on northern fur seal diets began with the work of Lucas (1899). The most extensive research was based on the pelagic sampling of over 18,000 fur seals between 1958 and 1974 (Perez and Bigg 1986). Of the fur seal stomachs collected, 7,373 contained food and an additional 3,326 had trace remains of food. Their diet consists of 67% fish (34% walleye pollock, 16% capelin, 6% Pacific herring, 4% deep-sea smelts and lanternfishes, 2% salmon, 2% Atka mackerel, and <1% of eulachon, Pacific cod, rockfishes, sablefish, sculpins, Pacific sand lance, flatfishes and other fish) and 33% squid (Perez 1990). These data showed marked seasonal and geographic variation in the species consumed. In the EBS, pollock, squid, and capelin accounted for about 70% of the energy intake. In contrast, sand lance, capelin, and herring were the most important prey in the GOA.

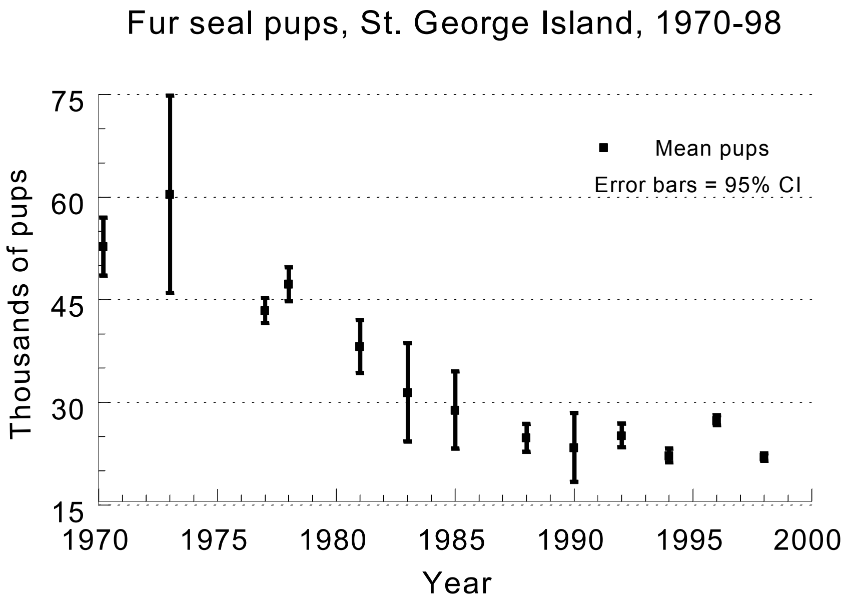
Based on diet studies conducted since the early pelagic collections (Sinclair et al. 1994; Sinclair et al. 1996), some prey items such as capelin have disappeared entirely from fur seal diet in the eastern Bering Sea and squid consumption has been markedly reduced. At the same time, pollock consumption has tripled while the age category of pollock eaten has decreased. Consumption of walleye pollock, gonatid squid, and bathylagid smelt in the EBS has, however, remained consistently important in all diet studies, despite the wide variety of prey available to fur seals within their diving range.

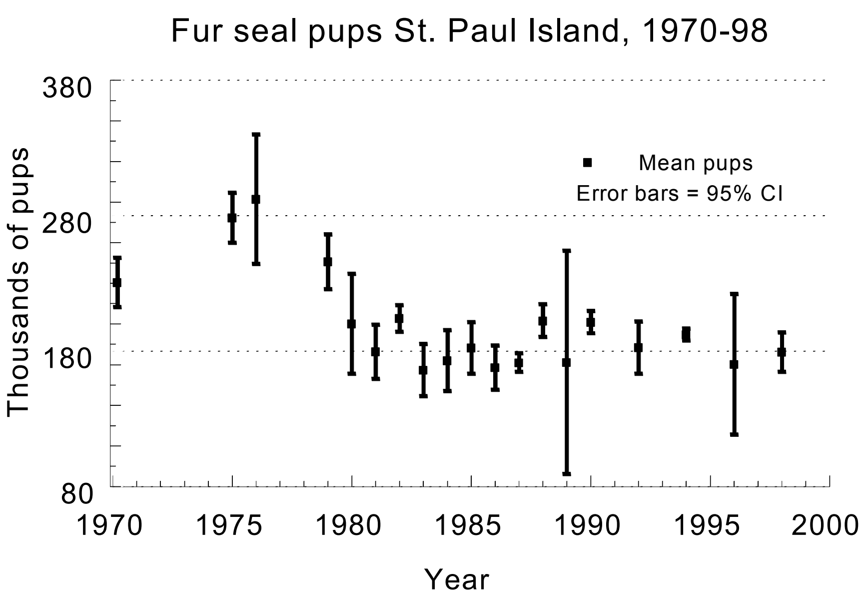
Gastrointestinal contents of 73 northern fur seals collected from the Bering Sea in 1981 (n=7), 1982 (n=43), and 1985 (n=43) indicated consumption of nearly 100% fish (1981), 88% fish and 12% squid (1982), and 88% fish and 12% squid (1985) (Sinclair et al. 1994). Analysis of these data showed that pollock and squid were the most frequently eaten prey in the EBS, and that a positive correlation exists between pollock year-class strength and the frequency of pollock in fur seal diets (Sinclair et al. 1994). The same report concluded that northern fur seals are size-selective mid-water feeders during the summer and fall in the EBS. Since 1987, studies of northern fur seal diet have been based on fecal samples (scats). A comparative study of fur seal diet based on the current method of scat analysis vs. stomach content analysis from the 1980s collections (Sinclair et al. 1996) demonstrated that walleye pollock represented 79% of all prey for all years combined in gastrointestinal tracts, and 78% of the total prey in fecal samples. The frequency of occurrence of pollock in all years averaged 82% in gastrointestinal tracts and 76% in fecal samples (Sinclair et al. 1996).

Based on the pelagic collections from the 1970s, annual food consumption by the northern fur seal population in the EBS was 432.4 x 10^3 mt, of which 289.7 x 10^3 mt represented fish species. Of the total annual fish consumption, commercial groundfish comprised 56%, which was an estimated 0.7% of the standing biomass of commercial groundfish consumed (i.e., by all predators combined) annually in the EBS (Perez and McAlister 1993). Based on data collected in the 1980s consumption of groundfish has increased with a decrease in forage fishes (Sinclair et al. 1994; 1996). Trites (1992) estimated 133,000 mt of walleye pollock (ages 1-2) are consumed annually by northern fur seals in the EBS.

Abundance varies by season. During the breeding season, approximately 74% of the worldwide population is found on the Pribilof Islands with the remaining animals spread throughout the North Pacific Ocean. Of the seals in U.S. waters outside of the Pribilof Islands, approximately one percent of the population is found on Bogoslof Island in the southern Bering Sea and San Miguel Island off southern California (Lloyd et al. 1981, NMFS 1993a). Two separate stocks of northern fur seals are recognized within U.S. waters: An Eastern Pacific stock and a San Miguel Island stock. The most recent estimate for the number of fur seals in the Eastern Pacific stock is approximately 1,019,192 (Hill and DeMaster 1999).

Northern fur seals were listed as depleted under the MMPA in 1988 because population levels had declined to less than 50% of levels observed in the late 1950s and no compelling evidence existed that carrying capacity had changed substantially since that time (NMFS 1993a). Under the MMPA, this stock remains listed as depleted until population levels reach at least the lower limit of its optimum sustainable population (estimated at 60% of carrying capacity). Recent trends in pup counts in St. Paul and St. George Islands in the eastern Bering Sea are shown below.





A Conservation Plan for the northern fur seal was written to delineate reasonable actions to protect the species (NMFS 1993a). Following that, fisheries regulations were implemented in 1994 (50 CFR 679.22(a)(6)) to create a Pribilof Islands Area Habitat Conservation Zone, in part, to protect the northern fur seals.

The NMFS observers monitored incidental take on the BSAI and GOA groundfish trawl, longline, and pot fisheries during 1990-1996. Incidental mortality was observed only in the BSAI groundfish trawl fishery with a mean annual (total) rate of 2.2 animals (Hill and DeMaster 1999).

Harbor seal

Harbor seals (*Phoca vitulina*) inhabit coastal and estuarine waters off Baja California, north along the western coasts of the U.S., British Columbia, and southeast Alaska, west through the GOA and Aleutian Islands, and in the Bering Sea north to Cape Newenham and the Pribilof Islands. They haul out on rocks, reefs, beaches, and drifting glacial ice, and feed in marine, estuarine, and occasionally fresh waters. Major food items vary by availability and include sand lance, smelt, sculpins, herring, capelin, shrimp, mysids, octopus, pollock, and flatfishes (Lowry et al. 1982).

Based on an average of data for the Aleutian Islands and eastern Bering Sea areas, harbor seal diet composition is approximately 75% fish (12% walleye pollock, 9% Atka mackerel, 9% sculpins, 8% greenlings, 8% Pacific cod, 5% capelin, 5% Pacific herring, 4% eulachon, 4% Pacific sand lance, 3% flatfishes, 3% saffron cod, 2% other fishes, and <1% Arctic cod, eelpouts, rockfishes, and Pacific salmon) and 25% invertebrates (Perez 1990). The total estimated annual food consumption by the population in these areas is 43.3 x 10^3 mt, of which 32.5 x 10^3 mt is fish (Perez and McAlister 1993). Ashwell-Erickson and Elsner (1981) reported that annual fish consumption by harbor seals in the Bering Sea was 79.0 x 10^3 mt, assuming a population of 150,000 seals.

Daily consumption rates of 6-8% of total body weight have been estimated for captive harbor seals. Spaulding (1964) estimated an average daily consumption of 6% body weight per day from the stomach contents of wild pinnipeds (range 2-11%). Food consumption by captive subadult harbor and spotted seals, as reported by Ashwell-Erickson and Elsner (1981) was about 4% of body weight in March through August and increased to about 8% of body weight in the winter.

Mean daily per capita food requirements for harbor seals in the Strait of Georgia, British Columbia, were estimated to be 1.9 kg, or 4.3% of mean body mass. Total annual consumption of the total Strait of Georgia population was estimated at 9,892 mt, which included 4,214 mt of hake, 3,206 mt of herring, 398 mt of salmon, 335 mt of plain-fin midshipman, and 294 mt of lingcod (Olesiuk 1993).

Three separate stocks of harbor seals are recognized in Alaska waters: (1) The southeast Alaska stock - occurring from the Alaska/British Columbia border to Cape Suckling, (2) the GOA stock - occurring from Cape Suckling to Unimak Pass, including animals throughout the Aleutian Islands, and (3) the Bering Sea stock - including all waters north of Unimak Pass (Hill and DeMaster 1999). Population sizes and mortality rates in fisheries are calculated separately.

The most recent comprehensive aerial surveys of the southeast Alaska stock were conducted during the autumn molt in 1997 and 1998. Uncorrected (for animals not present during assessment surveys) counts for the northern SE Alaska region, in 1997 (from Kayak Island to Frederick Sound) yielded 18,933 seals (Withrow and Cesarone 1998). Uncorrected counts for the southern SE Alaska region (from Federick Sound to the US/Canada border), in 1998, was 26,106 animals (Withrow and Cesarone 1999). Utilizing a correction factor to account for harbor seals in the water (i.e. not accounted for in aerial photographs), the combined population estimate for SE Alaska is 77,917. This apparent increase from the previous SAR estimate (37,450) Hill and DeMaster 1999) should be interpreted as a result of improved and refined assessment procedures and not a population explosion. The NMFS observers monitored harbor seal incidental take in the GOA groundfish trawl, longline, and pot fisheries during 1990-1996. Incidental takes within the range of the southeast Alaska stock of harbor seals occurred only in the longline fishery, with annual mortality estimated to be 4.0 seals (Hill and DeMaster 1999).

The GOA stock was assessed in sections with photographic aerial surveys during the autumn molt in 1994 and 1996. Utilizing a correction factor to account for harbor seals in the water (i.e. not accounted for in aerial photographs) the estimate was 29, 175 (Hill and DeMaster 1999). The NMFS observers monitored incidental take in the GOA groundfish trawl, longline, and pot fisheries, and the Prince William Sound and Alaska Peninsula/Aleutian salmon drift gillnet fisheries. The mean annual (total) mortality from fisheries with observers was estimated to be 24.6 harbor seals (Hill and DeMaster 1999).

The Bering Sea stock was surveyed during the autumn molt of 1995 throughout northern Bristol Bay and along the north side of the Alaska Peninsula (Withrow and Loughlin 1996). The estimated abundance, corrected for animals in the water, is 13,312 (Hill and DeMaster 1999). The NMFS observers monitored incidental take in the BSAI groundfish trawl, longline, and pot fisheries. The mean annual (total) mortality was 2.2 for the BSAI groundfish trawl fishery, 0.6 for the BSAI longline fishery, and 1.2 for the BSAI pot fishery, a total of 4 harbor seals (Hill and DeMaster 1999).

Cetacea

Large cetaceans with ranges (or historical occurrence) in the fisheries management areas include humpback, grey, sei, fin, blue, sperm, beaked (Baird's, Cuvier's, and Stejneger's), minke, and northern right whales. Bowhead whales are also present seasonally, extending as far south as St. Matthew Island in some winters (Moore and Reeves 1993). Small cetaceans include beluga whales, killer whales, Pacific white-sided dolphins, harbor porpoises, Dall's porpoises.

