APPENDIX D

# Ecosystem Considerations for 2000

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

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## ECOSYSTEM CONSIDERATIONS –2000
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## Summary of Ecosystem Status and Trend Indicators

**Physical Environment Indicators:**
North Pacific climate indicators - Winter sea level pressure indicators show there was warmer winters in the late 70's and early 80's but a minor shift around 1989 to colder winters. 1998 showed a warming and 1999 a cold winter. Spring North Pacific index values – high values mean increased surface temperature due to solar heating. This index has been increasing through the late 70's but saw a major decrease in 1998. GOA pollock precipitation-based and wind-mixing based survival indices are still high

EBS ice cover still appears lower than the 70's. EBS summer bottom and surface temperatures were colder than usual in 1999, particularly in the shallow, inner shelf areas and southern middle shelf. There were some indications of differences in distribution and catchability of various groundfish species due to the cold conditions in 1999.

Indicators seem mixed with regard to whether we are moving into a different climate state. There is presently a lack of ability to predict the short-term (3-5 years) and longer-term climate state for the North Pacific.

**Contaminants:**
GOA mussel watch site – contaminants are generally low except for some metals. In some cases metal concentrations exceed 85$^{th}$ percentile values of the nationwide database for chromium, nickel, and selenium.

Benthic surveillance project of contaminants in bottom dwelling fish and sediments – data from sites in Alaska are extremely limited and unable to make any conclusions at this time.

Arctic regional assessment of radionuclides and contaminants indicates low anthropogenic radionuclide activity in the US Arctic but radionuclides are pervasive – indicating global fallout as likely the predominant and perhaps only source. Subsistence foods from marine food chains, such as seals and bowhead whales contain very small and nearly negligible amounts of radiation.

Toxic elements such as arsenic, chromium, coper and nickel show generally elevated levels in eastern Bering Sea and Beaufort Sea sediments. There appears to be no anthropogenic sources for these elements in these regions. The elevated levels are attributed to enriched source rocks and regional mineralogy. There is little scientific data on the evnironmental pathways, including food chain transfers and biological effects of these toxic elements on the fish and wildlife resources of the Arctic.

Organic contaminants in Alaska are low and are among the lowest recorded by the National Status and Trends program.

**EFH progress** – A data base on surficial sediments is now available for the EBS. Spawning sites of Atka mackerel are being surveyed. Sediment and infauna samples are being collected and processed. Benthic species composition and diversity are being compared in trawled versus untrawled sites. EBS results indicate some differences in overall diversity of benthic epifauna from EBS and GOA results. Nearshore juvenile groundfish habitat is now being explored and identified in SE AK.

**Effects of fishing gear on habitat research progress** – Seafloor habitat in trawled in untrawled areas in the central GOA are being examined. Benthic community structure in low and high trawling areas in the GOA are also being analyzed. Trawl impact studies in the Bering Sea are continuing along with evaluations of acoustic technology for seabed classification. A benthic sled has been developed to observe seafloor habitat. Some seamounts and pinnacles have been examined via submersibles as habitat areas of particular concern. Trawl tracks in the GOA have been examined over time by submersibles. Effects of trawling on hard bottom habitat in the Aleutian Islands were examined using a towed observation system. Description and distribution of corals in the GOA and EBS have been summarized.

**Zooplankton biomass** in the EBS may be increasing in the late 1990's. This has unknown food chain implications. There is a need to continue and improve on the monitoring of phytoplankton and zooplankton. It is possible that the impacts of climate fluctuations on fish, birds, and mammals are mediated strongly through lower trophic forcing.

**Forage fish**: In the late 1970's, GOA capelin abruptly declined in abundance in inshore small mesh trawl surveys, presumably in response to the increase in water column temperature that occurred during that same period. There is still no indication of any increase in forage species in those areas at present. Eulachon are at lowest recorded levels in this survey. However, smelts biomass estimated from the NMFS offshore survey showed an increasing trend from 1984 to 1996, with some decline in 1999. Sandlance might be increasing since the beginning of the 1980's. EBS presently has no similar survey to assess these species although the absence of capelin in bottom trawl surveys and commercial vessel bycatch since the late 1970's appears to suggest a decline of capelin on the southeastern Bering Sea shelf. Improvements in understanding of the spatial distribution and abundance of forage fish are needed.

**Other species trends**:
There is an increasing trend for spiny dogfish and sleeper sharks in GOA. Large increases in skate biomass were observed. Sculpins declined overall from 1984 to 1999 but there were divergent trends across individual species within this group. No explanation yet but investigations on life history characteristics might shed light on these trends. These species are sensitive to fishing pressure so determination of species-level abundance, age composition and other population characteristics is important.

In EBS, sculpins and skates are large part of the other fish species biomass assessed by trawl surveys. Sculpin biomass trends have been about constant from 1984 to the present although a decline in 1999 is noted. As in the GOA, skates have also shown a large increase since the late 1970's but have shown a fairly constant level of abundance since around 1992. Aleutian Island sculpin biomass has decreased since 1980 but skates have increased.

Pandalid shrimp have declined uniformly in all study areas in the GOA with most significant declines occurring after 1981. Some species were not targeted by commercial shrimpers and showed declines after the closure of shrimp fisheries. Abrupt changes in winter temperatures are hypothesized as the primary mechanism for these changes.

Predatory sea stars have increased in both the GOA and EBS and may have food web implications for other benthic populations. Previously high king crab populations may have exerted some mediating effect on these populations that no longer exists due to the king crab declines.

Jellyfish in both the GOA and EBS have increased with the largest increases occurring in the 1990's in the EBS and late 1980's for the GOA. Some relationship with oceanographic variables is hypothesized.

The cyclic nature of some population trends of sculpins, eelpouts, poachers, snailfish, ronquils, and greenlings in the EBS is noted. These species groups showed very similar trends in population abundance with low values in the mid-1980's, a peak in abundance in the early 1990's and a decline to the mid-1990s, suggesting environmental influences as the dominant force.

Population trends for many species are unknown (e.g., squid, sharks) because they are not well sampled by existing surveys. Species identification of some species is still difficult and life history information is lacking on many species.

**Marine Mammals:**
Harbor seal trends are presently being analyzed and will be available in December 1999. Northern fur seal show a slight, nonsignificant decline from 1997 to 1998. Beluga whale status in Cook Inlet will be available in December 1999. 1998 Steller sea lion surveys indicate declines of the western stock are still occurring. Steller sea lion surveys in March 1999 are still being analyzed.

**Seabirds:**
Fulmars and storm petrels show increasing population trends. Albatrosses may be stable or increasing but short-tailed albatross is still seriously endangered. Murres are stable or increasing in most areas but with declines still seen in Cook Inlet and Bristol Bay sites.
Cormorants show mixed population trends with increases in EBS, western Aleutian Islands, and SE AK but declines at other Aleutian site and Chiniak Bay in Kodiak. Kittiwakes also show mixed trends. They previously had sharp declines around 1976 but are now stable or increasing on the Pribilof Islands. They have steadily increased in the western Aleutians and mixed trends in the GOA. Declines have been ascribed to lack of sufficient food during the breeding season.
Guillemots in the N. GOA have steadily declined over the past two decades, possibly due to reductions in prey availability. Puffins have increased or been stable.
Gulls are stable.

Seabirds appear to rely heavily on oceanographic processes to concentrate prey. Most prey consumed by seabirds are in the 5-15cm size range and do not overlap with fish sizes removed by commercial harvest. Stock size and productivity of forage species in the foraging range appears to heavily influence breeding success of bird species. There is still much that is unknown about the ways that physical factors influence forage fish density and availability to seabirds.

**Historical evidence** from the eastern Aleutian Islands and observations from other Native communities highlight the cyclical nature of resource changes. Cod, salmon, and other marine fish showed significant decreases in the E. AI from 1820's to 1830's. Sea otter, sea lion, and seal populations also were recorded as declining during this period. Since then cod have shown fluctuations and marine mammals and fish showed sudden decreases in the late 1940's and mid-1950's. Some Alaska Natives have linked these changes with changes in the environment. Locals in the GOA area have noted a decline in forage fish since the early 1990s. Continuing and enhancing Native community and local observations and building longer time series of observations are important.

**Multispecies and community indicators** in the GOA show an increase in overall groundfish biomass. Changes in species diversity and richness were observed but their significance has not been determined. An index of species composition from small mesh surveys shows a definite shift in the early 1980s from a species mix that contains high abundances of shrimp and several small forage fishes and low abundances of cod, pollock, arrowtooth flounder, and flathead sole to one that now contains low shrimp and forage fish and high gadids and flatfishes. An index derived from offshore bottom trawl surveys shows a change from 1987 that highlights the large increases in skates, and the increases in some areas of sleeper sharks, capelin, eulachon, Dover sole, rex sole, arrowtooth flounder, and POP. These results seems to validate the hypothesis that some forage stocks may have moved to offshore areas due to the warming of inshore waters that occurred in the late 1970s.

Multispecies forecasts of the effects of fishing on the groundfish complex indicates that at the present levels of recommended and actual fishing removals of groundfish, there do not appear to be large multispecies implications of the present fishing regime, which favors more full exploitation of gadids and lesser removals of flatfish, at least under the constant recruitment scenario that was the focus of this initial study. There appeared to be some compensation in the present scenarios between predation on pollock by pollock and arrowtooth flounder that might not occur in other scenarios. There were also large differences in the predictions of single and multispecies models in the no-fishing scenario, with multispecies models predicting smaller increases in biomass when fishing is stopped than single species models. This may have some implications when considering optimal rebuilding schedules for stocks. Implications of different recruitment assumptions will be explored in the future to better understand how trends in recruitment and recruitment variability may affect these predictions.

Further development of change indicators is required. Updates of species diversity and richness patterns for EBS, AI, and GOA needs to be done. Future ecosystem chapters should also include more explicit definition of the predator-prey relationships. In addition, when research is better able to link either human or climate effects to particular species, those species can be used as sensitive change indicators.

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## Summary of Ecosystem-based Management Indices

Since the mid-1990's there have been declines in the bycatch rates of prohibited species off Alaska. Substantial declines in the amount of managed groundfish species discarded were also realized in 1998 as part of the implementation of full utilization for pollock and Pacific cod. The aggregate discard rate dropped below 10% of the total groundfish catch. However, improvements are needed in order to better quantify discards of other species in the catch.

Since the mid-1990's there has been an increase in the amount of area closed to bottom trawling in the GOA and EBS/AI areas. Approximately 28.9% of the total potential time-area closures have been implemented in the EBS/AI and 18% of the total potential has been instituted for the GOA. These are positive trends but more analysis needs to be done to decide on which areas are most critical for closure due to concerns about species habitat protection.

Areas exposed to highest densities of trawling over the years have been mapped in the EBS and GOA. Experimental evidence indicates changes in diversity and patchiness in epibenthic communities occurs due to trawling. Better understanding of the linkages between the epibenthos and fish production is needed. Tracking recent bottom trawl patterns would be recommended for inclusion in the next ecosystem chapter (e.g., annual bottom trawl patterns for the most recent 3-5 years relative to the historic pattern). The estimated amount of bottom trawl time has declined in the Aleutian Islands and Gulf of Alaska from 1990 to the present and may partly be related to the increased amount of areas closed to bottom trawling.

Trophic level of the catch in the EBS, AI, and GOA areas remains stable and high, indicating no fishing down of the food web is occurring. More indicators need to be developed such as the effects of fishing on the size composition of the ecosystem, diversity of the catch, and others.

Status of groundfish, crab, scallop, and salmon stocks indicates large gaps in knowledge with regard to status of many groundfish species (144 out of 207 stocks have unknown status with regard to overfishing) and highlights the status of shellfish stocks (3 out of 14 stocks are now in the overfished category: Bering Sea bairdi and opilio and St. Matthew blue king crab).

There are several programs in place to reduce or stabilize fishing capacity in the North Pacific. A new license limitation program will place stricter controls on where groundfish vessels can fish and what gear can be used. Declines have been seen in the number of vessels participating in the sablefish and halibut IFQ regulated fisheries. Nine large capacity catcher/processors were retired from the BSAI pollock fishery under the American Fisheries Act. The total number of vessels participating in groundfish fisheries has declined from 1994 to 1998, with the number of vessels deploying hook and line declining over this period, pot vessels increasing, and trawl vessels remaining almost constant. The declines are attributed to the the IFQ programs for halibut and sablefish, the implementation of the vessel moratorium for the groundfish fishery, scheduled implementation of the license limitation program, and high levels of excess fishing capacity

Time trends for fishing capacity in the crab fleet were not available but might be informative.

# 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

This year's Ecosystem Considerations document includes 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.

## WHAT'S NEW IN ECOSYSTEM-BASED MANAGEMENT?

### *ICES/SCOR Symposium on Ecosystem Effects of Fishing*

Contributed by Pat Livingston

An international symposium was held this past March in Montpellier, France to highlight the scientific knowledge and provide recommendations with regard to the effects of fishing on ecosystems (see the ICES web site for more information on the program, http://www.ices.dk/symposia/ecoeff/ecoeffe.htm ). It is presently recognized that fisheries management is no longer a question of maximizing the yield of commercially exploited resources. Managers must also consider the direct and indirect impacts of fishing on other ecosystem components such as benthos, non-commercial fish species, seabirds and marine mammals. The main purpose of the symposium was to provide a global synthesis of the impacts of fishing on the marine ecosystem, report on new methods for quantifying these impacts at the ecosystem level, and to provide a forum for discussion of how objectives related to nature conservation can be integrated in future fisheries management. There were three different symposium themes in which invited papers and submitted posters were given: 1) ecosystem synthesis, 2) quantification of fisheries impacts on ecosystems, and 3) integrating fisheries and environmental management.

The symposium showed clear evidence that some ecosystems have been altered by fishing. In other cases, the evidence was not so clear because of lack of data at the appropriate time and space scales, inadequate knowledge of pristine conditions, and insufficient data on certain ecosystem components. As a result of the symposium, the scientific community is now being challenged to develop and apply ecosystem indicators of the effects of fishing for their regions and to establish standards that can be related to ecosystem-based management objectives. Some recommendations to the international science community in the North Pacific have been made by PICES (see PICES Press, May 1999 Issue at http://pices.ios.bc.ca/picespub/ppress/May99.htm). A special volume of the ICES Journal of Marine Science, which will contain some of the papers and posters presented at the symposium, is planned for publication in the near future.

## *Report of the NMFS Ecosystem Advisory Panel*

Summary of the NMFS Ecosystem Principles Advisory Panel Report to Congress, "Ecosystem-Based Fishery Management"
Contributor: Dave Fluharty

In the Sustainable Fisheries Act amendments to the Magnuson-Stevens Fishery Conservationa and Management Act, Congress required the NMFS to appoint an Ecosystem Principles Advisory Panel to report on the use of ecosystem principles in fisheries management and research in the United States. A group of 20 scientists, administrators, industry and environmental was convened for this purpose. Their Report, delivered to Congress in March 1999 sets out a practical, yet ambitious approach to making ecosystem principles, goals and policies a larger part of fisheries management in the US. The full report is available electronically ( http://www.nmfs.gov/sfa/reports.html )and will be published later this year. This summary highlights the findings and recommendations.

The Panel developed a list of basic ecosystem principles, goals and policies as a guide to its assessments.

Principles

- The ability to predict ecosystem behavior is limited
- Ecosystems have real thresholds and limits
- Once thresholds and limits are exceeded change can be irreversible
- Diversity is important for ecosystem functioning
- Multiple scales interact within and among ecosystems
- Components of ecosystems are linked
- Ecosystem boundaries are open
- Ecosystems change with time

Goals

- Maintain ecosystem health and sustainability

Policies

- Change the burden of proof
- Apply the precautionary approach
- Purchase "insurance" against unforeseen, adverse impacts
- Learn from management experiences
- Make local incentives compatible with global goals
- Promote participation, fairness and equity in policy and management

The Panel found that while some of these principles, goals and policies were employed in fishery management and research, they were not applied comprehensively or evenly across regions and ecosystems. This is due, in part, to the lack of a legal mandate and financial support and in part due to ecosystem-based fishery management being a new concept with considerable gaps in knowledge and practice.

In order to extend the use of ecosystem principles, the Panel recommends the preparation of a fishery ecosystem plan (FEP) that would be similar to the current Fishery Management Plans (FMP) but would focus on the role of fisheries in an ecosystem context. While this can be done under the present Council mandates, the Panel recommends that the FEP be required as part of the next round of Magnuson-Stevens reauthorization.

A FEP would require the regional councils to take the following eight actions:

1. Delineate the geographic extent of the ecosystem(s) that occur(s) within Council authority, including characterization of the biological, chemical and physical dynamics of those ecosystems, and "zone" the area for alternative uses.

2. Develop a conceptual model of the food web.

3. Describe the habitat needs of different life history stages for all plants and animals that represent the "significant food web" and how they are considered in conservation and management measures.

4. Calculate total removals -- including incidental mortality – and show how they relate to standing biomass, production, optimum yields, natural mortality and trophic structure.

5. Assess how uncertainty is characterized and what kind of buffers against uncertainty are included in conservation and management actions.

6. Develop indices of ecosystem health as targets for management.

7. Describe available long-term monitoring data and how they are used.

8. Assess the ecological, human, and institutional elements of the ecosystem that most significantly affect fisheries and are outside Council/Department of Commerce authority. Included should be a strategy to address those influences in order to achieve both FMP and FEP objectives.

The Panel recognizes that much of this information may not be available at the present time. However, efforts to obtain and use these types of information and to raise broad questions about fishing ecosystems, will benefit long-term management of these fisheries. To get the ball rolling, the Panel recommends that Councils start to apply these ecosystem principles, goals and policies in their activities. This may require that Councils receive training. In order to implement the FEP concept, NMFS should prepare guidelines for the Councils to use. In the beginning, the Panel suggests that a few Councils develop "demonstration" FEPs to see how best to accomplish this task. NMFS should provide oversight to ensure that Councils are developing FEPs. As soon as possible, Congress is encouraged to make FEPs mandatory. Research is required to accomplish these tasks. NMFS scientists should seek to determine the ecosystem effects of fishing, monitor trends and dynamics in marine ecosystems and explore the kinds of institutions that are needed to implement this new management approach.

Based on submissions from the Alaska Region, the Panel was made aware of the efforts to manage fisheries sustainably. The preparation of the Ecosystem Chapter in the SAFE document is an excellent start toward the preparation of the FEP. In fact, the Panel's endorsement of the FEP drew inspiration from the efforts to provide that chapter. At present, the Office of Sustainable Fisheries in NMFS headquarters is developing an implementation plan for the Administration and rumblings are being made about including the recommendations in the text for reauthorization.

# 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*

### Ecosystem Indicators and Trends Used by FOCI

Contributed by FOCI

**NORTH PACIFIC REGION**

<u>Interannual variability of atmospheric forcing</u>

Two patterns represent interannual variability of atmospheric forcing over the North Pacific Ocean and Bering Sea area. They are the magnitude and position of the Aleutian Low during winter and spring. The Aleutian Low is a statistical feature of the climate field, generated by averaging North Pacific sea level pressure for long periods. Because this is a region of frequent storm progression, the averaged pressure appears as a low-pressure area, much like a weather map showing an individual storm. The magnitude and position of the Aleutian Low have a strong bearing on weather in the region and are correlated with other climate indices such as ENSO (El Niño Southern Oscillation). These winter and spring patterns are somewhat independent and have different oceanographic consequences.

The winter index is referred to as the North Pacific Index (NPI, Fig. 1) and is the sea level pressure over the North Pacific averaged for January through February. There is a shift from high to low values of the index in 1925, a shift 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. Lower pressure implies stronger winds and warmer temperatures over the Bering Sea.

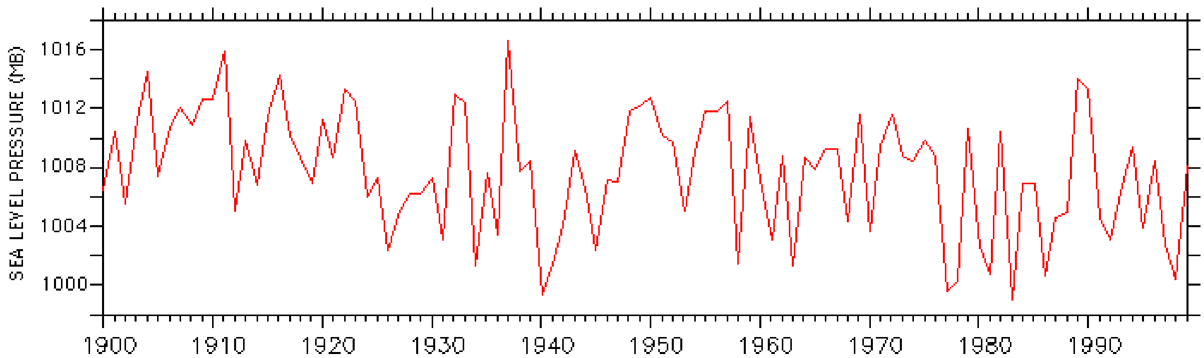



**Figure 1.** The North Pacific Index (NPI) from 1900 through 1999 is the sea-level pressure averaged for January through February.

In spring, the index is a displacement in pressure northward or southward. This is referred to as the NP Index (Fig. 2). The shift to lower values in the 1970s occurred earlier than in the winter pattern. A shift to positive values is clear in the 1990s. This provides for higher pressure and increased number of days with clear skies and increased Bering Sea surface temperature due to solar heating. This may have been a factor in developing oceanic conditions on the Bering Sea shelf that contributed to the coccolithophorid bloom during summer 1997. A major negative value occurred in 1998.

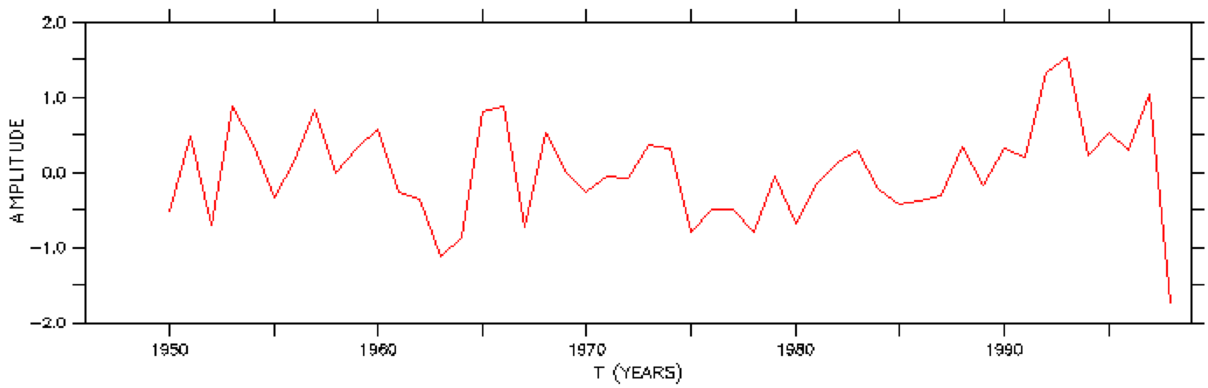



**Figure 2.** The NP Index for April-July 1950 through 1999 is a measure of the displacement of the Aleutian Low.

## WESTERN GULF OF ALASKA

Seasonal rainfall at Kodiak

There is a propensity for the coincidence of patches of larval walleye pollock and mesoscale eddies. For early larvae, presence within an eddy is 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 Fig. 3. Although there is large interannual variability, a trend 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.

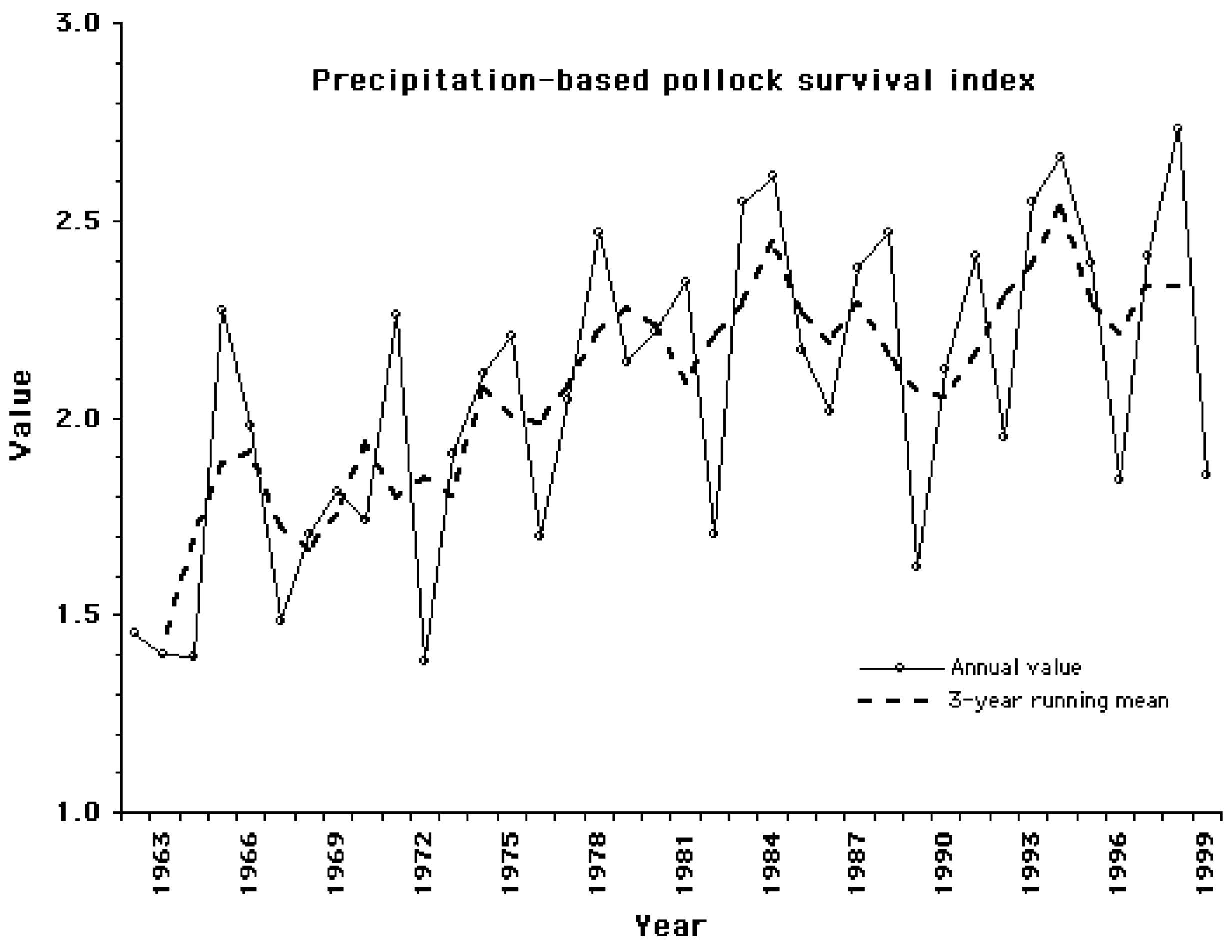



Figure 3. Index of pollock survival potential based on measured precipitation at Kodiak from 1962 through 1999. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Wind mixing south of Shelikof Strait

Another survival index relates to first-feeding pollock larvae, a key survival stage when they 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. 4) 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.

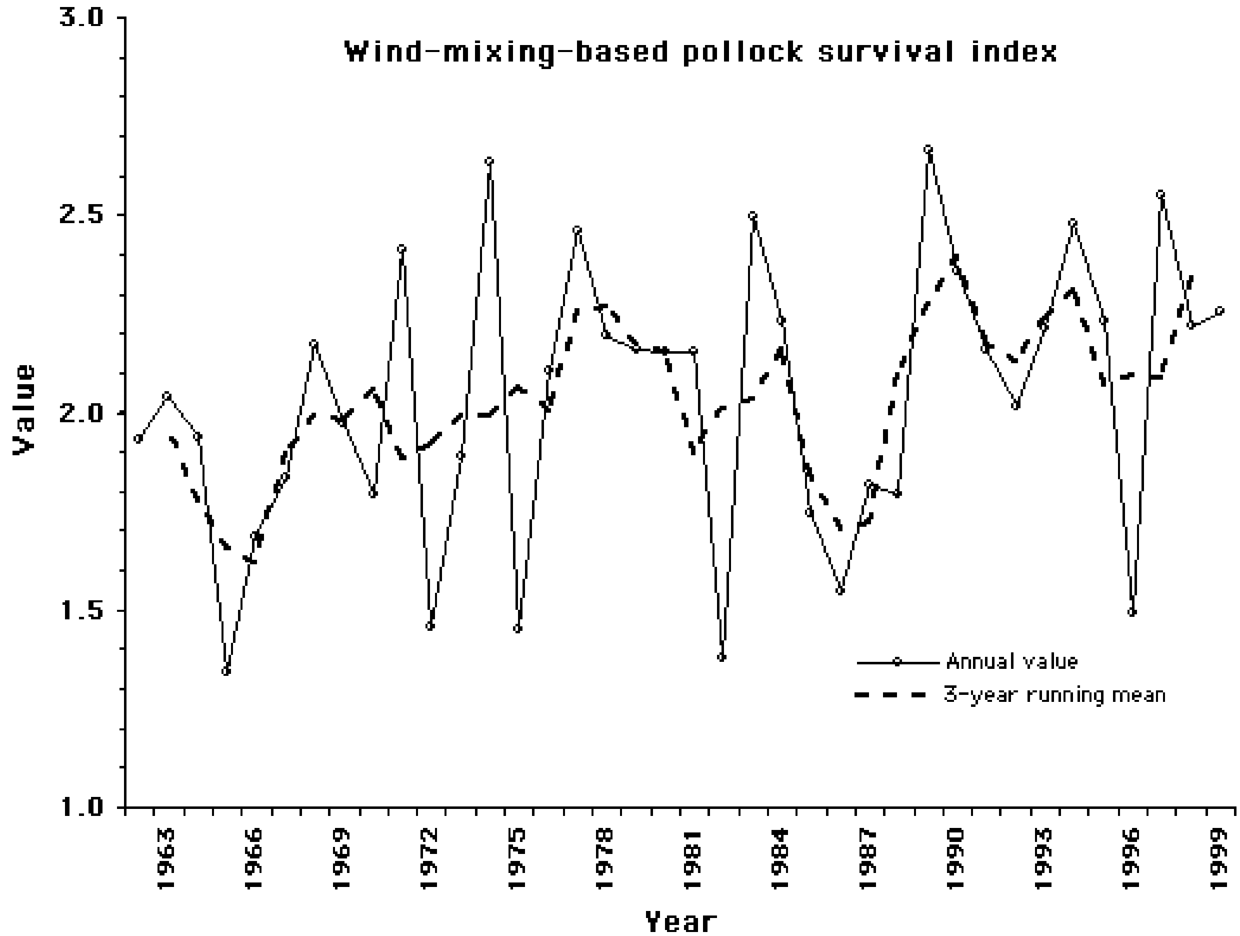



Figure 4. Index of pollock survival potential based on estimated wind mixing energy at a location south of Shelikof Strait from 1962 through 1999. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

COADS SST, Air Temperature, and Sea Level Pressure**:** To account for the variability in fluid temperature affecting the ocean's mixed layer in Shelikof Strait, FOCI also considers air temperature, sea-surface temperature, and sea-level pressure from the Monthly Summaries Trimmed Group of the Comprehensive Ocean-Atmosphere Data Set (COADS) (Woodruff et al. 1987). These data, which begin in 1962, are monthly averages of marine observations subjected to quality control to remove outliers and binned into 2º latitude by 2º longitude boxes. Our subset comprised monthly averaged data from three locations: 55ºN 159ºW, 57ºN 155ºW, and 59ºN 153ºW.