Killer whale

Killer whales (*Orcinus orca*) have been observed in all oceans and seas of the world (Leatherwood et al. 1982). In Alaska waters, killer whales occur along the entire Alaska coast from the Chukchi Sea, into the Bering Sea, along the Aleutian Islands, GOA, and into southeast Alaska (Braham and Dahlheim 1982). They occur primarily in coastal waters, although they have been sighted well offshore (Heyning and Dahlheim 1988). Seasonal movements in polar regions may be influenced by ice cover and in other areas primarily by availability of food. There are two types of killer whales, resident and transient. Resident pods prey on fish and squid, while transients tend to feed on marine mammals and birds. Prey include marine mammals, birds, fish, and squid (Jefferson et al. 1991). The total estimated annual prey consumption by the population in the eastern Bering Sea is 16.1 x 10^3 mt, of which 10.5 x 10^3 mt (65%) is fish (Perez and McAlister 1993). Interactions with commercial longline fisheries are well-documented throughout the Bering Sea and Aleutian Islands. Depredation rates of bottomfish by killer whales on longline catches, based on four different methods of calculation, suggested that whales took 14-60% of the sablefish, 39-69% of the Greenland turbot, and 6-42% of the arrowtooth flounder caught in commercial gear (Yano and Dahlheim 1995).

Four killer whale stocks are recognized along the west coast of North America from California to Alaska. Two of them occur in Alaska, the Eastern North Pacific Northern Resident stock and the Eastern North Pacific Transient stock (Hill and DeMaster 1999). The combined counts of resident and transient killer whales are 717 and 336, respectively (Dahlheim 1994, Dahlheim et al. 1996, Dahlheim and Waite 1993). Reliable data on trends in population abundance for either stock are not available (Hill and DeMaster 1999).

The NMFS observers monitored incidental take on the BSAI and GOA groundfish trawl, longline, and pot fisheries during 1990-1998. Observed incidental mortality of killer whale occurred in the BSAI groundfish trawl and longline fisheries with a mean annual (total) mortality of 1.0 for BSAI trawl and 0.4 for BSAI longline. No killer whale mortality was observed in the pot fisheries (Hill and DeMaster 1999). Killer whales interact with longline fisheries in the southeastern Bering Sea where predation on catch, especially sablefish and Greenland turbot, occurs periodically as gear is being retrieved (Dahlheim et al. 1996). Fishermen within the fixed gear Pacific halibut and sablefish fisheries are allowed to use longline pot gear to reduce interactions with killer whales (61 FR 49076, September 18, 1996).

Pacific white-sided dolphin

Pacific white-sided dolphins (*Lagenorhychus obliquidens*) are found throughout the temperate North Pacific Ocean. In the eastern North Pacific the species occurs from the Southern Gulf of California, north to the GOA, west to Amchitka in the Aleutian Islands, but is rarely encountered in the southern Bering Sea. They are mostly pelagic but also occur occasionally on the continental shelf (Dahlheim and Towell 1994, Hobbs and Jones 1993). Prey include a variety of small schooling fish and squid (Walker and Jones 1993).

Of two stocks recognized in the North Pacific Ocean, the North Pacific stock is the one present in the BSAI and GOA management areas (Hill and DeMaster 1999). The most complete population abundance estimate for Pacific white-sided dolphins was calculated from line transect analyses applied to the 1987-90 central North Pacific marine mammal sightings survey data (Buckland et al. 1993). The Buckland et al. (1993) abundance estimate, 931,000 animals, more closely reflects a range-wide estimate rather than one that can be applied to either of the two management stocks off the west coast of North America. However, the portion of the Buckland et al. (1993) estimate derived from sightings north of 45º N in the Gulf of Alaska can be used as the population estimate for this area (26,880).

Between 1978 and 1991, thousands of Pacific white-sided dolphins were killed annually incidental to high seas fisheries. However, these fisheries have not operated in the central North Pacific since 1991. Six different commercial fisheries in Alaska that could have interacted with Pacific white-sided dolphins were monitored for incidental take by NMFS observers from 1990 to 1998: Bering Sea (and Aleutian Islands) and Gulf of Alaska groundfish trawl, longline, and pot fisheries. The mean annual (total) mortality was 0 in the Bering Sea groundfish trawl fishery and 0.8 in the Bering Sea groundfish longline fishery (Hill et al. 1999).

Harbor porpoise

Harbor porpoises (*Phocoena phocoena*) are found in the eastern North Pacific Ocean from Point Barrow, along the Alaskan coast, and down the west coast of North America to Point Conception, California (Gaskin 1984, Suydam and George 1992, Dahlheim et al. 2000). They occur primarily in coastal waters, but are also found in offshore regions where the shelf extends offshore (Gaskin 1984, Dahlheim et al. 2000). Harbor porpoise occur continuously along the North American coast, with regions of higher concentrations such as Puget Sound and Glacier Bay (Gaskin 1984, Taylor and Dawson 1984, Raum-Suryan and Harvey 1998). Significant differences found in genetic samples from California, Washington, British Columbia, and Alaska (Rosel 1992, Rosen et al. 1995) and contaminant levels from California to Washington (Calambokidis and Barlow 1991) show that harbor porpoise along the west coast of North America are not panmictic and do not move great distances. However, available data are insufficient to separate biological stocks of harbor porpoise in Alaska. But because regional populations are believed to exist, it was considered prudent to establish management units (Rosel 1995, Taylor et al. 1996, Hill and DeMaster 1999). Three separate management units are recognized in Alaska: Southeast Alaska, GOA, and Bering Sea stocks. Aerial surveys conducted in 1991-1993 (Dahlheim et al. 2000) produced an uncorrected abundance estimate of 8,940 for the three stock areas combined. Hill and DeMaster (1999) split the overall estimate into the three stock ranges and applied a correction factor to produce the following three abundance estimates: 10,301 for the Southeast Alaska stock, 8,497 for the GOA stock, and 10,946 for the Bering Sea stock. No reliable information on trends in abundance exists.

No prey studies have been conducted in Alaska, however, prey studies in Washington and British Columbia found the diet of harbor porpoise to include cephalopods and a wide variety of fish including Pacific herring, smelt, eelpout, eulachon, walleye pollock, Pacific sandlance and gadids (Gearin et al. 1994, Walker et al. 1998). The total estimated annual food consumption by the population during summer in the EBS is 1.0×10^3 mt, of which 0.8×10^3 mt (85%) is fish (based on the estimated average pelagic abundance of 1500 animals) (Perez and McAlister 1993). Captive, non-lactating harbor porpoise of various age and sex classes were found to consume between 750 and 3,250 g of fish per day (equivalent to 4-9.5% of their body weight) (Kastelein et al. 1997). Rates of consumption depended on the caloric content of the fish as well as the age, body weight, exercise level, and individual basal metabolic rates. Wild harbor porpoise are expected to need more energy for thermoregulation and locomotion than the animals in this study.

The NMFS observers monitored incidental take on the BSAI and GOA groundfish trawl, longline, and pot fisheries during 1990-1995. During this period, 21 - 31 % of the GOA longline catch occurred within the range of the Southeast Alaska harbor porpoise stock (Hill and DeMaster 1999). No incidental mortalities were recorded by observers, but an annual mean of 3.25 mortalities was documented from log book records from the Southeast Alaska salmon drift gillnet fishery (1990 - 1993). The estimated minimum annual mortality rate incidental to commercial fisheries is 4 animals for the Southeast Alaska stock. For the GOA and Bering Sea harbor porpoise stocks, an estimated minimum annual mortality rate incidental to commercial fisheries was calculated to be 25 and 2, respectively, based on observer and logbook data (Hill and DeMaster 1999). For all three stocks, a reliable mortality estimate rate incidental to commercial fisheries was considered unavailable because of the absence of observer placements in several fisheries.

Dall's porpoise

Dall’s porpoises (*Phocoenoides dalli*) are endemic to the northern North Pacific Ocean region and adjoining seas, inhabiting both pelagic and near shore habitats. The species is common along the entire coast of North America as far south as 32º N (Morejohn 1979). In the BS, sightings are infrequent north of 62º N (Nishiwaki 1966). Food habits data from the western Aleutian Islands suggests a diet composed primarily of cephalopods and myctophid fishes (Crawford 1981). The total estimated annual food consumption by the population during summer in the EBS is 169 x 10^3 mt, of which 84.5 x 10^3 mt (50%) is fish (Perez and McAlister 1993).

One stock of Dall's porpoise is recognized in Alaska waters (Hill et al. 1997), although a separate Bering Sea stock has been suggested, based on differences in reproductive timing and parasite associations (Amino and Miyazaki 1992, Kasuya and Ogi 1987, Walker 1990, Walker and Sinclair 1990) and preliminary genetics analyses Winans and Jones (1988) . The Alaska stock of Dall's porpoise is estimated at 417,000. This number, however, may be overestimated by as much as five-fold because of vessel attraction behavior (Hill et al. 1997, Turnock and Quinn 1991).

Six different commercial fisheries operating within the range of the Alaska stock of Dall’s porpoise were monitored for incidental take by NMFS observers during 1990-98. No mortalities were observed in pot fisheries or in the Gulf of Alaska longline fishery. The mean annual (total) mortality was 6.0 for the Bering Sea groundfish trawl fishery,1.2 for the Gulf of Alaska groundfish trawl fishery, and 1.6 for the Bering Sea groundfish longline fishery (Hill and DeMaster 1999).

Sperm whale

Sperm whales (*Physeter macrocephalus*) are distributed widely in the North Pacific Ocean, as far north as the Pribilof Islands in the Bering Sea (Leatherwood et al. 1982, Omura et al. 1955). They are a pelagic species, known to dive deeper than 1,000 m and remain submerged for periods of an hour or more. They feed primarily on medium- to large-sized squids (Gosho et al. 1984) but may occasionally take octopus and a variety of fish, including salmon, rockfish, lingcod, and skates. The total estimated annual food consumption by the population in the EBS is 952.8 x 10^3 mt, of which 171.5 x 10^3 mt (18%) is fish (Perez and McAlister 1993).

One stock is recognized in Alaska, the North Pacific stock (Hill and DeMaster 1999). The number of sperm whales occurring within Alaskan waters is unknown. Reliable information on trends in abundance are not available.

The NMFS observers monitored incidental take on the BSAI and GOA groundfish trawl, longline, and pot fisheries during 1990-1998. No mortalities were observed, however, sperm whale interactions with longline fisheries operating in the GOA are known to occur and may be increasing in frequency. In 1996, NMFS received reports from observers on commercial fishing vessels that sperm whales were preying on sablefish caught on commercial longline gear in the Gulf of Alaska. A pilot project using fishery observers in 1997 and 1998 was initiated to determine the extent of the interactions between sperm whales and the commercial longline fishery in Alaska (Hill et al. 1999).

Ecological Interactions Between Marine Mammals and Commercial Fisheries

Ecological interactions between marine mammals and commercial fisheries are difficult to identify in most cases. Examples of observable interactions are generally restricted to direct mortality in fishing gear. Even then, the ecological significance of the interaction is related to the number of animals killed and subsequent population level responses. None of the marine mammal incidental mortality estimates for Alaskan groundfish fisheries exceed the PBRs (Hill and DeMaster 1999); therefore, those interactions are not expected to have large ecosystem consequences.

More difficult to identify and potentially more serious are interactions resulting indirectly, from competition for resources that represent both marine mammal prey and commercial fisheries targets. Such interactions may limit foraging success through localized depletion, dis-aggregation of prey or disturbance of the predator itself. Compounding the problem of identifying competitive interactions is the fact that biological effects of fisheries may be indistinguishable from changes in community structure or prey availability that might occur naturally. The relative impact of fisheries perturbations compared to broad, regional events such as climatic shifts are uncertain, but given the potential importance of localized prey availability for foraging marine mammals, they warrant close consideration.

Lowry (1982) developed qualitative criteria for determining the likelihood and severity of biological interactions between fisheries and marine mammal species in the Bering Sea. His criteria were based on marine mammal diet, focusing on species consumed, prey size composition, feeding strategy, and the importance of the Bering Sea as a foraging area. This approach is applicable for adjacent waters such as the GOA because many of the same marine mammals found in the Bering Sea are found there as well, with diets comparable to those of their conspecifics. Based on Lowry's (1982) Bering Sea assessment, three pinniped species (northern fur seal, harbor seal, and Steller sea lion) had the greatest potential for adverse ecological interactions with commercial fisheries. All of these species have also undergone major declines in abundance over the past 30 years (Loughlin et al. 1992, NMFS 1993a, Pitcher 1990). NMFS has used similar criteria to assess the extent of overlap between commercial fisheries and Steller sea lions.