Advection: Advection through Sheilkof Strait, expressed as an index of continuous transport, is inferred from satellite tracked drifters and is available beginning in 1980.

Freshwater Runoff: The Alaska Coastal Current has a strong buoyancy-driven component created by freshwater runoff originating from ice melt, precipitation and coastal river discharge. Buoyancy-driven coastal flows are typical of subarctic regions where changes in salinity rather than temperature generate density gradients. Royer (1982) modeled the monthly freshwater runoff as a line source around the Gulf of Alaska by estimating the effects of insolation, local precipitation minus evaporation, and air temperature around the northern Gulf of Alaska. This series was modified (Parker 1989a, 1989b) to include freshwater additions from Cook Inlet and sources along Shelikof Strait. Values used in this study are indices that represent deviations from the mean winter (November-April) estimates of integrated coastal freshwater discharge into the Gulf of Alaska as provided by Parker (1989a, 1989b).

Wind Mixing: Over-the-water winds transfer mechanical energy between the atmosphere and the ocean. The main effects of wind on early life stages of larvae are transport by wind-driven currents and deepening of the mixed layer. Wind stress, proportional to the square of the wind speed, causes the former, and wind mixing, proportional to the cube of the wind speed, causes the latter. The relative importance of these energy-transfer mechanisms depends on wind and current directions and the structure of the oceanic mixed layer (Klein 1980). To account for the maximum effect of wind on early life stages of pollock larvae, we picked mixing, the highest mode. A study of survival of first-feeding larvae with respect to wind mixing in Shelikof Strait (Bailey and Macklin, 1993) supports this choice. Twice daily, winds were computed from the gridded NMC sea level pressures by applying a geotriptic wind model tuned to the Shelikof Strait region (Macklin et al. 1993). The wind speeds were cubed and monthly averages determined for the study period. We retained monthly averages to avoid the possibility of missing the influence of small-scale wind events, which are episodic in nature. One NMC time series was produced for wind mixing near the exit of Shelikof Strait (57ºN 156ºW) and one for the Shumagin Islands (55ºN 160ºW). An independent estimate of wind mixing was determined from COADS wind data. The COADS wind data comprised monthly averaged wind speed observations from three locations: 55ºN 159ºW, 57ºN 155ºW, and 59ºN 153W. The time series begins in 1962.

OSCURS Model Output**:** OSCURS (Ocean Surface Current Simulations) is an empirical ocean-wide model covering the subarctic Pacific region with a 1/4 mesh FNOC (U.S. Navy Fleet Numerical Oceanography Center) grid (about 90 km). Expanding the studies of Hubert and Laevastu (1965) and Larson and Laevastu (1972), the model combines long-term mean surface geostrophic currents (Ingraham and Miyahara 1989) with wind-generated surface-mixed-layer currents to form a resultant current vector at each grid point. Wind speed and direction are derived from daily FNOC sea-level pressure data to provide daily continuity from 1946 to 1990 following the methods of Larson (1975). Wind-induced ocean currents are then calculated from the empirical functions of the wind (Witting 1909; Huang 1979; Weber 1983). The Gulf of Alaska portion of the model was first tuned so that the model trajectories calculated for the period 21 September to 31 December 1978 (about 3 mo) matched the trajectory of a satellite-tracked drifter (drogued at 20-m) from Reed (1980) for the same dates and starting locations (Ingraham and Miyahara 1989).

OSCURS data consist of an annual index (1946-1991) of the tendency for surface currents to flow southwestward out of the Gulf of Alaska, as derived from model trajectory patterns. The numerical value of the index used in this study is defined as the number of trajectories out of six starting on 1 February that are along 55ºN between 137ºW and 152ºW and move west of 154ºW by the end of April. This is the same index used by Ingraham et al. (1991) to show that large-scale interannual changes in surface currents in the Gulf of Alaska during February-April (1976-1989) were connected to changes in water properties below sill depth in Shelikof Strait. The data are extended annually back to 1946.

NEPPI**:** Much of the variability in the physical environment of the Gulf of Alaska is due to large-scale atmospheric phenomena (Schumacher and Kendall 1991). The Aleutian Low dominates the variability of the atmospheric circulation over the Gulf of Alaska and plays a crucial role in the hydrological cycle (Neibauer 1988). NEPPI (Northeast Pacific Pressure Index (Emery and Hamilton 1985)), is a scalar index of the large-scale, sea-level pressure gradient across the northeast Pacific Ocean from (40ºN,120ºW) near Reno, Nevada to (50ºN,170ºW) south of Amukta Pass in the Aleutian Islands. NEPPI, which varies with the intensity of the atmospheric circulation and the track of storms over the northeast Pacific Ocean, provides a measure of the strength, frequency, and location of the Aleutian Low. NEPPI correlates strongly with northeastern Pacific sea-surface temperatures and adjusted coastal sea levels (Emery and Hamilton 1985), with coastal volume transport in the Shelikof Strait region (Roach and Schumacher 1991), and with Gulf of Alaska circulation (Ingraham et al. 1991). We computed a monthly mean NEPPI from twice daily, gridded (381 km at 60ºN) sea-level pressures produced by the U.S. National Meteorological Center (NMC), and archived and averaged by the Department of Atmospheric Sciences, University of Washington, Seattle, WA. Linear interpolation of gridded pressures yielded sea level pressures at (40ºN, 120ºW) and (50ºN, 170ºW). The time series begins in 1962.

## 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 5 shows the presence of ice over the southeastern shelf during the last 30 years. Heavy black lines in the figure denote the presence of sea ice at mooring site 2 [56.9°N, 164.0°W] on the shelf. Ice was most common at this location until 1976. After that came a warm period that lasted until the late 1980s. Since then, ice has been more persistent but not as extensive as it was prior to 1977. Recently, 1995 had the most extensive seasonal sea ice pack since 1976. There appears to be a slight reduction in ice cover during El Niño years (dashed lines in Fig. 5), but the relationship is weak.

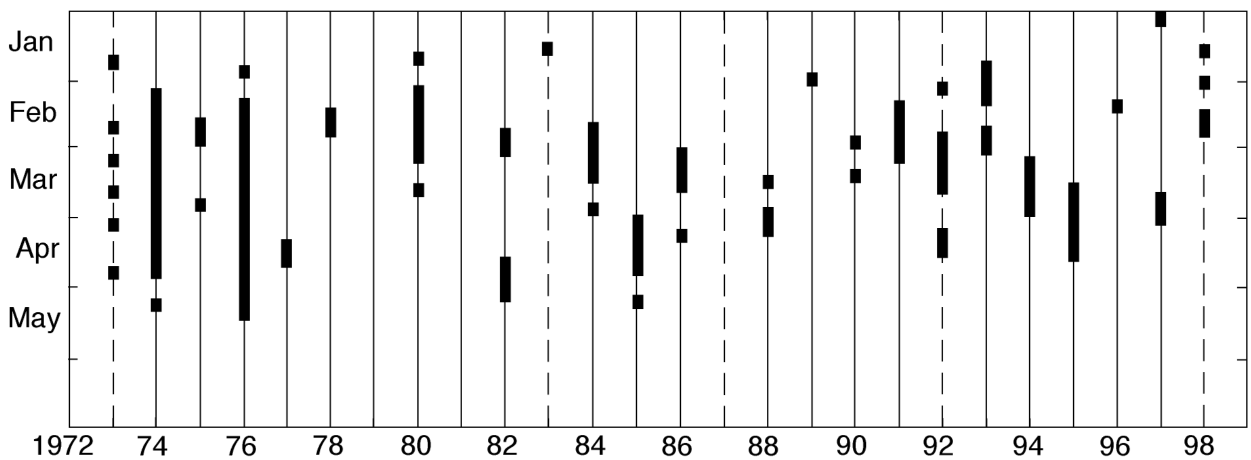



**Figure 5.** Black bands denote the presence of sea ice at mooring site 2 on the southeastern Bering Sea shelf. Dashed vertical lines designate El Niño years.

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 the color figure at http://corona.pmel.noaa.gov/~stabeno/moor2.gif ) that occurred in 1995, 1997 and 1998, resulted from the arrival and melting of ice. During 1996, ice was present for only a short time in February, however no mooring was in place. 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.

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; by contrast, May of 1997 and 1998 were characterized by strong individual wind events (Fig. 7). 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. 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 the phytoplankton community. If production is prolonged into summer, the total productivity of the shelf could be enhanced, thereby affecting higher trophic levels.

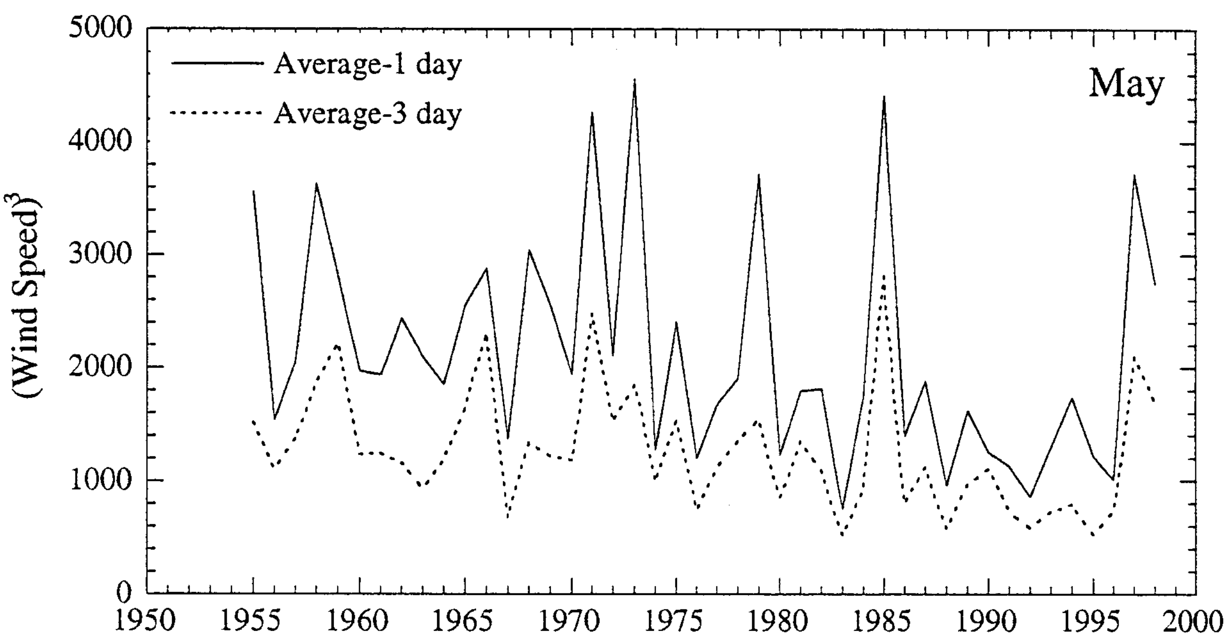



**Figure 7.** Cube of wind speed (proportional to wind mixing energy) measured at St. Paul, Alaska. The solid line is the daily average; the dashed line is the 3-day average.

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 and 1999, 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 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 overall but individual stations are sampled within a few days of the same date each year and represent comparative synopses. Due to charter vessel time conflicts, the 1999 survey was started on 23 May, approximately 10-12 days earlier than normal.

The temperature regime discovered during the 1999 survey was the coldest ever recorded since the advent of shelf-wide surveys in 1975. The overall mean bottom temperature was $0.81^{o}$ C, nearly a degree lower than the previous record (Figures 1-2). Individual station temperature anomalies (Figure 3) from the 1982-98 mean values were negative for all but 5 out of over 330 stations for bottom temperature and all but 1 station for surface temperature. Pack ice was discovered in inner Bristol Bay, resulting in the abandonment of 2 survey stations. A huge field of floe ice was found at the northern limits of the survey, north of St. Matthew Island, in late June. Although the data was confounded slightly by the earlier starting date, it was obvious that summer water temperatures were significantly colder than in any previous year.

How these conditions may have affected distributions and catchability of groundfish species is little known at this time. Initial examination suggests that a significant portion of the spawning yellowfin sole (*Limanda aspera*) may have moved inshore, out of the reach of survey activity. The demersal population of walleye pollock (*Theragra chalcogramma*) on the other hand, were most abundant in outer shelf waters that were warmest.

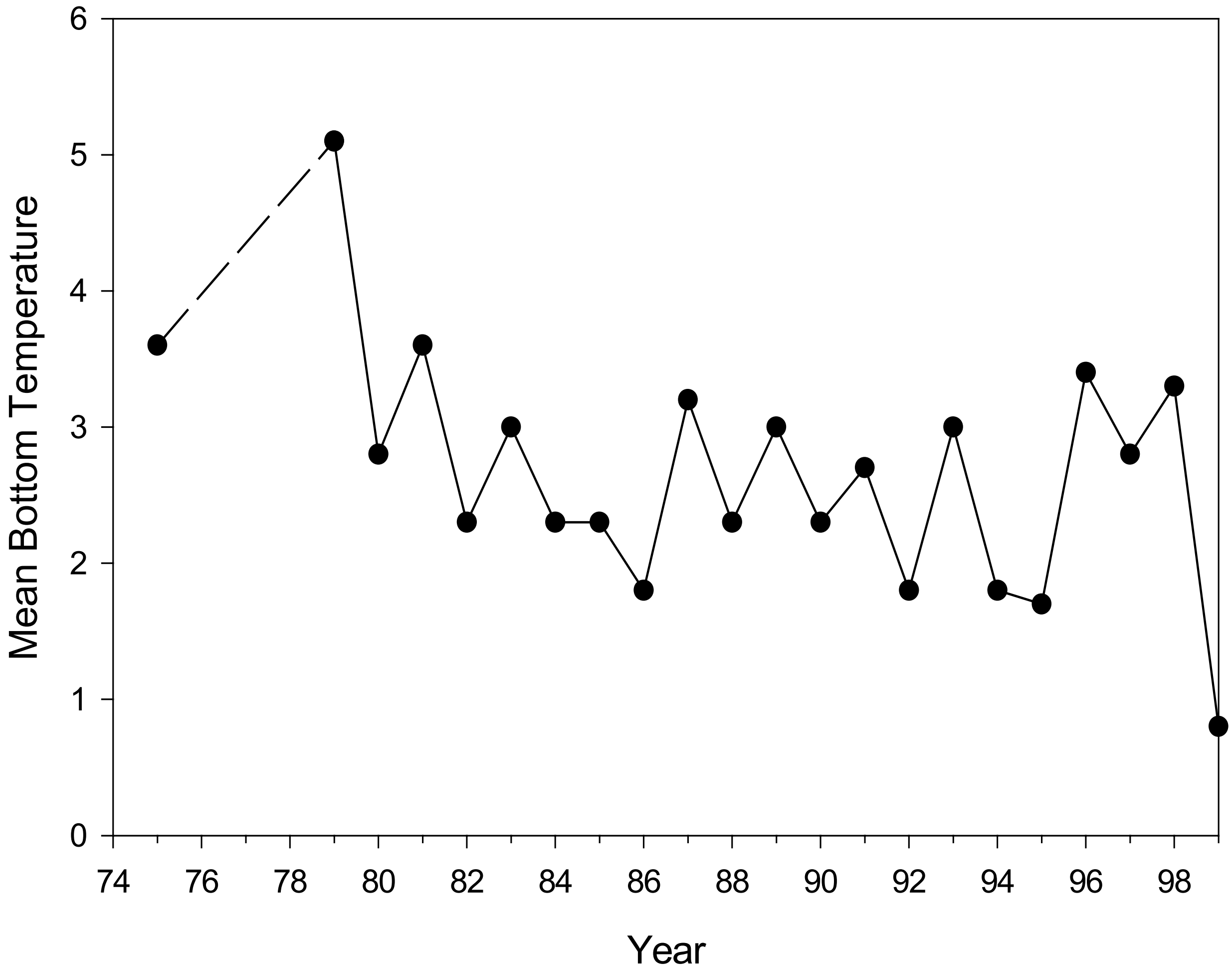



Figure 1. Mean bottom temperatures (degrees C) over the eastern Bering Sea shelf during the AFSC summer bottom trawl surveys from 1975 to 1999.

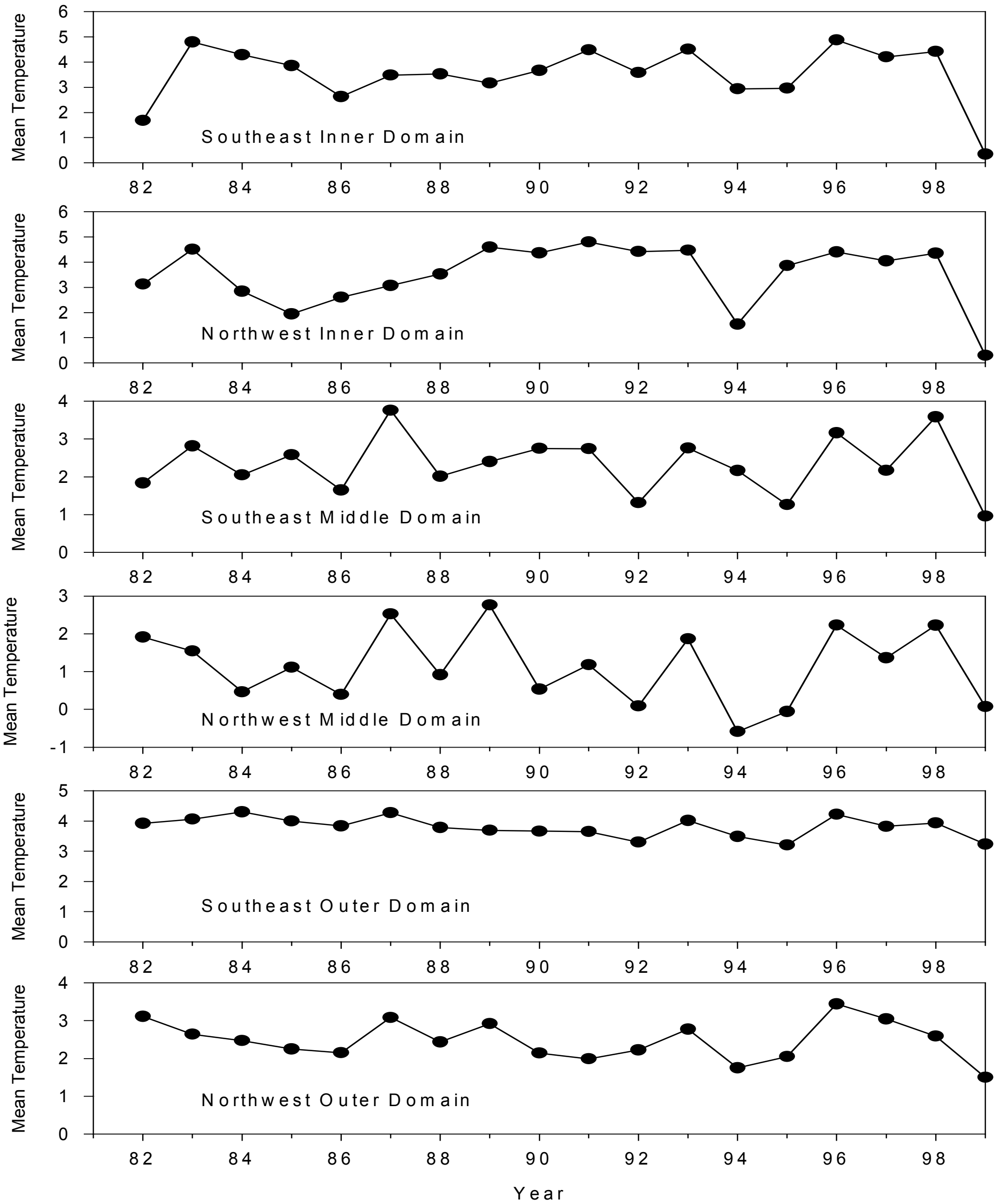



Figure 2. Mean bottom temperatures (degrees C) on the eastern Bering Sea shelf during the summer AFSC bottom trawl surveys (1982-1999)

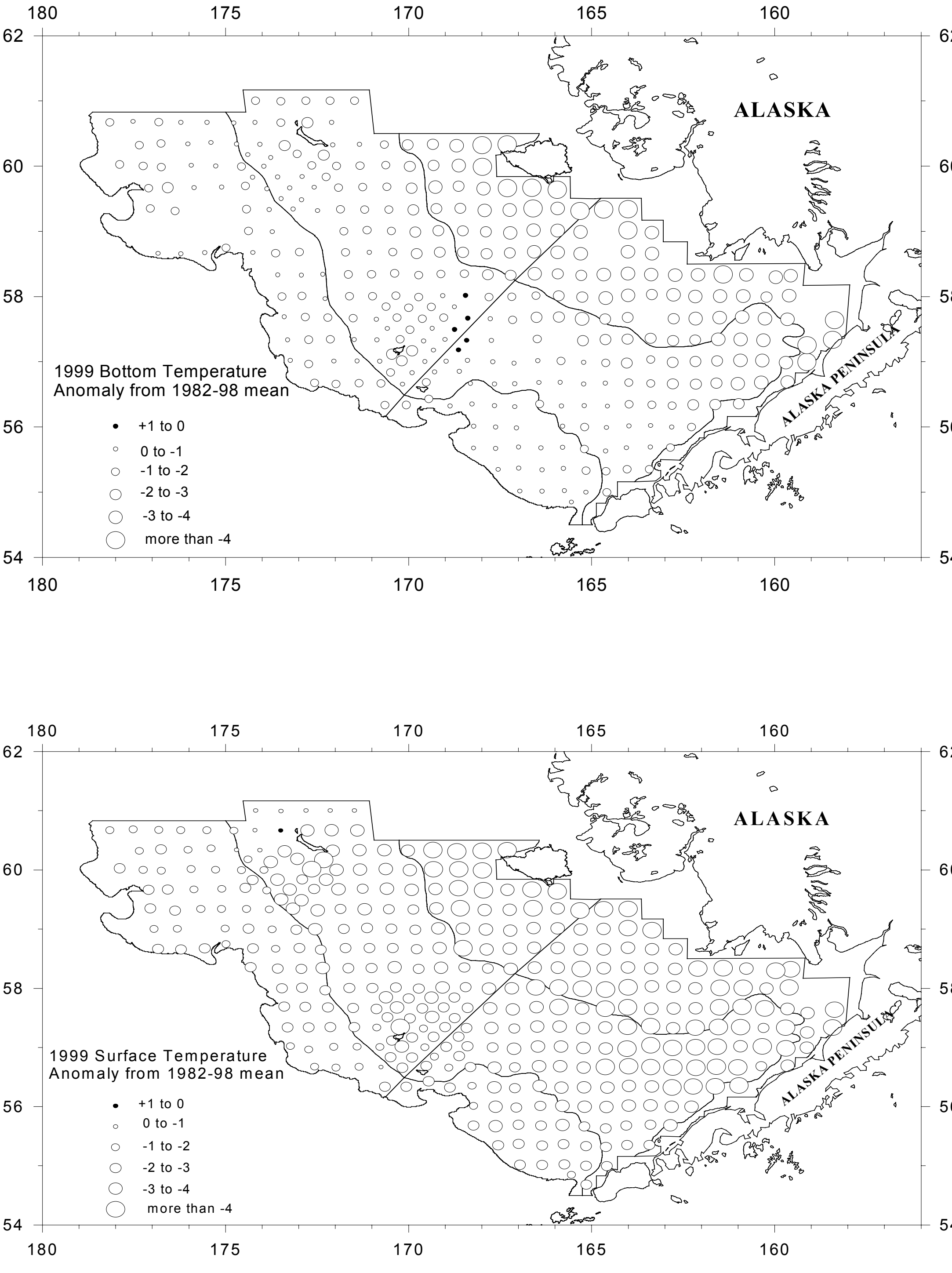



Figure 2. Summer bottom and surface temperature anomalies (degrees C) on the eastern Bering Sea shelf from AFSC bottom trawl surveys.

### *Habitat*

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

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 85$^{th}$ 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 85$^{th}$ percentile values of the nationwide database.

<u>Benthic Surveillance Project</u>
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.

<u>Arctic Regional Assessment</u>
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., 1999; Valette-Silver, et al., 1999). Preliminary results from the eastern Bering Sea samples have also been reported (Hameedi and Efurd, 198; Hameedi, et al., 1998; Hameedi, et al., 1999) 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 $85^{th}$ 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. 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 much, 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., 1981). 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, et al., 1992) for Bristol Bay samples was general higher, occasionally exceeding 70. This index can range between 100 for fossil fuel [as computed, the index value can exceed 100 under certain circumstances] to nearly zero for pyrogenic PAHs; values for Prudhoe Bay crude oil, Cook Inlet crude oil, and Alaska diesel fuel are about 95. 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.

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

<u>Chlorinated pesticides</u>

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

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

Mono-, Di, Tri-butyltin

<u>Polycyclic aromatic hydrocarbons</u>

<u>2-ring</u>
Biphenyl
Naphthalene
1-Methylnaphthalene
2-Methylnaphthalene
2,6-Dimethylnaphthalene
1, 6, 7-trimethylnaphthalene
C1-C4 naphthalenes

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

<u>4-ring</u>
Fluoranthene
Pyrene
Benz(a)anthracene
Chrysene
C1-C4 Chrysene

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

<u>6-ring</u>
Benzo(ghi)perylene
Indeno(1,2,3-cd)pyrene

<u>Major elements</u>

Aluminum
Iron
Manganese
Silicon

<u>Trace elements</u>

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

<u>Related parameters</u>
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 |

## Bottom Habitat Composition in the eastern Bering Sea

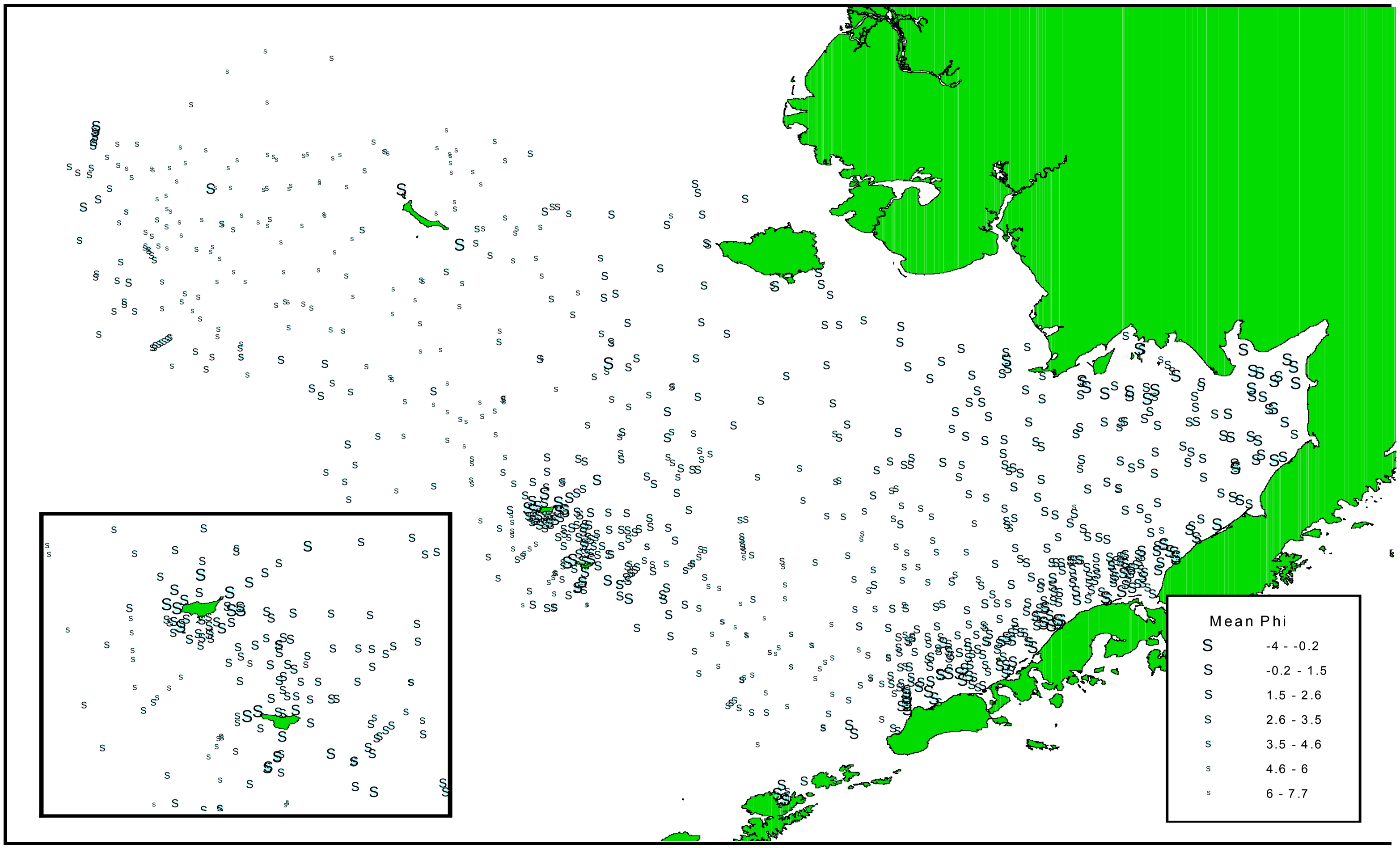
Contributed by Bob McConnaughey

**Compilation of Surficial Sediment Data for the Bering Sea**

The texture of surficial seafloor sediments, that is, the frequency distribution of grain sizes, is a fundamental property of the benthic marine environment. It affects such basic physical characteristics of the seafloor as porosity, permeability, and compaction, which in turn may affect the distribution of plants and animals.

A number of investigations have reported spatial variation in texture on the eastern Bering Sea (EBS) continental shelf. However, many of these studies were limited to relatively small portions of the shelf, while others characterized larger areas by spatially averaging relatively sparse data. The original studies varied somewhat in methods of analyzing sample texture or in the descriptors used to characterize it. In order to facilitate descriptions of groundfish habitat over a large portion of the EBS shelf, we have assembled a single comprehensive database of the point sample data (EBSSED; n = 2,587) from all available sources collected from 1934-1997. The database represents sediment variation over the study area with uncompromised (i.e., original) spatial detail (Fig. 2). Textural data in the database are of two main types: (1) standardized statistics characterizing sample grain size distribution based on laboratory measurements (granulometric data), including % composition by size grades (e.g., gravel, sand, mud) and size distribution parameters (e.g., mean size); and (2) sample descriptions from less exacting, more subjective visual/tactile observations, usually made in the field, establishing size-grade constituents. In addition, the EBSSED database includes two descriptive fields that were each added to characterize sample grain size distribution by a single, standardized variable based on the original data. These fields classify samples according to gravel-sand-mud composition using high- and low-resolution schemes derived from Folk's (1954) classic ternary diagram. The high-resolution scheme classifies 903 samples with detailed granulometric data into 15 textural classes, providing the greater detail regarding textural variation. The low-resolution scheme (7 classes) is designed to allow unambiguous classification of nearly all samples (n = 2457) including those with subjective visual/tactile descriptions. It represents the maximum number of samples according to a single common variable and thus provides the most spatially extensive data for the study area, albeit at the expense of some of the textural detail for samples analyzed in the laboratory.