Possible ecological interactions between marine mammals and commercial fisheries can be illustrated using the Steller sea lion case. Steller sea lions have a moderately diverse diet composed primarily of pelagic or semidemersal schooling fish such as walleye pollock, Atka mackerel, Pacific cod, capelin, Pacific herring and Pacific salmon, most of which are commercially exploited (Calkins and Pitcher 1982, Lowry 1982). Merrick and Calkins (1995) suggested that the diet diversity differed from area to area. More recent analyses of Steller sea lion scat samples indicate that pollock is the primary prey in the GOA and eastern Aleutian Islands, while Atka mackerel assumes the dominant role from the central Aleutian Islands, westward (Sinclair et al., unpub. data). Pacific cod is also well represented in sea lion scats collected in the GOA and eastern Aleutians. Such prey preferences on commercially harvested species represent overlaps that could be expected to result in competition, particularly where fisheries operate in important foraging areas. Attempts to correlate time series of sea lion abundances on rookeries with nearby removals of pollock by fisheries have not provided insight on the correlations between fisheries activity and sea lion declines (Alaska Sea Grant 1993, Ferrero and Fritz 1994, Loughlin and Merrick 1989). Data on either the available prey base or on Steller sea lion's response to potential changes in prey availability have not been collected in sufficiently fine levels of resolution to facilitate more thorough analyses.

The selectivities of the fishery and sea lions for various sizes of pollock suggests that at some level, competition exists every year a fishery occurs (Loughlin and Nelson 1986). Overall, sea lions are capable of consuming all size pollock, and appear to utilize whatever sizes are present in the foraging areas. The fishery may be somewhat more size selective than sea lions, because it generally targets and retains pollock greater than 30 cm in length (Wespestad and Dawson 1992)(Figure 1). Smaller fish are caught by the fishery roughly in proportion to their abundance (Fritz 1996). On average (based on 1979 to 1998 data), about 4% of the total population of 2-3 year-old pollock (20-35 cm in length) were caught each year by fisheries in the eastern Bering Sea, and about 2% in the GOA, but very few 0-1 year-old pollock have been caught.

Limited data available on feeding behavior from the early 1980s in the Kodiak Archipelago suggest that adult Steller sea lions ate sizes of pollock nearly in proportion to their abundance (Figure 3-26), while juvenile sea lions preferred pollock <30 cm in length (Merrick and Calkins 1996). Juvenile sea lion prey preferences from other years or locations are not available and the extent to which they consume larger fish is unknown. However, both adult and juvenile Steller sea lions forage in areas designated as critical habitat in the Bering Sea and Aleutian Islands where almost 70% of the pollock trawl fishery (total pollock catch from critical habitat of almost 850,000 mt) occurred as recently as 1995 (Fritz and Ferrero 1998). Most of this critical habitat catch of pollock occurred during the roe fishery in January-March (45% of the annual total), when 80% or more of the harvest often came from these sensitive areas. However, since 1999, catches of pollock from eastern Bering Sea critical habitat have been capped by season, and the Aleutian Islands region has been completely closed to the pollock fishery, as part of the Revised Final Reasonable and Prudent Alternatives (RFRPA) to mitigate jeopardy and adverse modification. This has had the result of reducing the annual percentage removals from BSAI critical habitat to under 40% and the catch to approximately 350,000 mt. These actions have not entirely eliminated competition for prey between pollock fisheries and Steller sea lions in critical habitats, but may have reduced them.

A potential mechanism by which marine mammals may be disadvantaged by competition with commercial fisheries for food resources is localized depletion of prey. Whereas the overall abundance of prey across the entire Bering Sea or GOA may not be affected by fishing activity, reduction in local abundance, or dispersion of schools could be more energetically costly to foraging marine mammals. Thus, the timing and location of fisheries, relative to foraging patterns of marine mammals may be a more relevant management concern than total removals.

Such a case for concern over possible localized depletion has been identified for Steller sea lions and the Atka mackerel fishery in the western and central Aleutian Islands. As previously noted, Atka mackerel are a major item in the diet of Steller sea lions, particularly those in the Aleutian Islands. The Atka mackerel fishery is concentrated in several compressed locations, most of which are adjacent to Steller sea lion haulouts and rookeries, inside critical habitat. Evidence of Atka mackerel localized depletion has been presented by Lowe and Fritz (1997a) based on reductions in catch per unit effort (CPUE) of Atka mackerel over the course of the fishing season. The potential for impacts to Steller sea lion recovery efforts was recognized by NMFS and the NPFMC, warranting action to move fishing effort away from sea lion critical habitat beginning in 1999. Spatial as well as temporal Atka mackerel fishery dispersion measures enacted in 1999 consisted of a 4-year time schedule for reducing to 40% the proportion of Atka mackerel catch taken from critical habitat, as well as splitting the annual TAC into two seasons (beginning in January and September). These actions both reduced the catches from critical habitat and the likelihood of creating localized depletions of sea lion prey.

Recently, in the ESA Section 7 Biological Opinion on the authorization of the walleye pollock fisheries in the BSAI and GOA (NMFS, Alaska Region, 1998), NMFS investigated more fully the potential for competitive interactions between Steller sea lions and the pollock fisheries. The questions regarding competitive interactions that were used to guide this analysis were:

1. Is the fished species a significant sea lion prey?
2. Are the sizes of fish eaten by sea lions and caught by fisheries similar?
3. Are the depths at which the fish are caught by sea lions and fisheries similar?
4. Are there significant temporal and spatial overlaps in feeding and fishing distributions?
5. Is there evidence of disproportionate harvest rates or localized depletions of prey in sea lion feeding areas?

For Steller sea lion/pollock fishery interactions, NMFS concluded that the answer to each of these questions was “yes”, and proposed reasonable and prudent alternatives (RPAs) to modify the fishery to reduce the competitive interactions. NMFS demonstrated that since the late 1970s, the pollock fisheries in the GOA and BSAI had caught increasing amounts and proportions of total catch from critical habitat. Furthermore, in the eastern Bering sea, comparisons of fishery and survey information revealed disproportionately high catch rates of pollock from sea lion critical habitats in the summer and fall. This suggested that the fishery could be reducing the prey available to sea lions and thus, jeopardizing their recovery. RPAs for the pollock fisheries in the GOA and BSAI consisted of more temporal and spatial dispersion of the pollock fishery, reduced catches of pollock in sea lion critical habitat, and creation of pollock trawl exclusion zones around sea lion haulouts.

Steller sea lions may also interact with the Pacific cod fishery, much as in the case of pollock. Pacific cod is a significant sea lion prey, the size range of cod harvested and the depths fished overlap with Steller sea lion foraging habits. Furthermore, a large proportion of the catch is taken from critical habitat during winter (when sea lion prey availability and foraging ability is thought to most sensitive). Analysis of the Pacific cod fishery and the seasonal distribution of the species is warranted to determine the likelihood and severity of such interactions.

Recent discussion has suggested that prey quality may be as important to the health and survival of marine mammals, notably Steller sea lions, as is prey quantity and the role of localized depletion. The present dominance of pollock over more nutritionally superior forage fish such as herring, capelin, and cod could compromise sea lion health (Alverson 1992). Changes in blood parameters have been noted in harbor seal studies when different prey are consumed (Thompson et al. In press) and changes in Steller sea lion and other pinniped blood parameters may be linked to their nutritional plane (Rea and Mioskowski 1997, Zento-Savin et al. 1997). However, captive studies have shown that Steller sea lions obtain a larger portion of ingested energy from numerous small meals than from fewer large ones, suggesting that prey distribution is an important factor in sea lion nutrition (Rosen and Trites 1997). Additional studies are needed to clarify the importance of prey quality in contributing to the current population dynamics of Steller sea lions.

Disturbance from either vessel traffic or fishing activities may also be a disadvantage to marine mammals, particularly foraging Steller sea lions. Vessel traffic alone may temporarily cause fish to compress into tighter, deeper schools (Freon et al. 1992) or split schools into smaller concentrations (Laevastu and Favorite 1988). Hydroacoustic observation of the effects of trawling on Pacific whiting school structure in Puget Sound, Washington suggest that while the school deforms and has a "hole" in it due to the removal of fish and their avoidance of the gear, its structure returns relatively quickly (on the order of 10 minutes) to a pre-trawling condition (Nunnallee 1991). Preliminary results on the effects of the noise produced by a single vessel (no trawl in the water) on pollock school structure suggests that the fish may move down and to either side of the vessel, but return to the undisturbed structure within minutes of the vessel passage (C. Wilson, NMFS, AFSC, personal communication). Neither study, however, documents the effects of repeated trawling by many vessels over several days or weeks on fish school structure, nor the possible impact on prey availability to Steller sea lions.

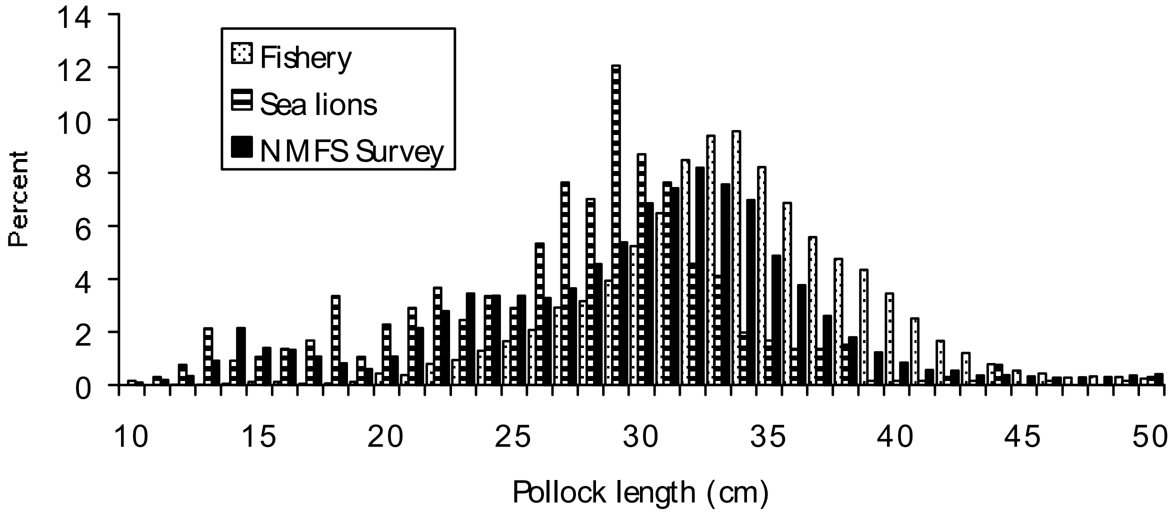


Figure.—Length frequency distributions of walleye pollock caught by thefishery, consumed by Steller sea lions, and the population based on the NMFS bottom trawl survey in spring and summer of 1981 in the Bering Sea. Fishery (April through June) and survey (July through September) length-frequencies were from collections in NMFS statistical area 521, located northwest of the Pribilof Islands. Steller sea lions (n=27) were collected pelagically in Area 521 in April. (Pollock length data computed from otoliths found in sea lion stomachs.)

Seabirds

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Seabirds spend the majority of their life at sea rather than on land. The group includes the albatrosses, shearwaters, and petrels (*Procellariiformes*), cormorants (*Pelecaniformes*), and two families of the *Charadriiformes*: gulls (*Laridae*), and auks, such as puffins, murres, auklets, and murrelets (*Alcidae*). Several species of sea ducks (*Merganini*) also spend much of there life in marine waters. Other bird groups contain pelagic members such as swimming shorebirds (*Phalaropodidae*), but they seldom interact with groundfish fisheries and, therefore, will not be discussed further.

Thirty-eight species of seabirds breed in Alaska. More than 1600 colonies have been documented, ranging in size from a few pairs to 3.5 million birds (Figure 1). The USFWS is the lead Federal agency for managing and conserving seabirds and is responsible for monitoring populations, both distribution and abundance. Breeding populations are estimated to contain 36 million individuals in the Bering Sea and 12 million individuals in the GOA (Table 1); total population size (including subadults and nonbreeders) is estimated to be approximately 30 percent higher. Five additional species occur in Alaskan waters during the summer months and contribute another 30 million birds (Table 2).

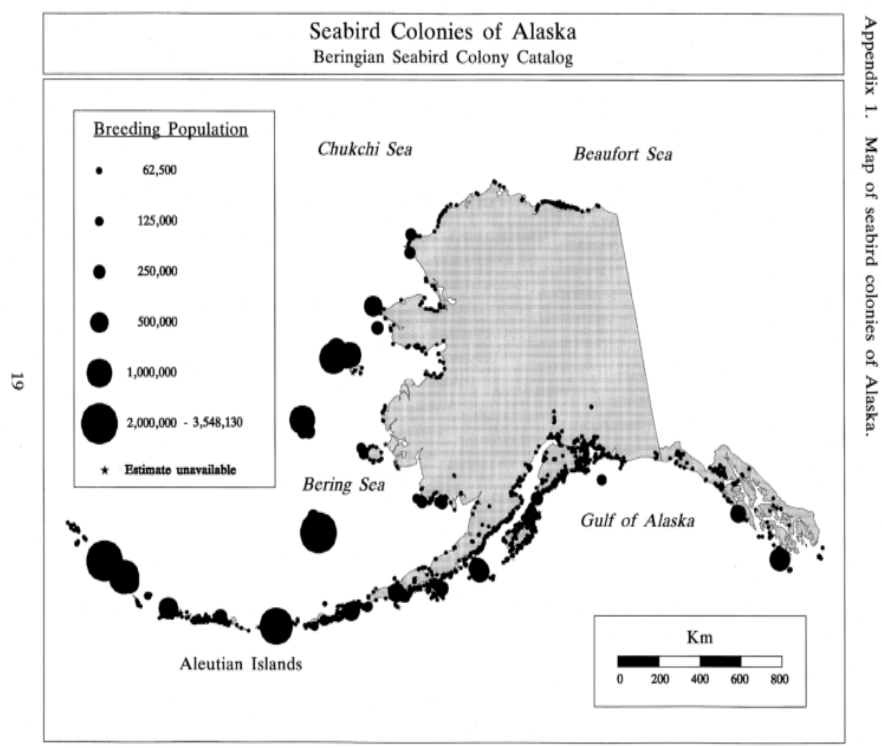


Figure 1. Seabird Colonies of Alaska. Beringian Seabird Colony Catalog, 2000. USFWS.