Overall, the EBSSED database is the most comprehensive and detailed source of information about surficial sediment textures in the EBS study area. Patterns observed in the data generally agree with large-scale textural maps and summaries by previous investigators, particularly a general pattern, with exceptions, of decreasing average grain size with increasing depth and distance from shore. However, those previous large-scale works spatially smoothed data for the study area from smaller, more sparsely distributed sets of samples. The EBSSED database preserves potentially important fine-scale variation.


Mean Phi
-4 - -0.2
-0.2 - 1.5
1.5 - 2.6
2.6 - 3.5
3.5 - 4.6
4.6 - 6
6 - 7.7

## ***Progress Report on Essential Fish Habitat Research***

Contributed by K Koski

PROJECT: Identification and Characterization of Atka mackerel (*Pleurogrammus monopterygius*) Reproductive Habitat
PERIOD: FY99
REGION/OFFICE: Alaska Fisheries Science Center, Seattle (F/AKC3)
PROJECT PARTICIPANTS: Robert Lauth, Scott McEntire, Frank Wood, Lowell Fritz

The basic biology of Atka mackerel has been poorly studied despite its commercial value and importance as a key forage species for the endangered Steller sea lion and other marine piscivores. A peculiar aspect of Atka mackerel's life history is that the adults switch from a predominantly pelagic to mostly demersal existence during spawning in summer and early fall. Adults migrate to shallower water where females deposit their eggs onto rocky substrate. Males fertilize the demersal egg clusters and remain over the nests to guard and aerate the eggs. Such nesting sites have been documented in Russian waters but have never been verified in U.S. waters until now.

In August 1999, AFSC scientists collaborated for a second consecutive year to find areas in the Aleutian Islands where Atka mackerel spawn. No nesting sites were found in August 1998 after searching 10 days around Unalaska Island in the eastern end of the Aleutian Islands. This year's efforts were focused in the central Aleutian Islands around Seguam and Amlia Islands, near one of the largest Atka mackerel fishing grounds.

The commercial fishing vessel *Vesteraalen* was used as the primary support vessel. A 6-m rigid-hulled inflatable was deployed from the support vessel and used for exploring nearshore areas. Underwater video and SCUBA diving were primary research tools to locate and study Atka mackerel nesting areas. The towed video camera we used did not have adequate resolution to detect embryo clusters as it was dragged through the water. Direct observations by divers were necessary to verify the presence of nests. During 5 days of actual fieldwork, scientists made a total of 18 man-dives, filmed more than 8 hours of underwater video footage, collected numerous biological specimens jigging and spearfishing, and measured depth and temperature at nesting sites. The principal nesting site chosen for most of this work was on the northeast side of Seguam Island south of Finch Cove. The depth of the dive site was between 15 and 30 m and the bottom consisted of rock outcroppings interspersed with moderately-size boulders less than one-half meter in diameter. Fist-size clumps of embryos were deposited in the interstices of the boulders and their color blended with the encrusting algae and other marine life. Nest sizes were difficult to discern because males were guarding non-discrete batches of embryos spread over areas more than 1 m in diameter. Behaviors of aggregated adults and guardian males at nesting sites were observed *in situ* using an autonomous underwater video recorder. Strip transects were also used to estimate nest density. Stomachs of red Irish lords (*Hemilepidotus jordani*), yellow Irish lords (*H. hemilepidotus*), Pacific cod (*Gadus macrocephalus*), and male Atka mackerel all contained Atka mackerel embryo masses, indicating that predation and cannibalism of Atka mackerel nests were common.

PROJECT: Effects of Fishing on Benthic Habitat
PERIOD: 1999
REGION/OFFICE: Alaska Fisheries Science Center, Auke Bay Lab
PARTICIPANTS: Robert Stone, Lincoln Freese, John Karinen

The Marine Fisheries Program of the Auke Bay Laboratory conducts research to identify essential fisheries habitat in the Gulf of Alaska and to assess the effects of fishing on those habitats. During 1998 and 1999 studies focused on assessing changes to the seafloor caused by chronic long-term trawling near Kodiak Island. Three areas were examined where bottom trawling occurs for many species of groundfish including walleye pollock, Pacific cod, flathead sole, butter sole, arrowtooth flounder, and several species of rockfish. These fisheries occur adjacent to areas which were closed in 1986 by the North Pacific Fisheries Management Council to assist in rebuilding severely depressed crab stocks.

Study objectives were to compare areas closed to trawling to areas open to trawling to determine if differences exist for infauna and epifauna species composition, abundance, and diversity, and substrate characteristics including grain-size characteristics, biogenic structure distribution, and total organic carbon. During the two-year study 44 transects were completed and visual counts and observations were recorded over 136 km of seafloor. More than 200 sediment samples have been collected along those transects.

EFH funds were used to supplement 1999 funding for effects of fishing on seafloor habitat. These funds were used to 1) collect additional sediment samples at each transect and process those infauna samples, 2) to purchase equipment necessary to complete development of a towed benthic sled which we intend to use in future seafloor habitat studies, and 3) contract the research submersible *Delta* for two additional days to investigate the uniqueness of shallow water areas of Albatross Bank as a potential "Habitat Area of Particular Concern". The waters of Albatross Bank are among the most heavily fished waters in the Gulf of Alaska.

PROJECT: Nearshore Habitat Utilization by Juvenile Groundfish
PERIOD: FY99
REGION/OFFICE: AFSC, Auke Bay Laboratory, Juneau (F/AKC4)
SCIENTISTS: Scott Johnson, Michael Murphy

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. The objective of this study in 1999, was to link habitat and fish assemblages in nearshore waters of Southeast Alaska; a remotely operated vehicle (ROV) equipped with a video camera was used to observe groundfish in a variety of nearshore habitat types (e.g., eelgrass meadows, kelp forests).

In May, July, and August, 1999, the NOAA ship *John N. Cobb* was used as a platform to stage ROV studies. Approximately 100 ROV dives were conducted 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 commercial 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 complex habitat (e.g., bedrock walls, boulder piles) with numerous cracks and overhangs for cover, whereas areas with not much relief (e.g., basin bottoms) were 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.

We observed some distinct associations between fish assemblages and habitat in nearshore waters of Southeast Alaska. For example, juvenile rockfish, lingcod, and Pacific cod were often in shallow water areas with vegetation (e.g., eelgrass, *Laminaria*), whereas juvenile yelloweye rockfish were only in high-relief, vertical wall-habitat. Distribution of fish between northern and southern and inside and outside waters of Southeast Alaska was patchy, especially with few fish observed in inside waters near 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 study sites. Information on fish assemblages and habitat will help managers identify and protect those habitats in nearshore areas susceptible to impacts from shoreline development.

PROJECT: Effects of urbanization on essential fish habitat in estuarine wetlands.
PERIOD: FY99
REGION/OFFICE: AFSC, Auke Bay Laboratory, Juneau, AK (F/AKC4)
SCIENTIST: Mitch Lorenz, K Koski, Brandee Gerke, Lynn Mathes

Estuarine wetlands are among the most productive habitats for fish that sustain marine fisheries worldwide, yet little is known about their role in the productivity of FMP species for Alaska fisheries. Degradation of estuarine fish habitat due to anthropogenic effects is widespread and Alaska is no exception. In Alaska, nearly 60 coastal streams are listed by the State for impaired water quality and nearly one-half of those are listed due to urban runoff. The effects of urban development and pollution on nearby estuaries are not well known and urban estuaries are currently considered "habitat areas of particular concern" by the Alaska EFH Core Team.

Estuaries are critical for salmon migration and rearing. Salmon are particularly vulnerable to environmental change while in estuaries, as their physiology makes drastic adjustments between freshwater and marine environments. Other FMP species (e.g., yellowfin sole, rock sole, starry flounder) and important forage species (sand lance, herring, eulachon, and many invertebrates) are also plentiful in estuarine wetlands, however, links between estuarine habitat and productivity of such species are not well understood.

In 1998, scientists at Auke Bay Laboratory proposed two years of research on "essential fish habitat" issues for FMP species in Alaska's urban estuaries. By working in urban areas, both the research needed to better understand the role of estuaries in fish production and the outreach needed to develop community awareness and support for effective protection and restoration of essential fish habitat in such areas are being done.

The objectives of this work are: 1) Identify and describe "essential fish habitat" in estuarine wetlands; 2) Develop models to predict effects on fish habitat suitability as estuaries are altered by urban development; 3) Continue community outreach to develop public awareness and encourage public support for maintaining, protecting, and restoring "essential fish habitat;" 4) Help to coordinate NMFS "essential fish habitat" policy development with community-based visions for habitat protection and restoration.

Funding for both the FY 1998 and FY 1999 studies was about one-half of that requested, and expected scale and accomplishments of the project were gretly diminished. In 1998 methods for sampling of estuaries were established. Preliminary results of that sampling indicate that estuaries and tidal wetlands in both urban and rural areas are used either continually or seasonally by several important FMP species. Several distinct habitat types were sampled including emergent marsh wetlands, mud flats, sloughs, and sand and gravel beaches.

Studies done in 1999 indicated that, except for juvenile salmon, few fish actually occupied emergent wetland habitat associated with urban estuaries. However, most species present in the estuary fed primarily during tidal inundation of the emergent wetlands indicating that marsh wetlands likely have a critical role in food production for several FMP species. Work in 1999 also provided better information on spatial and temporal abundance, distribution, and habitat use of FMP species in estuaries.

Using the data collected in 1998 and 1999, models can be developed to estimate estuarine habitat suitability indices for FMP species and to predict changes in FMP species productivity due to habitat modification by urban development. Funding for that work will be requested for FY2000.

PROJECT: Operational Effectiveness of Anadromous and Resident Fish Stream Crossing Structures on the Kenai Peninsula
PERIOD: FY98-99
REGION/OFFICE: ADFG, Habitat and Restoration Division, Anchorage, AK

Background. Inadequately designed or improperly installed culverts and bridges on logging roads can cause serious degradation of salmon habitats in streams and can block or impede migrations of resident and anadromous fish. Any crossing structure is virtually certain to fail if not properly installed and maintained. A single poorly installed culvert can impact fish passage and eliminate access to an entire stream system for resident and anadromous fish populations.

Objectives

1. Inventory and assess condition of culverts and bridges on logging roads where they cross fish streams throughout the Kenai Peninsula;
2. Determine effects of crossing structures on fish passage, fish habitat and water quality;
3. Determine the amount of upstream habitat that is not accessible to salmonids because of migration blockage at each culvert; and
4. Organize the data for analysis and entry into a GIS database that will allow users to track the performance of crossing structures and identify those needing repair, maintenance, or replacement to alleviate problems with water quality, fish habitat, or fish passage.

Current Status . We located 135 stream crossing structures with the GPS on logging roads crossing anadromous and resident fish streams throughout the entire Kenai Peninsula. All field data have undergone quality assurance and control routines. Field data describing stream morphology, fish habitat, and individual crossing structures were subsequently entered into a database management system. A Geographic Information System (GIS) has also been developed for the project area to include coverages of fish habitat, logging roads, timber harvest areas, vegetation types, topography, land status and ownership, and all other pertinent mapped information. Over 1,000 digital photos have been directly linked to each crossing structure locations along with all field data. The GIS will function as a repository of baseline conditions, will be used to monitor the condition and functionality of these crossing structures for impacts to fish habitat and water quality, maintenance and retro-fitting, assess the amount of habitat inaccessible to fish, and geographically describe logging-fish habitat relationships at various spatial scales.

Pending receipt of remaining project funding, we hope to analyze field data and write a final report describing the study results and management implications.

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

Contributed by Jonathan Heifetz

Since 1996, the Alaska Fisheries Science Center (AFSC) has been conducting several studies to specifically address the effects of trawling on benthic organisms and their habitat (Heifetz, 1997). A progress report of activities in 1999 is included below. After each project title, the principal investigator and affiliation are identified. 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.

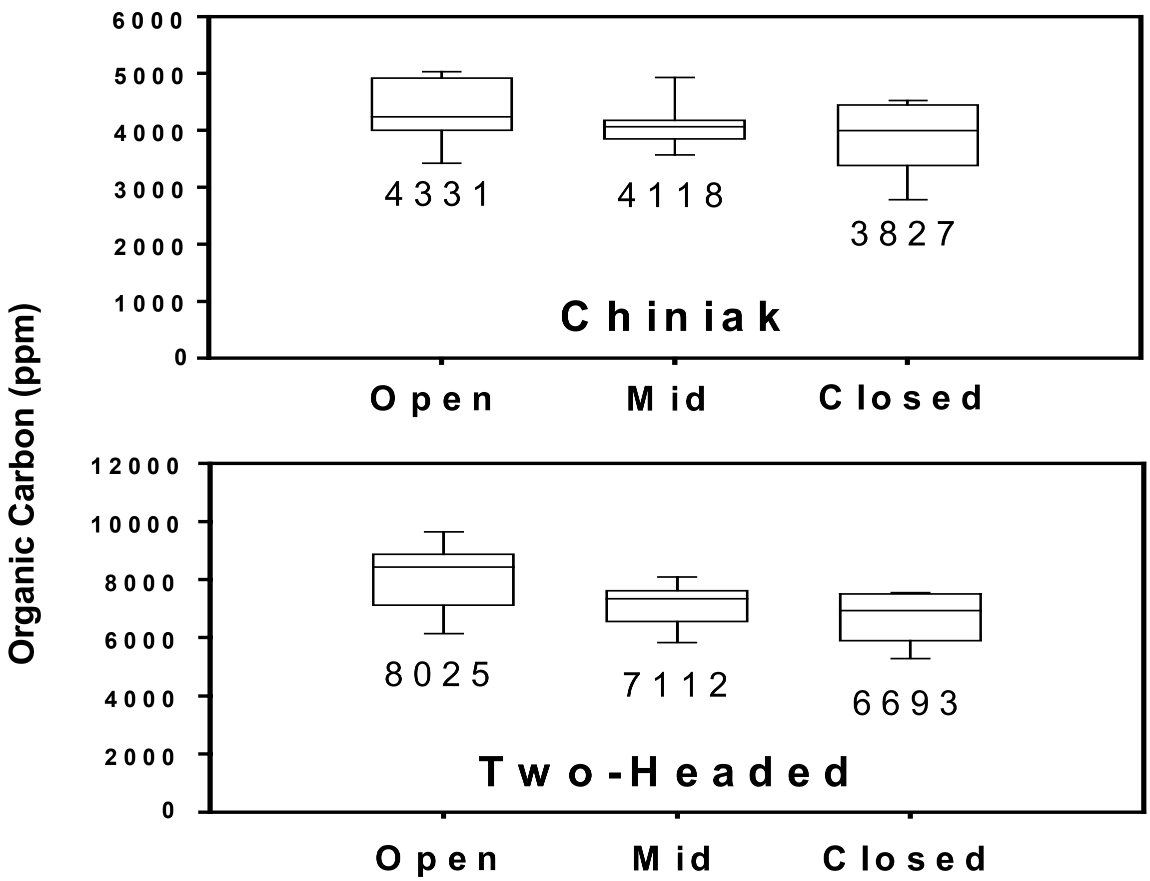
**A Description of Seafloor Habitat in a Trawled and Adjacent Protected Region of the Central Gulf of Alaska** Principal Investigator - Robert P. Stone (Alaska Fisheries Science Center - ABL)

During August 13-24, 1999 an occupied submersible was used to observe the seafloor at two areas near Kodiak Island that had been closed to bottom trawling since 1986. These areas were closed by the North Pacific Fisheries Management Council (NPFMC) to assist in rebuilding severely depressed crab stocks. Bottom trawl fisheries occur adjacent to the closed areas for walleye pollock, Pacific cod, flathead sole, butter sole, arrowtooth flounder, and several species of rockfish. The purpose of this study was to assess changes to the seafloor caused by chronic long-term trawling. Study objectives were to compare areas closed to trawling with areas open to trawling to determine if differences exist for infauna and epifauna species composition, abundance, and diversity, and substrate characteristics including grain-size composition, biogenic structures, and total organic carbon. This was the final cruise of a two-year study.