Table 1 Estimated populations and principal diets of seabirds that breed in the Bering Sea and Aleutian Islands and Gulf of Alaska regions

Species	**Population** [1,2]		**Diet** [3,4]
	BSAI	**GOA**	
Northern Fulmar (*Fulmarus glacialis*)	1.500,000	600,000	Q,M,F,Z,I
Fork-tailed Storm-Petrel (*Oceanodroma furcata*)	4,500,000	1,200,000	Z,Q,C
Leach's Storm-Petrel (*Oceanodroma leucorrhoa*)	4,500,000	1,500,000	Z,Q
Double-crested Cormorant (*Phalacrocorax auritis*)5	9,000	8,000	F.I
Pelagic Cormorant (*Phalacrocorax pelagicus*)	80,000	70,000	S,C,P,H,F,I
Red-faced Cormorant (*Phalacrocorax urile*)	90,000	40,000	C,S,H,F,I
Brandt's Cormorant (*Phalacrocorax penicillatus*)	0	100	?
Pomarine Jaeger (*Stercorarius pomarinus*)	Common	Common	C,S
Parasitic Jaeger (*Stercorarius parasiticus*)	Common	Common	C,S
Long-tailed Jaeger (*Stercorarius longicaudus*)	Common	Common	C,S
Bonaparte's Gull (*Larus philadelphia*)	Rare	Common	?
Mew Gull (*Larus canus*) [5]	700	40,000	C,S,I,D
Herring Gull (*Larus argentatus*) [5]	50	300	C,S,H,F,I,D
Glaucous-winged Gull (*Larus glaucescens*)	150,000	300,000	C,S,H,F,I,D
Glaucous Gull (*Larus hyperboreus*)[5]	30,000	2,000	C,S,H,I,D
Black-legged Kittiwake (*Rissa tridactyla*)	800,000	1,000,000	C,S,P,F,M,Z
Red-legged Kittiwake (*Rissa brevirostris*)	150,000	0	M,C,S,Z,P,F
Sabine's Gull (*Xema sabini*)	Common	Common	?
Arctic Tern (*Sterna paradisaea*) [5]	7,000	20,000	C,S,Z,F
Aleutian Tern (*Sterna aleutica*)	9,000	25,000	C,S,Z,F
Common Murre (*Uria aalge*)	3,000,000	2,000,000	C,S,H,0,F,Z
Thick-billed Murre (*Uria lomvia*)	5,000,000	200,000	C,S,P,Q,Z,M,F,I
Pigeon Guillemot (*Cepphus columba*)	100,000	100,000	S,C,F,H,I
Marbled Murrelet (*Brachyramphus marmoratus*)	Uncommon	Common	C,S,P,F,Z,I
Kittlitz's Murrelet (*Brachyramphus brevirostris*)	Uncommon	Uncommon	S,C,H,Z,I,P,F
Ancient Murrelet (*Synthliboramphus antiquus*)	200,000	600,000	Z,F,C,S,P,I
Cassin's Auklet (*Ptychoramphus aleuticus*)	250,000	750,000	Z,Q,I,S,F

Least Auklet (*Aethia pusilla*)	9,000,000	50	Z
Parakeet Auklet (*Cyclorrhynchus psittacula*)	800,000	150,000	F,I,S,P,Z
Whiskered Auklet (*Aethia pygmaea*)	30,000	0	Z
Crested Auklet (*Aethia cristatella*)	3,000,000	50,000	Z,I
Rhinoceros Auklet (*Cerorhinca monocerata*)	50	200,000	C,S,H,A,F
Tufted Puffin (*Fratercula cirrhata*)	2,500,000	1,500,000	C,S,P,F,Q,Z,I
Horned Puffin (*Fratercula corniculata*)	500,000	1,500,000	C,S,P,F,Q,Z,I
Total	36,000,000	12,000,000	

Notes; 1 = Source of population data for colonial seabirds that breed in coastal colonies: modified from USFWS 1998. Estimates are minima, especially for storm-petrels, auklets, and puffins.

2 = Numerical estimates are not available for species that do not breed in coastal colonies. Approximate numbers: abundant > 10^6; common = 10^5-10^6; uncommon = 10^3-10^5; rare < 10^3.

3 = Abbreviations of diet components: M, Myctophid; P, walleye pollock; C, capelin; S, sandlance; H, herring; A, Pacific saury; F, other fish; Q, squid; Z, zooplankton; I, other invertebrates; D, detritus; ?: no information for Alaska. Diet components are listed in approximate order of importance. However, diets depend on availability and usually are dominated by one or a few items (see text).

4 = Sources of diet data: see species accounts in text.

5 = Species breeds both coastally and inland; population estimate is only for coastal colonies.

Table 2 Comparative population estimates and diets of nonbreeding seabirds that frequent the Bering Sea and Aleutian Islands and Gulf of Alaska regions.

Species	**Population** [1,2]		**Diet** [3,4]
	BSAI	**GOA**	
Short-tailed Albatross (*Diomedea albatrus*)	Rare	Rare	Q,F
Black-footed Albatross (*Diomedea nigripes*)	Common	Common	Q,M,F,I,D
Laysan Albatross (*Diomedea immutabilis*)	Common	Common	M,Q,I,F
Sooty Shearwater (*Puffinus griseus*)	Common	Abundant	M,A,Q,C,S,F,Z
Short-tailed Shearwater (*Puffinus tenuirostris*)	Abundant	Common	Z,F,C,S,I
Ivory Gull (*Pagophila eburnea*)	Uncommon	0	?
Black Guillemot (*Cepphus grylle*)	Rare	0	?

1. Source of population data for colonial seabirds that breed in coastal colonies: modified from USFWS 1998. Eastimates are minima, especially for storm-petrels, auklets, and puffins.
2. Numerical estimates are not available for species that do not breed in coastal colonies. Approximate numbers: abundant $\geq 10^6$, common = 10^5-10^6, uncommon = 10^3-10^5; rare $\leq 10^{3.}$

3. Abbreviations of diet components: M, Myctophid; P, walleye pollock; C, capelin; S, sandlance; H, herring; A, Pacific saury; F, other fish; Q, squid; Z, zooplankton; I, other invertebrates; D, detritus; ?, no information for Alaska. Diet components are listed in approximate order of importance. However, diets depend on availability and are usually dominated by one or a few items (see text).
4. Sources of diet data: see species accounts in text.
5. Species breeds both coastally and inland; population estimate is only for coastal colonies.

Population trends are monitored at 3 to 14 colonies per species. The sizes of breeding populations of seabirds in the GOA, EBS, and Aleutian Islands are not static. There have been considerable changes in the numbers of seabirds breeding in Alaskan colonies since the original counts made in the mid-1970s. Trends are reasonably well known for species that nest on cliffs or flat ground such as fulmars, cormorants, glaucous-winged gulls, kittiwakes, murres and for storm-petrels, and tufted puffins (Tables 2, 3, and 4). Trends are known for one or two small areas of the state for the pigeon guillemots, two areas for murrelets, and two areas for auklets (Tables 3 and 4). Trends are unknown at present for other species [jaegers, terns, most auklets, and horned puffins; (Byrd and Dragoo 1997, Byrd *et al.* 1998, 1999)]. Population trends differ among species. Trends in many species vary independently among areas of the state, due to differences in food webs and environmental factors.

Seabirds are characterized by low reproductive rates, low annual mortality, long life span, and delayed sexual maturity; such traits make populations extremely sensitive to changes in adult survival (Russell 1999, Ricklefs 1990, Ricklefs 2000, Saether and Bakke 2000). Population trends can result from changes in either productivity or survival, but most trends that have been adequately investigated are attributed to changes in productivity. This may have more to do with the difficulty of obtaining long-term demographic data on seabirds than from a clear link between trends and productivity. Many seabirds have life-history traits that favor adult survival over reproductive effort (Russell 1999, Saether and Bakke 2000). For this reason, Russell (1999) cautions against relying on productivity studies to reach conclusions about population dynamics. For example, Weimerskirch *et al.* 1997 (cited and presented in Russell 1999) showed increased rate of decline in five populations of wandering albatrosses (*Diomedea exulans*) corresponding to local increases in long-line fishing effort. Furthermore, in long-lived animals, observable impact on the breeding population may take years or decades. One study modeled impacts of loss of juvenile wandering albatross from long-line bycatch, and estimated 5-10 years to detect the decline in breeding populations, and 30-50 years for population stabilization after measures were taken (Moloney *et al.* 1994). A major constraint on breeding for seabirds is the distance between the breeding grounds on land and the feeding zones at sea (Weimerskirch and Cherel 1998). Breeding success in most species is variable among years, but in stable populations, poor success is compensated for by occasional good years (Boersma 1998, Russell 1999). Fluctuations in fish stock recruitment are likely to affect the survival of adult seabirds and seabird reproduction differently. Adult seabird survival is unlikely to be affected by the common interannual variability of prey stock because adults can shift to alternative prey or migrate to seek prey in other regions. In contrast, breeding birds are tied to their colonies, and local fluctuations in fish recruitment can have a dramatic effect on seabird reproduction. If food supplies are reduced below the amount needed to generate and incubate eggs, or the specific species and size of prey needed to feed chicks is unavailable, local reproduction by seabirds will fail (Hunt et al. 1996). The natural factor most often associated with low breeding success is scarcity of food (Kuletz 1983, Murphy *et al.* 1984, Murphy *et al.* 1987, Springer 1991b, Furness and Monaghan 1987, Croxall and Rothery 1991, Cairns 1992). Seabird populations therefore are usually limited by food availability (Furness 1982, Croxall and Rothery 1991).

Foraging ecology differs among seabird species. Diets consist largely of fish or squid less than 15 cm long, large zooplankton, or a combination of both. Most seabirds depend on one or a few species of prey in each area (Springer 1991b). Diets and foraging ranges are most restricted during the breeding season, when high-energy food must be delivered efficiently to nestlings, and are somewhat more flexible at other times of the year. Seabird species differ greatly from one another in their requirements for prey and feeding habitats and, consequently, in their response to changes in the environment. Winter foraging ecology is not known for most species (Hunt *et al.* 1999).

The availability of prey to seabirds depends on a large number of factors and differs among species and seasons. All species of seabirds depend on one or more oceanographic processes that concentrate their prey at the necessary time and place, such as upwellings, stratification, ice edges, fronts, gyres, or tidal currents (Schneider 1990, Schneider *et al.* 1987, Coyle *et al.* 1992, Elphick and Hunt 1993, Hunt and Harrison 1990, Hunt 1997, review in Hunt *et al.* 1999, Springer *et al.* 1999). Prey availability may also depend on the ecology of food species, including productivity, other predators, food-web relationships of the prey, and prey behavior, such as migration of fish and zooplankton. Once a prey is captured, its value depends on its energy content.

Table 2 Recent Population Trends of Breeding Alaskan Seabirds: Fulmars, Storm-petrels, Cormorants, and Gulls.

Location	Northern Fulmar	Storm-Petrels	Pelagic Cormorant	Red-faced Cormorant	Glaucous-winged Gull
Chukchi Sea			?		
N. Bering Sea	0		?		
Central & SE Bering Sea	0	+	+	0	?
Bristol Bay			0	--	?
W. Aleutian Islands		+	--	?	--
C. Aleutian Islands	?	0	?	?	?
E. Aleutian Islands		0	--	–	0
W. Gulf of Alaska	?	?	?	?	?
N. Gulf of Alaska		?	--	--	0
SE Alaska		+	+		0

Increase: +; Stable: 0; Decline: --; trend unknown: ?; Species not present: blank.

Other notes: Trends are shown for the last 5 years, for species monitored over 4 or more years. Each area covers about 500 km of coast and includes 1 or more monitoring sites. If trends vary among colonies in area, trend is shown for overall population of area. No information on trends exists for double-crested cormorants gulls other than glaucous-winged gull, or jaegers.

Table 3 Recent Population Trends of Alaskan Seabirds: Kittiwakes, Murres, and Guillemots.

Location	Black-legged Kittiwake	Red-legged Kittiwake	Common Murre	Thick-billed Murre	Pigeon Guillemot
Chukchi Sea	0		+	+	
N. Bering Sea	0		0	--	?
Central & SE Bering Sea	0	0	+	0	?
Bristol Bay	0		0		?
W. Aleutian Islands	+	0	?	+	?
C. Aleutian Islands	0		?	?	?
E. Aleutian Islands	?		0	0	?
W. Gulf of Alaska	?		?	?	?
N. Gulf of Alaska	0		+		--
SE Alaska			--		?