Two separate sites were studied in 1999 and were about 200 km apart along the eastern side of Kodiak Island. Observations were also made in June 1998 at two sites (one site was studied during both years). Moderate trawling had occurred at all three sites during the last five years. Forty four transects were completed and visual counts and observations were made over 136 km of the seafloor. Each transect was 3000 m long and bisected the boundary between open and protected areas. Substrate samples were collected with a Shipek bottom sampler along each transect.

The seafloor at the two 1998 study sites was a relatively flat and unstructured bottom comprised of mostly fine sand and silt interrupted only by dense beds of several species of sea whips. At both sites, sediments from trawled areas had higher concentrations of organic carbon (Figure 1) and coarser mean grain-size than sediments from protected areas. One possible explanation for the higher carbon level in the trawled areas is that it is redistributed from within the sediment layers to the surface by trawls. Sediment samples collected in 1999 are currently being analyzed for total organic carbon and grain-size properties. Infauna samples from both years should be completed by January 2000.

Evidence of bottom trawling (e.g., trawl door furrows, broken sea whips) were observed at about one-third of the transects at the Chiniak and Two-Headed Gully sites. The Trinity Island site was nearly devoid of sea whips, but trawl tracks were clearly visible over much of the seafloor in the area open to trawling. Fish and invertebrates currently being quantified from the video footage include adult and juvenile flatfish, weathervane scallops, juvenile Tanner crabs, hermit crabs, shrimp, sea anemones, sea stars, and sea whips. Counts of megafauna have been completed on about 25% of the transects and all counts should be completed by October 2000.



**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. Scheduled to begin in summer 2000, it 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 are being 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 and chemical effects (in collaboration with scientists at the University of Alaska Fairbanks).

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* (4.5 m) and the ORE *Trackpoint II Plus* (7.6 m). When all other sources of error (*e.g.* errors due to GPS, the gyro and sound velocity estimates) are considered, total positioning error at the 99% level is 15 m and 23 m, respectively, for a trawl fishing 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 draft 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 sea floor 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 sea floor 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). A quality assessment procedure indicates that 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 will be identified using unsupervised classification methods and habitat maps will be generated. A specially configured *QTC View Series IV* will be deployed in summer 2000, 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 distributions in the Bering Sea associate with particular 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. A benthic sled was developed and tested in 1999 as a method of supplementing video collected via the submersible. 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 high quality video of the seafloor. A video system is currently being developed that will allow video to be collected at 2-4 knots and then replayed at slower speeds without a significant reduction in video resolution.

**Retrospective analysis of benthic community structure in areas of high and low commercial bottom trawl effort in the Gulf of Alaska and Aleutian Islands** Principal Investigators - Catherine Coon and Thomas C. Shirley (Juneau Center, School of Fisheries & Ocean Sciences, University of Alaska Fairbanks)

Species composition data from the 1990-1997 NMFS triennial bottom trawl surveys were analyzed to describe and compare attributes of community structure between areas of high and low bottom trawl concentrations for the Aleutian Islands and Gulf of Alaska. Locations of research trawl surveys were overlaid with bottom trawl effort data from the observer database (NORPAC) for 1990-1998 (Coon et al., 1999) and bathymetry of the area, using Geographical Information System (GIS) methodology. Areas of high trawl concentration (HTC, >364 days trawled/25 km2) that contained research trawl survey hauls were compared with neighboring areas of low trawl concentration (LTC, 0.007-73.817 days/25 km2 area) that also contained research trawl hauls, within 4 depth ranges (1-100, 101-200, 201-300, and 301-500m). Not all sites of adjacent HTC and LTC contained both observer and research trawl hauls; a total of 8 areas suitable for comparison were found. The analysis was limited to sessile or demersal and slow-moving, macrofaunal species (invertebrates and fish) that occurred in at least 10 hauls and were represented by at least 100 individuals. Data on these species were standardized to represent individuals/10,000 $m^2$. Population measures, including mean abundance, biomass, species richness and Shannon-Weiner diversity indices, were calculated for each site by depth and trawl concentration. A multivariate, non-multidimensional scaling metric was applied to dissimilarity matrices (Bray-Curtis) to help identify community relationships not amenable to univariate techniques.

The null hypotheses tested for each of eight sites were: 1) species richness; and, 2) average biomass were lower in HTC areas compared to LTC areas at similar depth. There were no consistent trends within or between sites that could uniquely identify trawl effects. Measuring trends in disturbance to quantify trawl effects were difficult at this spatial scale. Apparently, commercial trawlers target HTC areas because they contain higher concentrations of fish, which persist at higher levels post-trawling than in LTC areas. However the study documented, useful information on species assemblages and associations in areas that are fished with bottom trawls. Predominant species groupings of the five top fish/invertebrates species were quantified for each of the four depth categories. Common numerically predominant species included: Pacific ocean perch (*Sebastes alutus*), northern rockfish (*S. polyspinis*), arrowtooth flounder (*Atheresthes stomias*) and two species of sculpin for eight sites in the analysis. Species associations could be plotted with potential indicator species of bottom or sediment types to determine a more robust description of habitat. Using GIS layers to describe spatial patterns of demersal community structure may provide managers a tool to help document habitat areas of particular concern on small geographic scales.

**Identification of a Possible Habitat Area of Particular Concern from a Research Submersible** 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 Habitat Areas of Particular Concern. 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 (*Sebastes ciliatus*), kelp greenling (*Hexagrammos decagrammus*), and lingcod (*Ophiodon elongatus),* similar to aggregations noted on a pinnacle located in the vicinity of Cape Edgecumbe, Alaska (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 *Sebastes*) observed swimming among the kelp fronds. Although no evidence of fishing gear impacts were noted from the submersible, it is located on the Albatross Bank adjacent to areas that are extensively trawled (Coon et al., 1999).

**Observations of One Year Old Trawl Tracks 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. Analysis of the data failed to show statistically significant differences in densities of invertebrates between trawled and nearby reference transects. However, numerous large sponges that had been dislodged from boulders by the previous year's trawling activities were seen lying on the substrate within the trawl tracks. No evidence of regrowth of sponges that had been damaged by the trawl was observed. On the other hand most sponges, including those lying on the substrate and those damaged but still erect, still appeared viable. These observations indicate that habitat modification and damage to some invertebrate species caused by trawling in the Gulf of Alaska may be long lasting.

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

The area around Seguam Pass has been fished for decades, and at one point the NPFMC cited it as possibly having experienced significant trawl damage, especially to gorgonian corals. In response, a study was initiated to visually verify the status of the demersal environment in Seguam Pass. A simple, robust observation platform was required, because the passes that cross the Aleutian Archipelago are notorious for swift currents and very irregular terrain, making the use of submersibles and ROV's impractical. Scientists adapted the design for a "Towed automatically compensating observation system" or TACOS, developed by engineers and scientists at the CSIRO laboratory in Hobart, Tasmania. The apparatus uses a color underwater video camera and AC lighting. Electricity and video signals are transmitted through an electrical tow cable as the camera frame tracks 1-2 meters above bottom. In flat towing attitude, distance above bottom is controlled by counterbalancing flotation with the weight of a drag chain. Live-feed video on the tow vessel's bridge allows the operator to control the amount of deployed cable, responding to changes in the terrain.

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 are currently being reviewed and evaluated at AFSC in Seattle. In general, the study area is extremely varied, ranging from dense "gardens" 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.

**Description and Distribution of Coral in the Gulf of Alaska and Bering Sea** Principal Investigator - Jonathan Heifetz (Alaska Fisheries Science Center - ABL)

Coral has been identified by the NPFMC as a Habitat Area of Particular Concern (HAPC). To aid the NPFMC in identifying fishery management actions to minimize the adverse impacts on coral, information is being analyzed on the distribution and abundance of corals in Alaska and the species of fish managed by the NPFMC that are associated with coral. In addition a study has been initiated on the age and growth of gorgonian corals in collaboration with scientists at the Moss Landing Marine Laboratory in California. The taxonomic groups of coral found off Alaska are Alcyonacea (soft corals), Gorgonacea (sea fans and bamboo corals), Scleractinia (cup corals or stony corals), Stylasterinrina (hydrocorals), and Antipatharia (black corals). Given their size and longevity, gorgonian corals may also be most vulnerable to fishing impacts. The habitat created by gorgonians can be occupied by communities with high biodiversity and can be sources of shelter for fish (Risk et al., 1988; Fossa et al., 1999; Krieger and Wing, 1999)

Data being analyzed includes records of coral in the NMFS research survey database, the observer database, and the literature. The observer database (NORPAC) includes records back to 1987 of coral that is incidently caught by fishing gear. Unfortunately, there is no taxonomic identification of coral in the database, and coral is combined with bryozoans as a common code in the database. Thus, the observer data base is being used mostly to supplement trawl survey data and to document the types of fishing gear that incidently catch coral.

In the survey data, soft coral, primarily (*Eunepthya* formerly *Gersimi*), was the most frequently encountered coral in the Bering Sea. Over 96% of the coral encountered in the Bering Sea was soft coral. Whereas, in the Aleutian Islands soft coral was the least frequently encountered type. Only 21% of the coral encountered in the Aleutian Islands was soft coral. Gorgonian coral was the most frequently encountered coral in the Aleutian Islands. About 46% of the coral encountered in the Aleutian Islands was gorgonian coral, primarily *Primnoa sp*., *Paragorgia* sp., and *Fanellia* sp. Gorgonians and cup coral were the most frequently encountered coral types in the Gulf of Alaska. About 45 % of the coral encountered in the Gulf of Alaska was gorgonian coral, primarily *Callogorgia* sp. and *Primnoa* sp. About 31 % of the coral encountered in the Gulf of Alaska was cup coral, consisting mostly as “unidentified” cup coral (i.e., “Scleractinia unidentified”).

Some fish groups appeared to be associated with a particular types of coral. Relative to the other coral types rockfish, sablefish, Atka mackerel, and arrowtooth flounder were infrequently found with soft coral. Whereas, gadids, Greenland turbot, greenlings, and other flatfish were found with soft coral in the highest relative proportion. Gadids were present in most of the survey hauls regardless of coral type. Sharks and skates were found in hauls with hydrocoral and gorgonians in the highest relative proportion. Relative to the other coral types arrowtooth flounder were less frequently found on soft coral.

One alternative the NPFMC is considering is to close to fishing areas that have the highest abundance of coral. For gorgonian corals, this would include the following areas:

* an area in the western Aleutians Islands (vicinity of Attu Island.)
* an area in the central Aleutian Islands (vicinity of Kiska Island)
* an area in the Central Gulf of Alaska off the end of the Kenai Peninsula
* an area in Eastern Gulf of Alaska in Dixon entrance

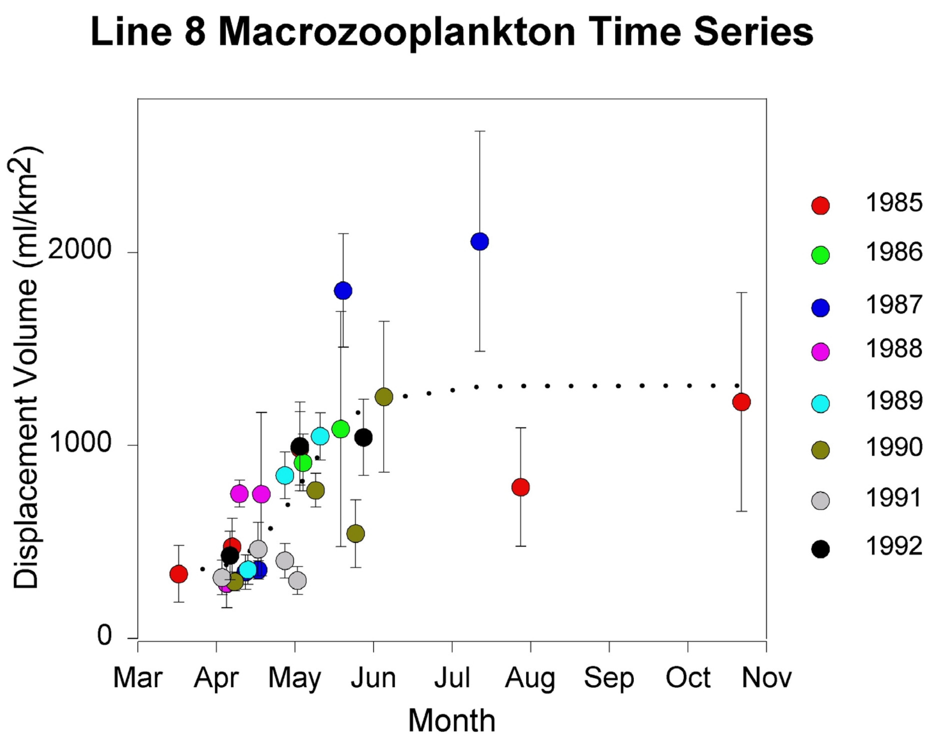
***Zooplankton, Chlorophyll and Nutrients***

Contributed by FOCI

## Gulf of Alaska

NOAA's Fisheries Oceanography Coordinated Investigations monitoring program of the Gulf of Alaska has dramatically declined in the recent past. Our cardinal sampling line (Line 8, 7 stations across Shelikof Strait between Cape Kekurnoi and Kodiak Island) was routinely sampled for nutrients, chlorophyll, icthyo- and zooplankton several times during each year from March – June. Monitoring began in 1985, but not all sample types were collected in all years. Currently Line 8 is sampled for nutrients, chlorophyll, and zooplankton only once or twice a year (May), and broad-scale surveys for ichthyoplankton are conducted approximately twice a year. Every other year a process-oriented springtime cruise is conducted in Shelikof Strait to investigate a physical or biological process that contributes to recruitment variability of walleye pollock.

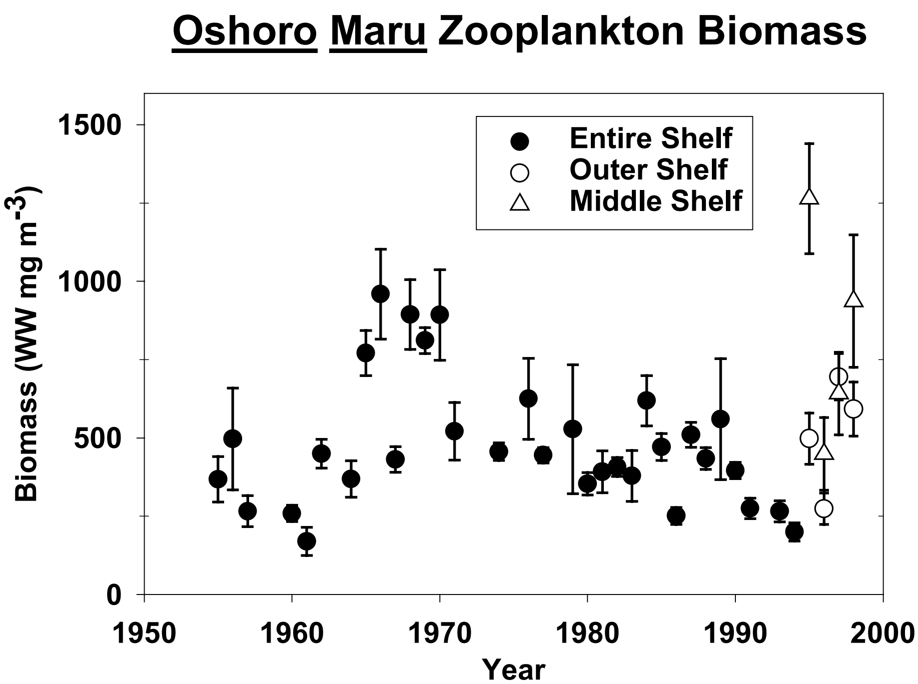
Below is an example of how zooplankton displacement volume data from Line 8 have been used to examine inter-annual variability despite seasonal trends in the data. For this exercise we examined the departures from a logistic population growth curve fit to the data. We are presently updating this time series to reflect data obtained in recent years through 1998. The updated time series should be available in the upcoming year.