Increase: +; Stable: 0; Decline: --; trend unknown: ?; Species not present: blank.

Other notes: Trends are shown for the last 5 years, for species monitored over 4 or more years. Each area covers about 500km of coast and includes 1 or more monitoring sites. If trends vary among colonies in area, trend is shown for overall population of area. No information on trends exists for terns or black guillemots.

Table 4 Recent Population Trends of Alaskan Seabirds: Auklets, Murrelets, and Puffins.

Location	Least Auklet	Crested Auklet	Kittlitz's Murrelet	Marbled Murrelet	Tufted Puffin
Chukchi Sea			?		?
N. Bering Sea	?	?	?		?
Central & SE Bering Sea	?	?			?
Bristol Bay			?	?	?
W. Aleutian Islands	?	?	?	?	?
C. Aleutian Islands	--	0	?	?	?
E. Aleutian Islands	?	?	?	?	0
W. Gulf of Alaska	?	?	?	?	?
N. Gulf of Alaska			--	0	0
SE Alaska			?	?	?

Increase: +; Stable: 0; Decline: --; Trend unknown: ?; Species not present: blank.

Other notes: Trends are shown for the last 5 years, for species monitored over 4 or more years. Each area covers about 500km of coast and includes 1 or more monitoring sites. If trends vary among colonies in area, trend is shown for overall population of area. No information on trends exists for other auklets, ancient murrelet, rhinoceros auklet, or horned puffin.

Table 5. Population Trends for Kittiwakes and Murres at Selected Breeding Colonies in the Bering Sea.[b]

Location	Species [a]	Number of years[b]	Range	Overall trend [c]	Subset Trends [d]
Agattu	BLK1	8	75-94	Increase (r2=0.63, p<0.02)	75-79<88-94 (t=2.746, p<0.03), No trend 88-94 (r2=0.03)
	UNMU	7	74-94	Increase (r2=0.55, p<0.06)	74-79<85-94 (t=5.086, p<0.01), No trend 85-94 (r2=0.07)
Buldir	BLK1	10	74-96	Increase (r2=0.87), p<0.01)	74-76<88-96 (t=12.109, p<0.01), No trend 88-96 (r2=0.14)
	RLK1	10	74-96	Increase (r2=0.84), p<0.01)	74-76<88-96 (t=9.96, p<0.01), No trend 88-96 (r2=0.15)
	TBMU	10	74-96	Increase (r2=0.86), p<0.01)	74-76<88-92<94-96 (F=155.529, p<0.001)
C. Pierce	BLK1	13	76-96	No trend (r2=0.01)	
	COMU	13	76-96	No trend (r2=0.10)	
Bluff	BLK1	14	79-95	Increase (r2=0.51, p<0.01)	No trend 87-95 (r2=0.07)
	COMU e	8	75-82	Decline (r2=0.75, p<0.01)	
		12	79-95	No trend (r2=0.01)	
St. Paul	BLK1	10	76-96	Decline (r2=0.63, p<0.01)	No trend 87-96 (r2=0.31)
	RLK1	10	76-96	Decline (r2=0.75, p<0.01)	No trend 88-96 (r2=0.78, p>0.10)
	COMU	10	76-96	Decline (r2=0.53, p<0.02)	No trend 86-96 (r2=0.11)
	TBMU	10	76-96	No trend (r2=0.12)	76>82-96 (t=10.051, p<0.01)
St. George	BLK1	10	76-96	No trend (r2=0.24)	Decline 76-86 (r2=0.89, p<0.02), No trend 87-96 (r2=0.64, p=0.11)
	RLK1	10	76-96	Decline (r2=0.64), p<0.01)	76-86>87-96 (t=2.086, p<0.10), No trend 87-96 (r2=0.01)
	COMU	10	76-96	Increase (r2=0.48), p<0.03)	No trend 76-92 (r2=0.18), Increase based on 96 count
	TBMU	10	76-96	No trend (r2=0.23)	Decline 76-88 (r2=0.94, p< 0.01), apparent increase 89-96.

[a] Codes: BLKI (Black-legged Kittiwake), RLKI (Red-legged Kittiwake), COMU (Common Murre), TBMU (Thick-billed Murre), UNMU (Unidentified Murre, includes both species).
[b] Number of years and earliest and latest year for which data are available.
[c] Trends indicated if simple linear models fit and slopes differed from zero at the 0.1 level.
[d] Trends suggested on graphs for subsets at least 4 years long were tested with regressions, and subsets were compared with t-tests or ANOVA to identify differences.
[e] Separate sets of data were analyzed for whole-colony counts (1975-1982) and plot counts (79-95).
This table used with permission of the primary author, Table 1 in Hunt, G.L., Jr., Byrd, G.V., Jr. (1999). Marine bird populations and the carrying capacity of the EBS. Pp.631-650 In, Loughlin, T. R., and K. Ohtani (eds.), Alaska Sea Grant Press, The Bering Sea: Physical, Chemical and Biological Dynamics. University of Alaska Sea Grant, Fairbanks.

Ecological Interactions Affecting Seabirds

Various ecological factors may determine whether valuable forage species are present within a bird's feeding range, and whether prey are available to the birds. Even where some information exists on forage species and areas that are important to seabirds, there usually is no information on the small age classes of fish (5-15 cm) consumed by birds.

Habitat requirements of forage species may limit whether a species is present within the foraging range of seabirds. Of the high-value forage species of seabirds, only one or two are typically available to seabirds in a given area (Springer 1991b): sand lance in most of the Bering Sea (Springer 1991b, Springer, Piatt *et al.* 1996), pollock and formerly capelin in the Pribilof Islands (Hunt, Burgeson *et al.* 1981, Springer, Roseneau *et al.* 1986, Decker 1995), capelin and pollock on the Alaska Peninsula (Springer 1991b, Hatch and Sanger 1992), and capelin, sand lance, herring, and pollock in the northern GOA (Hatch and Sanger 1992, Piatt, Abookire *et al.* 1998, Suryan, Irons *et al.* 1998b, Suryan, Irons *et al.* 2000, Golet, Kuletz *et al.* 2000). The availability of forage species often varies within small areas, such as PWS, Cook Inlet, and island groups in the Aleutian Islands (Byrd, Merrick *et al.* 1997, Piatt, Abookire *et al.* 1998, Suryan, Irons *et al.* 1998b). The preferred forage species in each area usually is essential for successful seabird reproduction (Springer, Roseneau *et al.* 1986, Springer, Murphy *et al.* 1987, Baird 1990, Piatt and Anderson 1996, Golet 1998, Golet, Kuletz *et al.* 2000, Piatt, Abookire *et al.* 1998, Suryan, Irons *et al.* 1998a, Suryan, Irons *et al.* 1998b, Suryan, Irons *et al.* 2000).

At the Pribilof Islands, there has been a shift from capelin to sandlance as the fatty forage fish available to diurnal seabirds (Decker *et al.* 1996). At the Pribilof Islands there has also been a decline in the use and abundance of age-1 pollock (Hunt, Kitaysky *et al.* 1996). In an analysis of diet changes of seabirds at the Pribilof Islands, Hunt, Decker *et al.* (1996) suggested that the decline in the use of fatty fishes, including myctophids, was correlated with reduced reproductive success. However, when pollock dropped significantly in diets and kittiwakes were forced to rely primarily on the fatty forage fishes that may have been scarce, reproductive success was also diminished. It appears, then, that at the Pribilofs, either because the colonies are so large, or because fatty forage fishes are generally scarce there, an abundant supply of pollock, preferably age-1 pollock, is important.

Habitat requirements of seabird forage species are poorly known, particularly for the size classes consumed by birds (6 to 15 cm for most bird species) and for the specific areas that are important to foraging seabirds. The information that exists is best for the species whose adults are prey of seabirds, such as capelin and sand lance, and for juvenile pollock. Habitats of other important forage groups, such as myctophids and juvenile herring, are poorly known. Recent studies, however, have provided data on the seasonal patterns and habitat for several species of forage fishes in Cook Inlet (Robards, Piatt *et al.* 1999, Blackburn and Anderson 1997) and juvenile herring (Brown, Wang *et al.* 1999, Paul and Paul 1999) and juvenile pollock (Paul, Paul *et al.* 1998) in PWS.

Stock sizes and productivity of forage species are among the factors that determine the abundance and availability of these species in seabird foraging areas. Seabirds must have access to prey within efficient foraging range of the breeding colony in order to raise their chicks successfully (Piatt and Roseneau 1998, Suryan, Irons *et al.* 1998a, Suryan, Irons *et al.* 2000, Golet, Kuletz *et al.* 2000). For instance, breeding success of black-legged kittiwakes in Cook Inlet varied with local stocks of capelin (Piatt, Abookire *et al.* 1998). In PWS, success of black-legged kittiwakes (Suryan, unpubl. data), pigeon guillemots (Golet, Kuletz *et al.* 2000) and marbled murrelets (Kuletz unpubl. data) correlated with relative abundance of forage species among years and among sites. For most seabird species or areas, specific information is rarely available on the relationship between forage stocks and breeding success. In other regions, however, there is considerable circumstantial evidence of links between depletion of forage fish stocks and subsequent declines in seabird populations (Furness 1982, 1984).

Presence of forage species in a bird's feeding range is not enough. Schools or swarms of forage fish must be of sufficient size and density for seabirds to exploit them efficiently (Hunt, Harrison *et al.* 1990, Piatt and Roseneau

1998). Schools also must be available in the respective habitat for each seabird species (Hunt and Harrison 1990, Ostrand, Coyle *et al.* 1998), including at a depth which the seabird can reach (Section 3.5.1). No information exist on the influence of stock size on the availability of forage schools to seabirds.

Stocks of many forage fish species may change with overall abundance. Seabird colonies near the edge of a forage species' range may therefore experience large fluctuations in food supply with changes in an overall forage stock, while food may be more reliable at colonies near the core of the forage species' range (MacCall 1984). Changes in overall fish stocks due to either fishery pressures or environmental changes may, therefore, affect the local availability of forage to seabirds. Any effects of stock changes on seabirds almost certainly will vary among areas. Although data on the relationship between stock sizes and availability to seabirds are lacking for most specific areas, improvements in hydroacoustic methods have increased our knowledge of these patterns (Hunt, Mehlum *et al.* 1999). The relationship between prey availability and density is complicated by different patterns of distribution for seabirds relative to their prey. When prey are at the surface, seabird aggregations may be tightly coupled with prey, but if prey are deep there is little correspondence beyond a coarse scale (review in Hunt, Mehlum *et al.* 1999). Several studies indicate that when prey abundance is above some threshold, birds will no longer track prey closely, but in years with low prey abundance, birds will be tightly associated with prey patches (review in Hunt, Mehlum *et al.* 1999). Three distinct levels of patchiness in the spatial relationship between murres and capelin in the Barents Sea have been observed with associations focused at >300 km, ~50 km and ~3 km. (Fauchald, Erikstad *et al*. 2000).

Movements and schooling behavior of forage fish species often determine whether the species will be available at a place and time suitable for seabird foraging. Densities of foraging seabirds are often correlated with densities of their prey (Hunt 1990, Hunt, Mehlum *et al.* 1999, Fauchald, Erikstad *et al.* 2000). Currents disperse some small forage species, but other species contribute to their own locomotion. Diurnal vertical migrations by pelagic plankton, myctophids, and squid determine their availability to surface-feeding birds such as northern fulmars and kittiwakes (Hatch 1993, Hatch, Byrd *et al.* 1993). Sand lance, juvenile herring, and other forage species are available to birds at times when they form dense schools in shallow water; these fish may be dispersed too greatly at other times for efficient foraging by many seabird species (Hunt, Harrison *et al.* 1990, Blackburn and Anderson 1997, Piatt and Roseneau 1998, Irons 1998). Breeding success and population trends of kittiwakes in the northern Bering Sea and of pigeon guillemots in PWS are correlated with years when schools of sand lance are available (Springer, Murphy *et al.* 1987, Hayes and Kuletz 1997). Schools must be at or near the surface in order for kittiwakes and terns to reach them; these birds are usually observed feeding on shoals of sand lance in years when reproductive success is high (Baird 1990).

Competition and predation may influence seabird prey availability. Links between seabirds and other species could be direct, or they could be extremely diffuse and indirect. Possible links include: competition between seabird species; competition of piscivorous seabirds with other large marine predators such as marine mammals and fish; cannibalism by large pollock on the smaller pollock that are eaten by some seabirds; competition for food among forage species of seabirds, such as small pollock, capelin, sand lance, herring, myctophids, and squid; competition between planktivorous seabirds with whales or planktivorous fish (including forage fish of other seabird species); and even ecosystem links with groups such as jellyfish. Little information is available on the magnitude or direction of these links.