## Bering Sea

A consistent monitoring program from FOCI did not emerge until very recently. Fall surveys for age-0 pollock around the Pribilof Islands (Lines A – D) were begun in 1994. These surveys included hydrography, nutrients, chlorophyll, zooplankton, and juvenile fish along the 4 sampling transects. The project that initiated these collections is not funded to continue sample collection past fall 1999. The Southeast Bering Sea Carrying Capacity (SEBSCC) Monitoring and Indices program began in 1997; field collections will end in FY00. In this program, nutrients, chlorophyll, and zooplankton are collected winter, spring, and fall at the shelf break, and around moorings in the Outer and Middle Shelf Domains (). Sample collection around Unimak Pass is less frequent. Biological and chemical data from this project are currently being synthesized with physical environmental data to produce indices for predicting survival potential of juvenile walleye pollock.

An extension of the published summer eastern Bering Sea zooplankton biomass time series collected by the Faculty of Fisheries, Hokkaido University, Japan was supplied by Japanese researchers collaborating with FOCI (Figure 1). The Oshoro Maru, a training ship for undergraduate cadets has been in the eastern Bering Sea almost every summer since 1954. The biomass is the wet weight of plankton retained by a 333 micron mesh NORPAC net towed vertically from near bottom to the surface. Wet weight measurements are made on the preserved catch. Sugimoto and Tadokoro (1997) recently published part of the time series and Dr. N. Shiga from Hokkaido University kindly provided the most recent data. Dr. Shiga provided the mean and standard deviation by domain. We still need to determine whether the measurements before 1994 had equal coverage of the Outer and Middle Domain or whether this might be a source of bias. If the measurements are unbiased and without error, then they suggest that recent levels of zooplankton biomass exceed those of the early 1990s and that some are comparable to values in the late 1960s.




Adapted from Sugimoto and Tadokoro, 1997

## *Forage Fish*

### Gulf of Alaska

**Small Mesh Survey Results**
Contributed by Paul Anderson

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 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 paper 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 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 plankters, in Alaska this is mostly copepods. As they mature, capelin feed on larger prey items such as euphausiids, shrimp, amphipods, capelin eggs, and copepods (Templeton, 1948; Rogers et al., 1979). Capelin are prey for Pacific cod and halibut (Hunter, 1979), Dolly varden, chum salmon, juveniles, and yellowfin sole (Blackburn et al., 1983), seals, whales, murres, puffins (Templeton, 1948), and cormorants, glacous-wing gulls, kittiwakes, horned and tufted puffins, Arctic and Aleutian terns (Hatch et al., 1978). Capelin play a key role in the trophic interaction of species, transfering energy from primary production to higher level predators.

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 (Blackburn, 1979). 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 fork length. Icthyoplankton surveys in the Gulf of Alaska 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 as adults during the day and stay primarily in surface waters, while adults may descend to the bottom. Difference in feeding preference probably explain these behavioral traits as well as the differential distributional patterns exhibited by each life history stage.

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 (Methven and Piatt, 1991), and probably were very susceptible to the increase in water column temperatures (Piatt and Anderson, 1996, Anderson et al. 1997).

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 (Figure 1). 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.

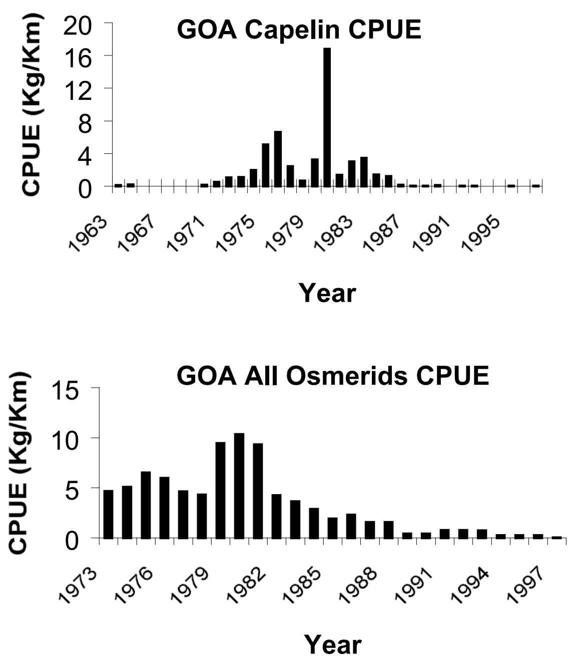



Figure 1.--Estimated trends in capelin and all osmerids abundance in the Gulf of Alaska from small-mesh trawl surveys, 1973-1997 (smoothed with a 3 year running mean).

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. 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*, 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 currently at the lowest recorded level in the survey series (1972-97) at 0.01 kg/km. Eulachon typically exhibit cyclic abundance changes possibly due to dominant spawning year-classes.

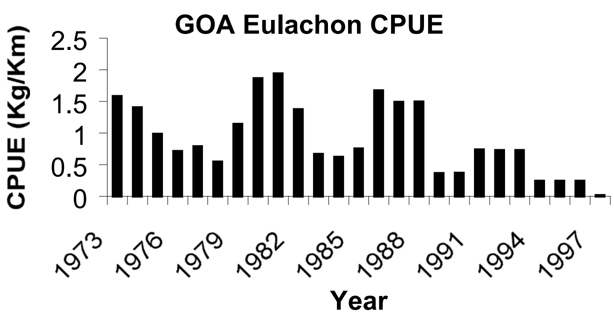



Figure 1. Eulachon abundance trends in the GOA from small-mesh trawl surveys, 1973-1997 (smoothed with 3 yr running average).

**Pacific sandlance**

The Pacific sandlance *Ammodytes hexapterus* is an extremely important forage species in the nearshore zone of the Gulf of Alaska (Dick and Warner, 1982). 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 nearshore fishes comsume sandlance as a major portion of the diet during certain months of the year (Blackburn, 1978; Blackburn et al., 1983, Blackburn and Anderson, 1997).

Sand lance in the Kodiak region 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 (Kandler in Reay, 1970). 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 (Clemens and Willoughby, 1961). Offshore icthyoplanton 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 (Dick and Warner, 1982). 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 begining of the 1980s (based on data from Rugen, 1990).

**FOCI Estimates of Early Life History Stages of Pollock**
Contributed by Bern Megrey

**Egg and Larval Pollock Abundance Indices:** Egg and larval index values are calculated from data collected on Alaska Fisheries Science Center (AFSC) research cruises. Since cruises were conducted for a variety of purposes, station patterns and the number of stations sampled are not consistent between cruises (Dunn and Rugen 1989). To deal with these inconsistencies, index values were calculated for regions and times that are of historic importance to eggs and larvae and were sampled during most years. This was done to avoid extrapolating data to areas where no information was available. The egg time series begins in 1978 and the larval series begins in 1979.

Because mortality can have a large effect during an index interval (one month in this case), abundance values were standardized to the mid-point of the index period. The egg mortality rate (z=0.186/day) was taken from Picquelle and Megrey (1993,1991) and larval mortality rate (z=0.110/day) was taken from Yoklavich and Bailey (1990). The abundances for eggs and larvae in the index region were calculated by year using the Sette and Ahlstrom method (Richardson 1981). Mean catch per $m^2$ was calculated by weighting catch per $10m^2$ for each station by the polygonal area of the station. The grand mean of all stations within the index region was then multiplied by the total area of the index region to give the abundance index. Because early sampling for eggs was done to an insufficient depth to cover the whole vertical range of distribution, egg abundances were corrected for tows sampled to less than 250m depth using the method described in

Kendall and Kim (1989). FOCI is in the process of updating this time series to make them as current as possible.

**Age-0 and Age-1 Juvenile Pollock Abundance:** Indices of juvenile pollock were derived from data generated from shrimp and juvenile pollock surveys conducted in the Shelikof Strait region. Data for age-0 pollock begin in 1975. Data for age-1 pollock begin in 1979. Spring and Bailey (1991) provide detailed descriptions of gear used to collect samples, geographic and temporal coverage of the surveys, gear-dependent mortality corrections, and all assumptions and data processing steps. Juvenile abundance values used in this study were corrected for gear and mortality affects. FOCI is in the process of updating this time series to make them as current as possible.

### Bering Sea

Distribution, species associations, and biomass trends of various forage fishes in the Bering Sea were recently summarized by Brodeur et al. (1999). In addition to observations on the eastern shelf, this summary also included data from two Russsian cruises that covered both eastern and western shelf regions in 1987. Spatial distributions of some forage species in the eastern Bering Sea (age-1 pollock, age-1 cod, Pacific herring, capelin and eulachon) showed some spatial separation of the groups and some changes in distribution in a cold versus a warm year. Capelin were associated with colder temperatures in the northern part of the study area whle age-0 pollock were associated with warmer temperatures than the overall measured temperature. Eulachon was found only in the warmer temperatures at the southern part of the sampling area. Although this study did not find any long-term trends in forage fish abundance in the Bering Sea, the study period began in 1982, which is generally considered to be a warmer period in the Bering Sea. Analysis of 36 years of Russian pelagic trawl data indicates different periods of fish abundance depending on environmental conditions. In the western Bering Sea and Okhotsk Sea, herring and capelin appear to alternate in abundance with pollock. Such a pattern has not been definitively identified for the eastern Bering Sea.

## *Other Species*

### Gulf of Alaska

Contributed by Sarah Gaichas, Lowell Fritz, and James N. Ianelli

Trends in the biomass of Gulf of Alaska "other species" (sharks, skates, sculpins, smelts, octopi, and squids) were investigated using the NMFS Triennial trawl survey data from 1984 through 1999. Any discussion of biomass trends should be viewed with the following caveats in mind: survey efficiency may have increased for a variety of reasons between 1984 and 1990, but should be stable after 1990 (Robin Harrison, personal communication). Surveys in 1984, 1987, and 1999 included deeper strata than the 1990 - 1996 surveys. Therefore the biomass estimates for deeper-dwelling components of the other species category are not comparable across all years. Bottom trawl survey gear is probably most efficient for skates and sculpins, less efficient for sharks, and least efficient for smelts, squid and octopus species. Considering the burrowing habits and rocky inshore habitat of octopus, we assume that octopus biomass is substantially underestimated by this survey.

The average biomass within the other species category using all (6) survey biomass estimates is 160,000 tons. The most recent estimate of other species biomass (1999) is 213,000 tons. Skates represent 30-40% of the other species biomass from all surveys and are the most common group in each year except 1984, when sculpin biomass was highest within the category. Total biomass for the other species category shows an increasing trend between 1984 and 1999 (Figure 1). This is the result of apparent increases in skate, shark, and smelt biomass, some of which may be difficult to resolve from changes in survey efficiency. Sculpin biomass appears relatively stable over this period, while squid and octopus biomass trends are difficult to resolve with this survey. An alternative method for evaluating survey trends is presented in GOA SAFE Appendix C.

Individual species biomass trends were evaluated for the more common and easily identified shark and sculpin species encountered by the triennial trawl survey. In general, the increasing biomass trend for the shark species group is as result of increases in spiny dogfish and sleeper shark biomass between 1990 and 1999 (Figure 2). Salmon shark biomass has been stable to decreasing according to this survey, but salmon sharks are unlikely to be well sampled by a bottom trawl (as evidenced by the high uncertainty in the biomass estimates). It should be noted that both salmon shark and Pacific sleeper shark biomass estimates may be based on a very small number of individual tows in a given survey. No salmon sharks were encountered in the 1999 survey, despite reports of their increased abundance in other areas of the GOA.

Individual sculpin species display divergent biomass trends between 1984 – 1999. While the biomass of bigmouth sculpins (*Hemitripterus bolini*) has decreased over the period of the survey, great sculpin (*Myoxocephalus polyacanthocephalus*) biomass has remained relatively stable, and yellow Irish lord (*Hemiliepidotus jordani*) biomass has increased (Figure 3). The biomass of yellow Irish lords appears to have increased over time despite general stability in the number of hauls where they occurred, whereas bigmouth sculpins were encountered in fewer hauls each year. Uncertainty in these estimates varies between years.

In addition to sharks and sculpins, we examined available biomass estimates for grenadiers (Macrouridae), which are not included in the other species category. The species most commonly encountered in the triennial trawl surveys was the giant grenadier, *Albatrossia pectoralis*. The Pacific grenadier *Coryphaenoides acrolepis* was present, but with much lower estimated biomass in all years. Survey coverage of deeper strata is particularly important to grenadier biomass estimates; therefore we consider the 1990 – 1996 survey estimates to be of little use for detecting trends in grenadier abundance

Investigation of biomass trends by skate species is in progress, although this may be difficult due to variable levels of species identification over time in the triennial survey. Skate taxonomy remains uncertain, especially for species in the genus *Bathyraja*, which further complicates field identification. However, it is important to try to resolve biomass trends by species where possible, since some skate species may be particularly vulnerable to fishing pressure (Brander, 1981). Populations of the barndoor skate *Raja laevis* have declined precipitously in the North Atlantic despite an increase in the biomass of skates as a group (Casey and Meyers, 1998; Sosebee, 1998).

Information on distribution, stock structure, and life history characteristics is extremely limited for other species in the Gulf of Alaska. In the GOA SAFE Appendix B, we attempt to describe general life history characteristics at least at the species group level using published information for the same or similar species in other geographic areas. Investigations specific to Gulf of Alaska stocks are necessary to fully evaluate abundance trends and ecological relationships.