The energy content of prey has recently been found to influence the growth of seabird chicks and reproductive success at the colony level (Kitaysky 1999, Kitaysky, Wingfield *et al.* 1999, Golet, Kuletz *et al.* 2000). Fish with high lipid and low water content provide the most efficient food "package" for growing seabird chicks; such fish include myctophids, capelin, sand lance, and larger age classes of herring. Energy-poor forage species include pollock and benthic fish. Young black-legged kittiwakes and tufted puffins fed high-value fish grow faster than those fed pollock (Romano, Roby *et al.* 1998). Slow-growing young birds in colonies may ultimately starve in the nest or be more vulnerable to post-fledgling stresses than well-fed young. Growth rates, reproductive success, and population trends of several seabird species are correlated with availability of high-value prey in the northern GOA (Anthony and Roby

1997, Golet 1998, Piatt, Abookire *et al.* 1998, Roby, Turco *et al.* 1998, Golet, Kuletz *et al.* 2000, Suryan, Irons *et al.* 2000).

The influence of prey energy content on seabird trends in other parts of Alaska has not been investigated. For instance, kittiwakes and murres often consume pollock in the Pribilof Islands, whereas capelin and sand lance are less available (Hunt, Eppley *et al.* 1981b, Schneider and Hunt 1984); the birds are able to raise chicks. However, breeding success of kittiwakes is relatively low in these colonies compared with other parts of Alaska (Hatch, Byrd *et al.* 1993), and murre and kittiwake populations declined recently on the Pribilof Islands (Section 3.5.1). The relative value of prey species to breeding seabirds may vary among areas, depending on factors such as distance to foraging areas and body composition of forage species. The relative value of pollock and other prey to seabird populations in the Pribilof Islands is unknown.

The fraction of total exploitable stocks in the EBS that are consumed by seabirds have been estimated at 3 percent for pollock and less than 1 percent for herring (Livingston 1993), which is similar to an estimate of 4 percent for sand lance in the North Sea (Furness and Tasker 1997). Seabirds, therefore, may account for a very minor proportion of forage fish mortality, even for the young age classes that they consume ((Livingston 1993). Seabirds may have greater impacts on fish stocks within foraging range of seabird colonies, however, because the birds are concentrated there during summer (Springer, Roseneau *et al.* 1986, Birt, Birt *et al.* 1987). Fifteen to eighty percent of the biomass of juvenile forage fish may be removed by birds each year near breeding colonies (Wiens and Scott 1975, Furness 1978, Springer, Roseneau *et al.* 1986, Logerwell and Hargreaves 1997). This suggests that food availability to birds may be limited, at least in a given season, by the size of the local component of fish stocks. Seabirds may, therefore, be vulnerable to factors that reduce forage fish stocks in the vicinity of colonies (Monaghan, Walton *et al.* 1994). The availability of forage fish to seabirds also would depend on the rate of fish immigration, and on factors that limit the ability of birds to capture the fish present in the area (Section 3.5.2).

Estimates of predation pressure by seabirds on forage stocks are based on incomplete data. Existing information on diet, consumption, and energetics of seabirds has been obtained during the breeding season. Broad assumptions must therefore be made for the other nine months of the year, and for the nonbreeding component of seabird populations (roughly 15 to 50 percent of the total) throughout the year. Diets and factors that limit prey availability during nonbreeding periods presumably are different from those in summer. Some authors believe that food is more limited in winter than summer for many species (Croxall 1987). Outside the breeding season, diets, feeding habitats, energy requirements, and distributions have been studied only minimally for most seabird species[i]. Limited information suggests that, in winter months, many seabirds consume a greater variety of fish as well as higher proportions of zooplankton and invertebrates (Sanger 1986, 1987b). Predation pressure of birds on forage fish stocks is unknown for most stocks and areas. The proportion of noncommercial forage fish species taken by seabirds cannot usually be estimated because no information exists on stock sizes for these species. Recent studies in Glacier Bay, Cook Inlet and Prince William Sound, however, which obtained estimates of forage fish biomass, will provide information in the near future.

Region-wide conditions that may influence local prey availability are not well described, but are being investigated by GLOBEC. Climate and food-web changes can occur over the entire Bering Sea or GOA, and several reviews indicate that such large-scale fluctuations affect prey availability for seabirds (Anderson and Piatt 1999, Francis, Hare et al. 1998, McGowan, Cayan *et al.* 1998, Agler, Kendall *et al.* 1999). The mechanisms of how the oceanographic changes alter marine communities require further investigation.

Seabird Responses to Changes in Forage Availability

The availability of food resources to seabirds depends not only on the forage fish species and their physical environment, but also on the response of each bird species to prey availability. Seabird species differ in their foraging adaptations, ways in which they respond to change, relationships with competitors, and the effects on populations of changes in their food supply.

The response of several seabird species to changing forage conditions has been studied in some detail. For many species, however, flexibility and behavioral limitations are known only in general. The effects on seabird populations of changes in the food supply, and the minimum abundance of forage that each species requires, have been studied for only a few species in the northern GOA. Information is needed on limiting prey densities for most Alaskan species (the prey densities at which breeding success is insufficient to maintain populations). Studies are needed of all species in several areas of Alaska; limiting densities of prey are likely to differ among regions, depending on which prey birds depend on, its availability, and whether alternate prey are available. More specific data on minimum biomass required for reproductive success in seabirds may soon become available for parts of the northern GOA as Exxon Valdez Trustee Council studies are concluded.

Foraging Behavior and Flexibility

Foraging behavior and flexibility limit each species' responses to changing conditions. In general, seabird diets consist of fish or squid 5-15cm long or large zooplankton. Diets and foraging ranges are most restricted during the breeding season, when high-energy food must be delivered efficiently to nestlings. Foraging adaptations and habitat selection for each bird species are described in Section 3.5.1. Species-specific adaptations include foraging range from breeding colonies, depth at which prey can be obtained, prey size and type, optimal and limiting densities of prey aggregations, and ability to switch to foods such as other fish species, invertebrates, detritus, or terrestrial organisms. Seabirds learn where to find aggregations of their prey under various conditions, and they may return to favorable areas regularly (Hunt, Mehlum *et al.* 1999).

Albatrosses are unique among seabirds in that they display the largest foraging areas so far recorded in any extant central-place forager (review in Gremillet et al 2000). During the breeding season, wandering albatrosses (*Diomedea exulans*), for example, may travel 15,000 km over the Southern Ocean during a single feeding trip (Jouventin and Weimerskirch 1990). This performance is made possible by dynamic-soaring, a flight technique which enables these birds to travel at low energy costs for extended periods (Pennycuick 1989). Satellite tagging is being used to identify the vast foraging areas for many albatross species in the Southern Ocean.

Seabirds differ from one another in their ability to respond to changing conditions. For instance, most surface-feeding species can forage over greater distances than diving birds (Shuntov 1993), but diving birds can exploit prey at greater depths than surface-feeders (Baird 1990, Monaghan 1996). Murres can forage deeper than any other species, which buffers them against changes in vertical distribution of their prey; however, their need for dense aggregations of prey may make them vulnerable to occasional "die-offs" when prey are scattered or otherwise unavailable (Piatt and van Pelt 1997). Murres can increase the daily foraging time needed in order to obtain scarce or distant prey, and they sometimes are able to maintain breeding success under poor conditions; in contrast, seabirds such as terns and kittiwakes often do not have the extra time available each day to make this adjustment (Monaghan, Wright *et al.* 1992, Furness and Tasker 1997, Piatt, Abookire *et al.* 1998). However, within Prince William Sound, differences can occur among kittiwake colonies in foraging range, trip duration and feeding rate, consistent with fish availability, suggesting some buffering capabilities (Suryan, Irons *et al.* 2000). Pigeon guillemots can forage either on schooling energy-rich fish or on dispersed, energy-poor benthic fish, but breeding success and population stability are supported best by schooling fish (Kuletz 1983, Golet, Kuletz, *et al* 2000). Gulls can switch to invertebrate prey or scavenging when schooling fish decline, but breeding success suffers (Murphy, Day *et al.* 1984). Foraging adaptations of seabirds may differ among areas according to sizes of prey aggregations, availability of alternate prey, distance to foraging areas, depth of the prey, and many other factors.

Seabird Interactions with Each Other and with Marine Mammals

Seabird interactions with each other and with marine mammals influence their populations (Mehlum *et al*. 1998, review in Hunt, Mehlum *et al* 1999). Seabirds compete within and between species for food and nesting space. The influence of such competition on populations is largely unknown, although evidence has been presented that large Alaskan colonies may be limited by competition for food (Hunt, Eppley *et al.* 1986). Seabirds that feed in flocks may benefit by interactions within and among other species; surface-feeding birds may attract others to aggregations of prey, while diving birds appear to drive subsurface prey within reach of surface-feeders (Hoffman *et al.* 1981, Hatch 1993, Maniscalco, Ostrand *et al.* 1998, Ostrand 1999). Bottom-feeding marine mammals such as gray whales also increase the availability of prey and detritus to surface-feeding birds (Harrison 1979, Hunt 1990, Obst and Hunt 1990).

Population Responses of Seabirds to Changes in Forage Availability

Trends in seabird populations are the result of forage availability and food-web changes. Depending on individual foraging success, the population of each species may maintain itself, increase, or decline. Population trends may last for a few years or many decades, and they may be local or cover large regions, depending on fluctuations in forage availability. Trends are likely to differ among seabird species in the same area and time period, because "forage availability" will vary with a seabird's body size and feeding behaviors (Chastel, Weimerskirch *et al.* 1995, Putz *et al.* 1998).

The responses of seabird populations to prey abundance have been examined theoretically, and forage/trend relationships have been studied for a few species in the field. When forage is below some minimum level of availability, birds cannot raise enough young to replace those that die, and (in extreme cases) adult birds may even die from starvation. One or two bad years will not cause a population decline, but if food remains scarce, the population decreases. Cairns (1990) theorized that seabird productivity and populations show sigmoidal >threshold' responses to prey abundance He suggested that at intermediate forage levels, breeding is increasingly successful; populations are stable or fluctuate only slightly. At some higher level of forage availability, birds are able to raise the maximum number of young (roughly 0.5 to 3 young per breeding pair in each year, depending on the species), and the population increases. Additional forage above this upper threshold will not increase breeding success or population growth further due to other density-independent factors.

The relationships between forage abundance and seabird population trends differ among species. Some species can maintain themselves while foraging on relatively low prey densities; others in the same area require much higher densities. Examples include puffins exploiting lower densities of capelin than murres in Newfoundland (Piatt 1990). Preliminary data that suggests that murres may be able to subsist on lower densities of sand lance in Cook Inlet than kittiwakes (Piatt, Abookire *et al.* 1998). Highly dispersed, non-colonial birds such as marbled murrelets may be particularly well adapted to patchy, highly dispersed prey in low-density schools (Ostrand, Coyle *et al.* 1998, Kuletz 1999).

Field studies and modeling work on the relationships of seabird populations to local prey densities are only beginning. Much more information is needed on limiting prey densities for most Alaskan species. Prey densities per se are not the limiting factor experienced by birds, but rather densities of available prey. Limiting densities for many bird species may vary among regions of the state, depending on factors such as the principal and alternate prey species.

Bycatch of Seabirds in Fishing Gear

Seabirds are caught incidentally in all types of fishing operations (Jones and DeGange 1988). In a coastal drift gillnet fishery in Washington state, sea state and time of day were significant predictors of seabird bycatch rates, indicating that visibility or maneuverability, as well as feeding behaviors, may affect susceptibility of birds (Melvin, Parrish *et al.* 1999). In groundfish fisheries, longlines account for most seabird bycatch. Trawls also take some seabirds, primarily those that feed beneath the surface on prey in the water column. Pots occasionally take diving seabirds. Some birds also are injured or killed by striking the vessel superstructure or gear while flying in the vicinity.

<u>Monitoring Seabird Bycatch and Seabird/Fishery Interactions</u>

Data collection regarding seabird/fishery interactions by NMFS in the groundfish fisheries began in 1990 and was expanded during the 1993, 1997, 1999 and 2000 seasons.

In the NMFS preliminary analysis of 1993 to 1999 observer data, only three of the albatross taken were identified as a short-tailed albatross (and all from the BSAI region). Of the albatross taken, not all were identified. This analysis of

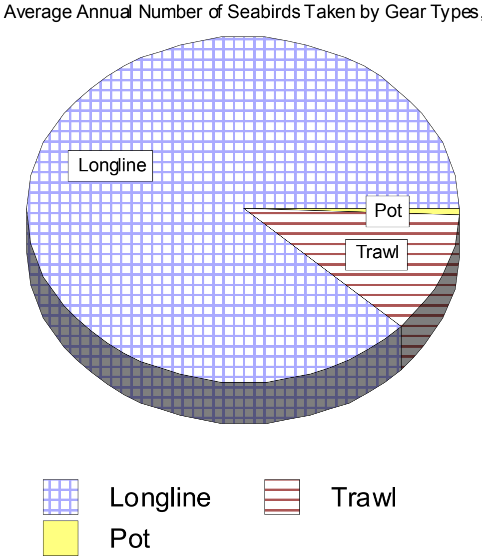
1993 to 1999 data resulted in an average estimate of two short-tailed albatross being taken annually in the BSAI groundfish hook-and-line fishery and zero short-tailed albatross being estimated taken annually in the GOA groundfish hook-and-line fishery. The incidental take limit established in the USFWS biological opinions on the effects of the hook-and-line fisheries on the short-tailed albatross is based on the actual reported takes and not on extrapolated estimated takes.

Based on estimates of seabirds observed taken in groundfish fisheries from 1989 to 1993, 85 percent of the total seabird bycatch was caught in the BSAI, and 15 percent in the GOA. Longline gear accounted for 90 percent of the total seabird bycatch, trawls for 9 percent, and pots 1 percent. (Wohl *et al.* 1995). NMFS analysis of 1993 to 1999 observer data indicates similar patterns as those seen in the 1989 to 1993 data (Figure 3). Longline gear accounted for 88.1 percent of the total average annual seabird bycatch, trawl gear for 11.5 percent and pot gear for less than 1 percent. Based on estimates of seabirds observed taken in groundfish longline fisheries from 1993 to 1999, 86 percent of the longline seabird bycatch was caught in the BSAI, and 14 percent in the GOA.

Bycatch on Longlines

Longlines catch surface-feeding seabirds that consume invertebrate prey which resemble bait. During setting of the line seabirds are hooked as they attempt to capture the bait. Birds that habitually scavenge floating material from the sea surface are also susceptible to being hooked on longlines (Brothers 1991, Alexander *et al.* 1997, Brothers, Cooper *et al.* 1999). Recent studies have implicated longline fishing in these population declines of albatross species. Longline fishing is considered the most recent and potentially most serious global threat faced by albatrosses and other procellariiforme taxa (Brothers *et al.* 1999a). Seabird mortality in Alaska longline fisheries represents only a portion of the fishing mortality that occurs, particularly with the albatrosses. Mortality of black-footed albatrosses and Laysan's occurs in both Alaskan and Hawaiian longline fisheries and may be assumed to occur in other North Pacific longline fisheries conducted by Japan, Taiwan, Korea, Russia, and China (Brothers *et al.* 1999b). USFWS has not analyzed the potential impacts of the seabird bycatch in the Alaska longline fisheries on other seabird species populations.

Fig. 3.5-3 Average Annual Number of Seabirds Taken by Gear Types, 93-99.



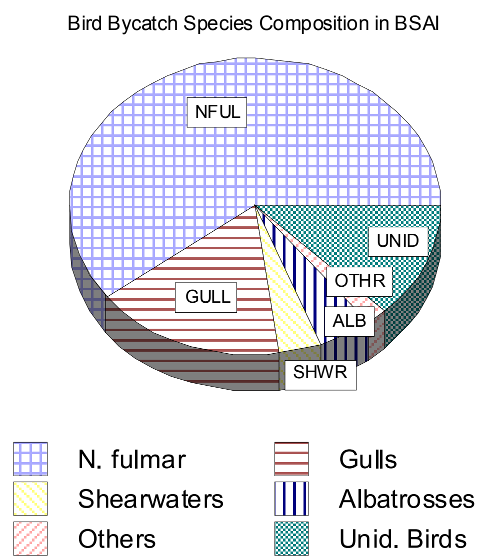


Figure 4. Relative Species Composition of Bird Bycatch in the Longline Fisheries in the BSAI, Average Annual Estimates, 1993-1999.

Preliminary estimates of the annual seabird bycatch for the Alaska groundfish fisheries, based on 1993 to 1999 data, indicate that approximately 17,000 seabirds are taken annually in the combined BSAI and GOA groundfish fisheries

(14,600 in the BSAI; 2,300 in the GOA) at the average annual rates of 0.10 and 0.06 birds per 1,000 hooks in the BSAI and in the GOA, respectively

Of the estimated 14,600 seabirds that are incidentally caught in the BSAI, the species composition is: 60 percent fulmars, 17 percent gull species, 12 percent unidentified seabirds, 5 percent albatross species, 4 percent shearwater species, and 2 percent 'all other' species (Figure 4).

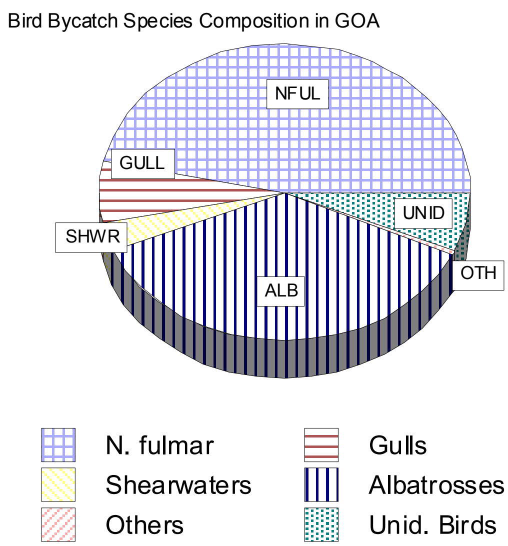


Fig. 5. Relative Species Composition of Bird Bycatch in the Longline Fisheries in the GOA, Average Annual Estimates, 1993-1999.

Of the estimated 2,300 seabirds that are incidentally caught in the GOA, the species composition is: 47 percent fulmars, 37 percent albatrosses, 6 percent gull species, 6 percent unidentified seabirds, 3 percent shearwater species, and less than 1 percent 'all other' species (Figure 5). Five endangered short-tailed albatrosses were reported caught in the longline fishery since reliable observer reports began in 1990: two in 1995, one in 1996, and two in 1998, and all in the BSAI. Both of the birds caught in 1995 were in the vicinity of Unimak Pass and were taken outside the observers' statistical samples; the bird caught in 1996 was near the Pribilof Islands in an observer's sample; the two short-tails taken in 1998 were in observers' samples.

It is difficult at this time to make valid comparisons of bird bycatch rates between regions. We cannot discern if the differences between the BSAI and GOA estimated bycatch rates are due to the vastly different levels of fishing effort in each region, the different types of vessels used in each region ('small' catcher vessel in GOA, 'large' catcher-processor in BSAI), different distribution and abundance of birds, etc. An analysis of covariance would allow for a valid statistical comparison of the regional bycatch rates.

Bycatch in Trawls

Trawls primarily catch seabirds that dive for their prey. This probably occurs as the trawl is being retrieved rather than while it is actively fishing. A few birds may also be caught as they are attempting to scavenge fish or detritus at the surface during retrieval. The species composition of seabird bycatch in observed trawl hauls is currently available for 1993 through 1999. The principal bird species reported in trawl hauls were alcids, northern fulmars, and gulls. Small numbers of other species also were caught. NMFS analysis of 1993 to 1999 observer data indicates that trawl gear accounted for 11.5 percent of the total average annual seabird bycatch in the BSAI and GOA groundfish fisheries combined (Fig. 3).

There is evidence that some forms of trawling may make fish vulnerable to diving birds by disturbing or injuring the fish. Black guillemots (Ewins 1987) and great cormorants (*Phalacrocorax carbo sinensis*) in the North Atlantic (Camphuysen 1999) are two species that may have learned to take advantage of such disruptions.

Onboard observations of birds (including Laysan's albatrosses) colliding with the trawl transducer wires (sometimes called third wire) have been made. These wires are typically deployed midship from a davit on midwater trawl vessels fishing for pollock and carry the transducer net sounder cable down to the head of the trawl net. Any birds killed by such collisions would most likely not be recorded in the observers' sampling of the trawl haul in that it is unlikely that such dead birds would make their way into the trawl net. This potential interaction was noted in the Nov 4, 1998 letter from the Regional Administrator of NMFS Alaska Region to the Field Supervisor of the Office of Ecological Services, USFWS, that initiated the section 7 consultation for the 1999-2000 groundfish longline fisheries. NMFS determined that the groundfish trawl vessels that deploy such a cable 'may affect' short-tailed albatrosses. Although collisions with short-tailed albatrosses have not been observed or reported, NMFS and FWS staff felt the potential was there, given that the closely related Laysan's albatross has been observed colliding with the wires. The December 2, 1998 response from USFWS noted that this 'may affect' determination constituted an active informal section 7 consultation with no statutory deadlines. NMFS is initiating efforts to research the issue to determine the extent of use of trawl third wires in the trawl fleet and specifics of the bird/vessel interactions. Solutions may be as simple as hanging streamers from the third wire (Balogh, USFWS pers. comm.).

Vessel Strikes

Striking of vessels by birds in flight is reported by observers, but bird-strike data have not yet been analyzed statistically. Some birds that strike vessels fly away without injury, but some are injured or killed. Bird strikes are probably most numerous during the night; birds are especially prone to strike vessels during storms or foggy conditions when bright deck lights are on, which can disorient them. The proximity of the vessels to seabird colonies during the breeding season is also a factor (USFWS, V. Byrd pers. com). Collisons of large numbers of birds occasionally occurs as in the case of where approximately 6,000 crested auklets which were attracted to lights and collided with a fishing vessel near Kodiak Island during the winter of 1977 or in the central Aleutians in 1964 when approximate1y 1,100 crested aukets attracted to deck lights on a processor and collided with structures on the vessel (Dick and Donaldson 1978). Species that most commonly strike vessels include storm-petrels, auklets, and shearwaters. Albatrosses have been observed striking the vertical cables from which sonar transducers of trawlers are suspended. Little information is available on the problem of transducer cables.

Ecosystem or Community Indicators and Modeling Results

Present and Past Ecosystem Observations – Local and Traditional Knowledge

Alaska Natives have the experience of thousands of years of observations on various aspects of the ecosystems of the North Pacific. Although Western science strives to achieve such a long term perspective, it presently resides with those who have inhabited these regions and used the resources for subsistence over the years. The Alaska Native community is working to join their collective knowledge together on the ecosystems of the North Pacific. Similarly, local observations are presently being made by other resource users and attempts are being made to collect and summarize that information in an organized fashion. Below are some summaries of these observations

Local Knowledge of Changes
Contributed by Chris Blackburn

1. Pacific cod: Kodiak fishermen fishing the State Water Pacific cod have had difficulty finding Pacific cod this year. (from ADF&G State water fishery data. In 1999 the pot quota was 2654 MT and the quota was reached April 29. This year (2000) the pot quota was 2722 MT and opened 10 days earlier than in 1999. As of August 14 the catch was 2331 MT.

2. Also, in the last few years pollock was abundant in the bays in the south end of Kodiak and on down to the Western Gulf during the salmon season -- The abundance was such that at times the seines came up with more pollock than salmon. This year there was only one small area where pollock notably mixed with salmon (Information from several salmon fishermen)

3. Pelagic Shelf Rockfish was mixed with Northern Rockfish during the August Trawl Rockfish fishery. Usually there is little mixing between these two species.

4. Doug Hoedel owner of the salmon seiner Tradition reports his crew found two hake in one of the sets in the Kodiak area

5. Miller Freeman survey earlier this year found amazing amounts of euphausids in the water samples.

6. During the ADF&G crab survey in the Aleutians around a dozen skil-fish were caught. Forrest Blau ADF&G Kodiak.

ECOSYSTEM-BASED MANAGEMENT INDICES AND INFORMATION

Indices presented in this section are intended to provide either early signals of direct human effects on ecosystem components that might warrant management intervention or to provide evidence of the efficacy of previous management actions. In the first instance, the indicators are likely to be ones that summarize information about the characteristics of the human influences (particularly those related to fishing, such as catch composition, amount, and location) that are influencing a particular ecosystem component.

Ecosystem Goal: Maintain Diversity

Time Trends in Bycatch of Prohibited Species

Contributed by Joe Terry

The retention and sale of crab, halibut, herring, and salmon generally is prohibited in the groundfish fishery; therefore, these are referred to as prohibited species. The prohibition was imposed to reduce the catch or bycatch of these species in the groundfish fishery. A variety of other management measures have been used to control the bycatch of these species and data from the groundfish observer program have been used to estimate the bycatch of these species and the bycatch mortality of halibut. Most of the groundfish catch and prohibited species bycatch is taken with trawl gear. The implementation of the halibut and sablefish IFQ programs in 1995 allowed for the retention of halibut in the hook and line groundfish fishery and effectively addressed an important part of the halibut bycatch problem in that fishery, but it also made it very difficult to differentiate between halibut catch and bycatch for part of the hook and line groundfish fishery. Therefore, the estimates of halibut bycatch mortality either for the hook and line fishery or for the groundfish fishery as a whole are not comparable before and after 1995. Estimates of the bycatch of prohibited species other than halibut and estimates of halibut bycatch mortality are presented in Figures 1-2. Halibut bycatch is managed and monitored in terms of bycatch mortality instead of simply in terms of bycatch. This is done to provide an incentive for fishermen to increase the survival rate of halibut that are discarded. The survival rates for discarded salmon and herring are thought to approach zero and there is substantial uncertainty concerning the survival rates for discarded crab. Currently, the limited ability to control or measure survival rates for the other prohibited species makes it impracticable to manage and monitor their bycatch in terms of bycatch mortality.

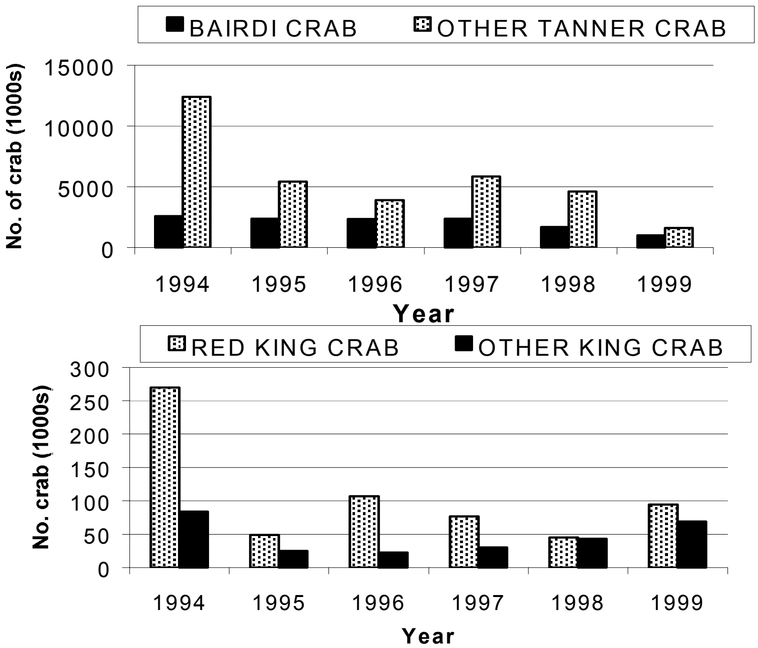


Figure 1.--Tanner and king crab bycatch in groundfish fisheries off Alaska, 1994-99.

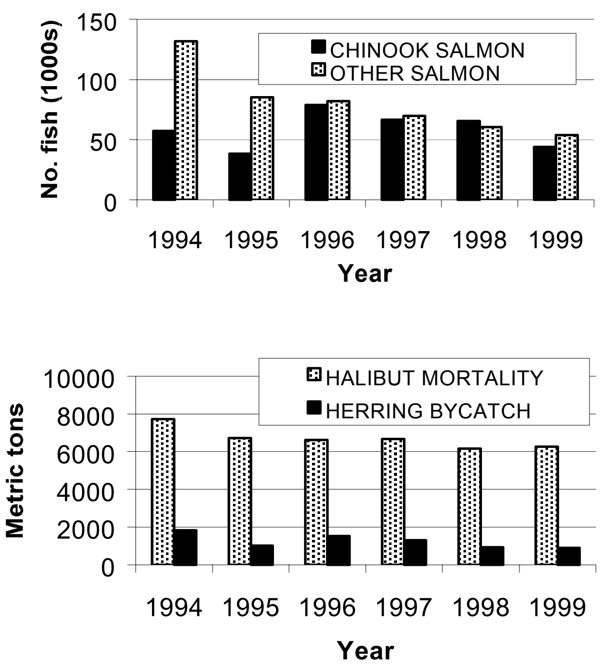


Figure 2. Bycatch of salmon, halibut, and herring in the groundfish fisheries off Alaska, 1994-99.

Time trends in groundfish discards

Contributed by Joe Terry

The amount of managed groundfish species discarded in Federally-managed groundfish fisheries dropped in 1998 compared to the amounts discarded in 1994-97 (Figure 1). The aggregate discard rate in each area dropped below 10% of the total groundfish catch. The substantial decreases in these discard rates are explained by the reductions in the discard rates for pollock and Pacific cod. Regulations that prohibit discards of these two species were implemented in 1998. The discard rates increased slightly in 1999, going up to 11% in the GOA and 9% in the BSAI.

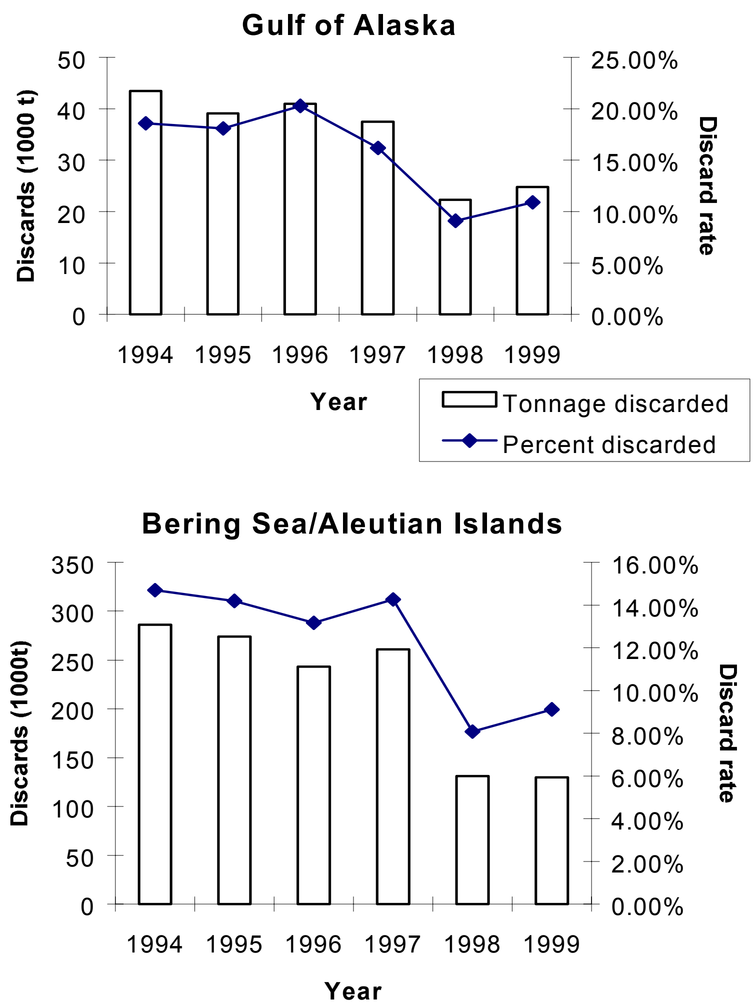


Figure 1. Total biomass and percent of total catch biomass of managed groundfish discarded in the GOA and BS/AI areas 1994-1999. (Includes only catch counted against Federal TACS.)

Ecosystem Goal: Maintain and Restore Fish Habitats

Areas closed to bottom trawling in the EBS/AI and GOA

Contributed by Pat Livingston and Dave Witherell

(not updated)

Ecosystem Goal: Sustainability (for consumptive and non-consumptive uses)

Trophic level of the catch

Contributed by Pat Livingston

(not updated)

Status of groundfish, crab, scallop and salmon stocks

Contributed by Dave Witherell

Table 1 summarizes the status of Alaskan stocks of groundfish, crab, scallop, and salmon stocks managed under federal fishery plans in 1999. Although only three stocks are considered in the overfished category, the status of a large proportion of the stocks is unknown.

Table 1 . Status of groundfish, crab, scallop and salmon stocks managed under federal fishery management plans off Alaska, 1999.

Number of Stocks by Overfishing Category

FMP	Overfished	Not Overfished	Unknown	Total
Groundfish	0	63	144	207
Crab	3	3	8	14
Scallop	1	0	1	
Salmon 0	5	0	5	

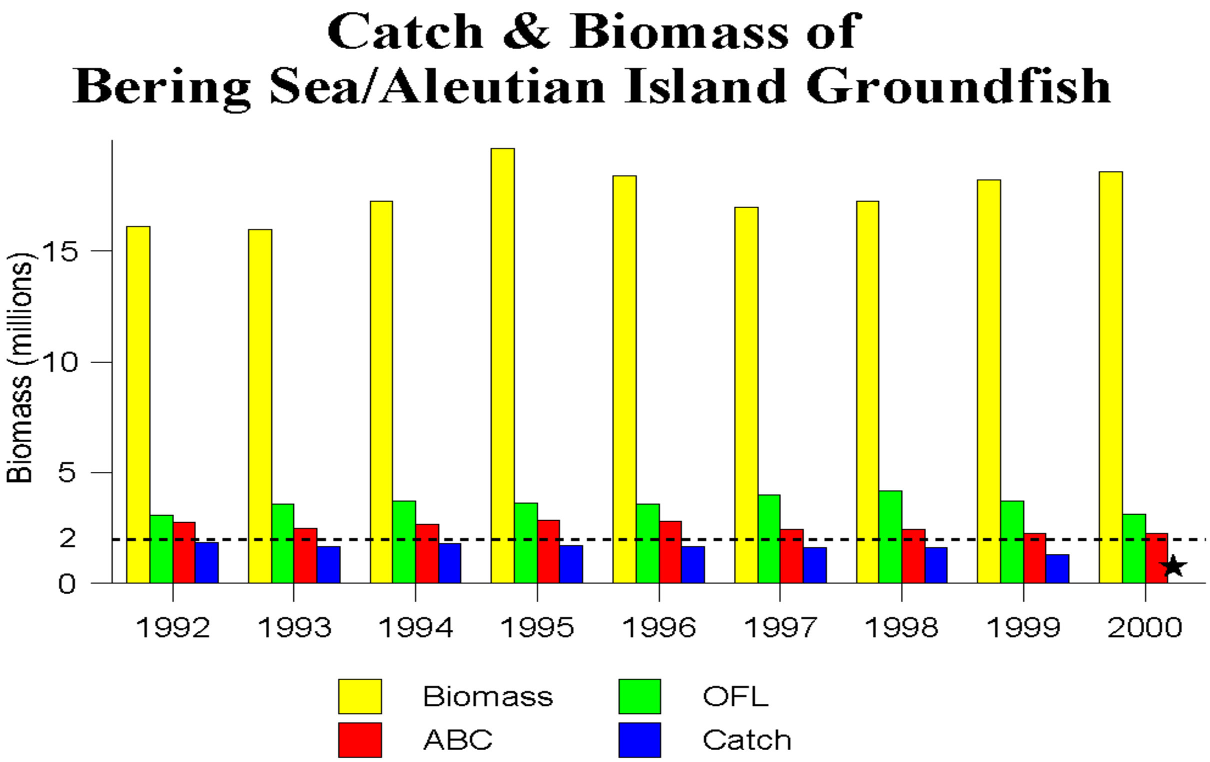


Figure 1. Exploitable biomass and catch specifications for Bering Sea and Aleutian Islands groundfish complex, 1992-2000. The dashed line shows the 2 million t optimum yield limit.

Ecosystem Goal: Humans are part of Ecosystems

Fishing overcapacity programs
Contributed by Dave Witherell
(not updated)

Groundfish and crab fleet composition
Contributed by Joe Terry (groundfish) and Dave Witherell (crab)

The Groundfish Fleet

Fishing vessels participating in the groundfish fisheries in the EEZ off Alaska principally use trawl, hook and line, and pot gear. The number of vessels harvesting groundfish with hook and line gear decreased annually from 1,410 in 1994 to 972 in 1999 (Figure 1) and more than offset both a substantial increase in the number of pot vessels (271 in 1999 compared to 136 in 1994) and a modest increase in the number of trawlers (242 in 1999 compared to 256 in 1994). As a result, the total number of vessels decreased from 1,683 in 1994 to 1,358 in 1999 with some vessels using more than one type of gear. The decreases in the number of hook and line vessels were not limited either to one vessel size class or to vessels in one catch level category. They occurred for each of the following two vessel length classes: less than 60 feet and at least 60 feet. Similarly, they occurred for hook and line vessels in each of the following three catch amount classes: less than 2 metric tons, 2 to 25 metric tons, and more than 25 metric tons. Between 1995 and 1998, the size of the fleet in terms of net registered tonnage decreased for the groundfish fleet as a whole and of each of the three fleets defined by gear type. The implementation of the individual fishing quota (IFQ) programs for the fixed gear halibut and sablefish fisheries, the implementation of the vessel moratorium for the groundfish fishery, the implementation of a license limitation program for the groundfish fishery, and high levels of excess fishing capacity have contributed to the decreases in the size of the groundfish fleet.

Number of vessels that caught crab in the BSAI area in 1996, by vessel length class (measured by length overall (LOA) in feet), catcher type, and gear.

	Catcher vessels			Catcher/
	≤60'	60-124'	≥125'	proc.s
Bristol Bay red king	0	130	62	4
Bering Sea Tanner	0	102	40	4
Bering Sea Snow crab	0	154	70	15
Norton Sound red king	41	0	0	0

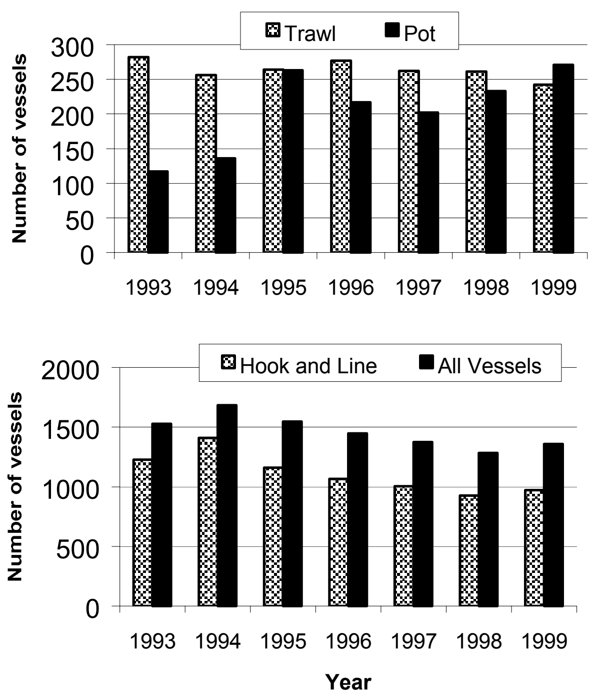


Figure 1.--Number of vessels participating in the groundfish fisheries in the EEZ off Alaska by gear type, 1993-99.

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