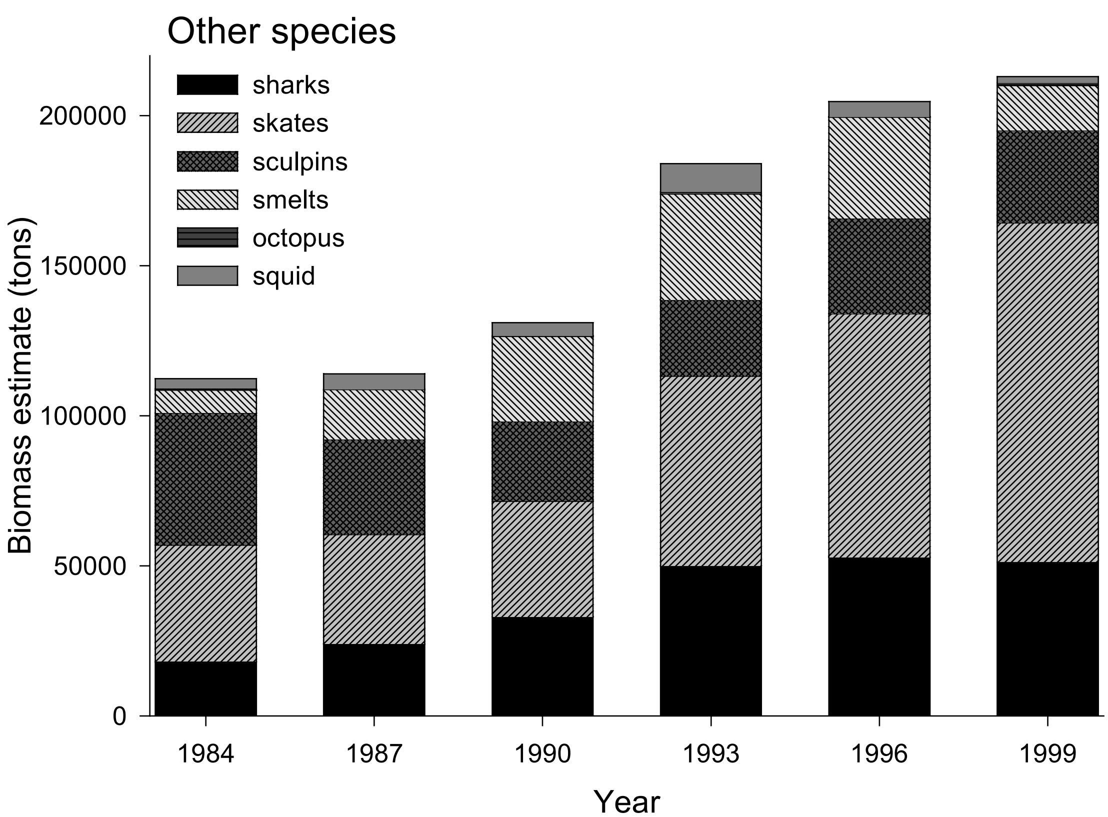



Figure 1. Other species biomass estimates from the GOA triennial trawl survey, 1984-1999.

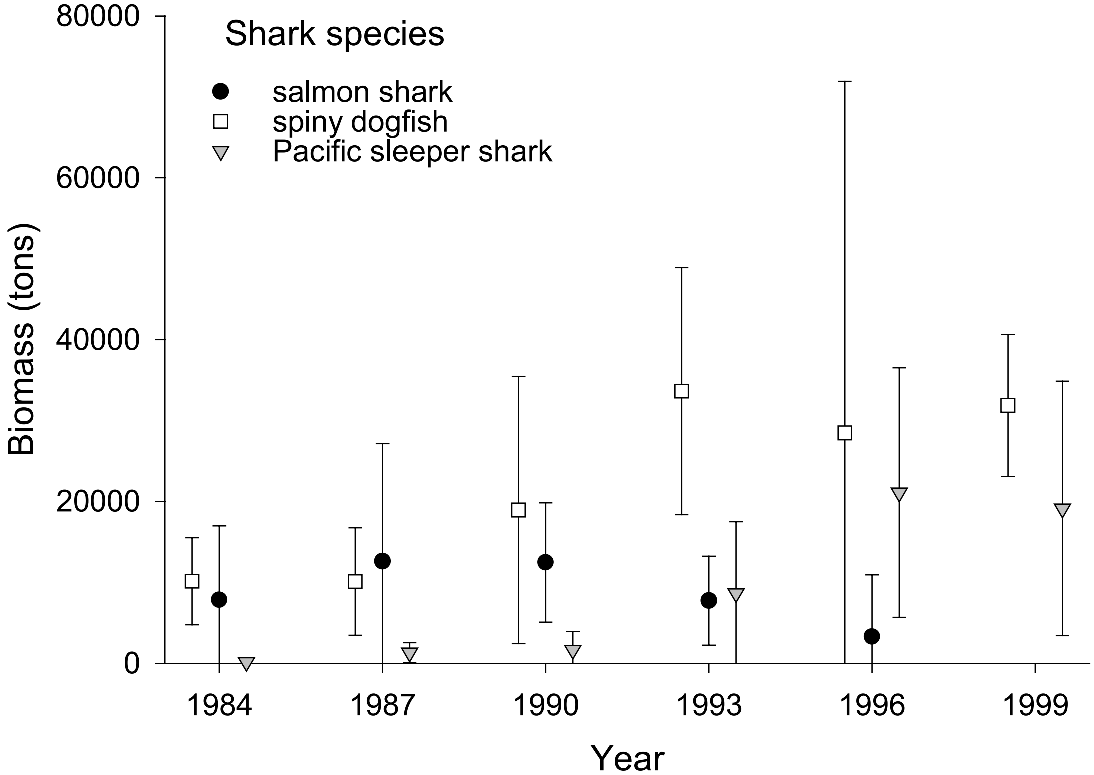



Figure 2. Shark species biomass trends in the GOA according to the triennial trawl survey.

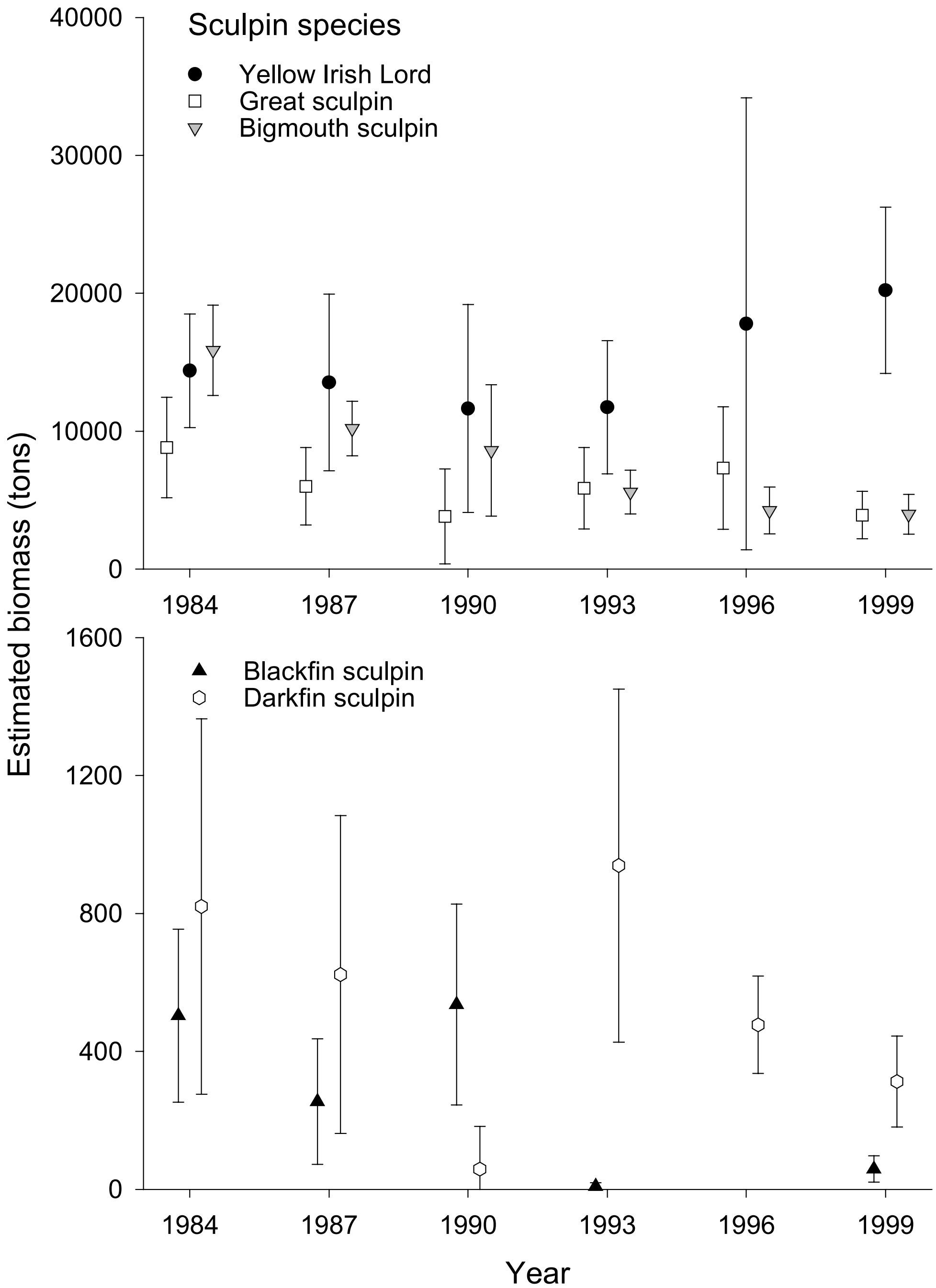



Figure 3. Sculpin species biomass trends, 1984-1999 NMFS GOA triennial trawl survey.

## Eastern Bering Sea

Contributed by Lowell Fritz

The "other species" management group has been established to account for species which are currently of slight economic value and upon which there is little, if any, directed fishing. However, these species could have economic value in the future, and many are important components of the ecosystem as prey for commercial fish species, marine mammals and birds. Squid is considered separately from the “other species” management group, which includes sculpins, skates, sharks, and octopus. Smelts were removed from the “other species” group and moved to the forage fish group beginning in 1999 as a result of fishery management plan (FMP) amendments 36 and 39 to the Bering Sea and Aleutian Islands and Gulf of Alaska groundfish FMPs.

Information on the distribution, abundance, and biology of squid stocks in the eastern Bering Sea (EBS) and Aleutian Islands region is limited. The predominate species in commercial catches in the EBS is the red squid, *Berryteuthis magister*, while *Onychoteuthis borealijaponicus*, the boreal clubhook squid, is the principal species encountered in the Aleutian Islands region. Assessment data are not available for squid from Alaska Fishery Science Center surveys because of their pelagic distribution.

During cooperative U.S.-Japan surveys from 1979-85, 41 species of sculpins were identified in the EBS and 22 species in the Aleutian Islands region (Bakkala et al. 1985; Ronholt et al. 1985; Bakkala 1993). During these same surveys, 15 species of skates were identified but inadequate taxonomic keys for this family may have resulted in more species being identified than actually exist. Species that have been consistently identified during surveys are the Alaska skate, (*Bathyraja parmifera*), big skate (*Raja binoculata*), longnose skate *(R. rhina*), starry skate (*R. stellulata)*, and Aleutian skate (*B. aleutica*). Biomass estimates of these species from demersal trawl surveys serve as valuable indices of their relative annual abundance on the eastern Bering Sea shelf.

While biomass estimates have been made for sharks and octopi, the AFSC bottom trawl surveys fail to adequately sample their habitats. Sharks are rarely taken during demersal trawl surveys in the Bering Sea. Spiny dogfish *(Squalus acanthias*) is the most common species caught, and the Pacific sleeper shark (*Somniosus pacificus*) has been taken on occasion. Two species of octopus have been recorded, with *Octopus dofleini* predominating and *Opisthoteuthis california* occurring rarely.

There is currently no reliable estimate of squid abundance in the eastern Bering Sea. Sobolevsky (1996) cites an estimate of 4 million tons for the entire Bering Sea made by squid biologists at TINRO (Shuntov et al. 1993), and an estimate of 2.3 million tons for the western and central Bering Sea (Radchenko 1992), but admits that squid stock abundance estimates have received little attention. It is clear that the AFSC bottom trawl surveys greatly underestimate squid abundance.

Data from AFSC surveys provide the only abundance estimates for the various groups and species comprising the "other species" category (Figure 1). Biomass estimates for the eastern Bering Sea are from a standard survey area of the continental shelf. The 1979, 1981, 1982, 1985, 1988 and 1991 data include estimates from continental slope waters (200-1,000 m in 1979, 1981, 1982, and 1985; 200-800 m in 1988 and 1991), but data from other years do not. Slope estimates were usually 5% or less of the shelf estimates, except for grenadiers. Stations as deep as 900 m were sampled in the 1980, 1983 and 1986 Aleutian Islands bottom trawl surveys, while surveys in 1991 and 1994 obtained samples only to a depth of 500 m.

Since the survey biomass estimates for species other than squid vary substantially from year-to-year due to different distributions of the component species, it is probably more reliable to estimate current biomass by averaging estimates of recent surveys. The average biomass of other species from the last 3 eastern Bering Sea surveys (1997-99) is 561,600 mt; adding the estimate from the 1997 Aleutian Islands survey (48,800 mt) yields a total **BS/AI "other species" biomass estimate of 610,400 mt**.

Biomass estimates from AFSC surveys illustrate that sculpins were the major component of this group until 1986, after which the biomass of skates exceeded that of sculpins. The abundance of skates increased between 1985 and 1990 (when a high of 583,800 mt survey biomass was observed), but has since declined to about 370,000 mt in 1999. The abundance of sculpins remained relatively stable through 1998, but declined to the lowest biomass estimate since 1975 in 1999.

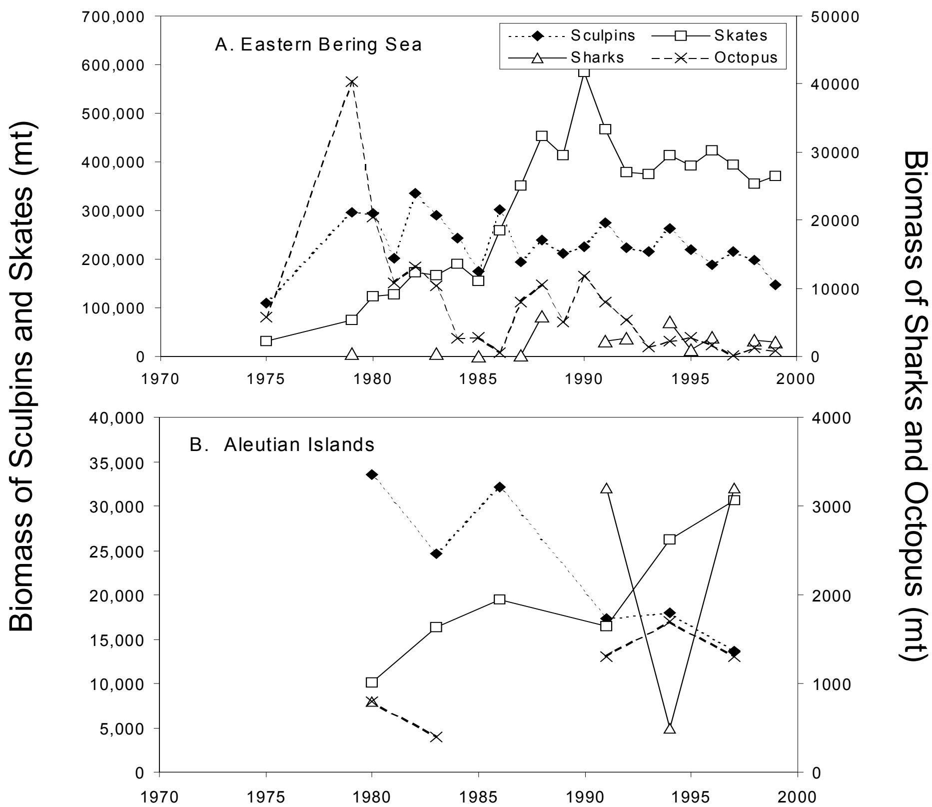



Figure 1. Bottom trawl survey biomass estimates of species groups in the other species complex in the eastern Bering Sea shelf (A) and the Aleutian Islands region (B).

## *Benthic Communities and Non-target fish species*

### Gulf of Alaska

**Trophic Regime Shift in Benthic Communities in the Gulf of Alaska**
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 *In Press*). 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 hermaphordites 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. Hatch et al. (1978) reported glacous-winged gulls, kittiwakes, and tufted puffins preyed on shrimp. Shrimp therefore, are a major forage species. In turn, shrimp are also prey on other crustaceans, many demersal and pelagic invertebrates, larval and small fishes, and can feed on dead or decaying organic matter.

Pandalid shrimp have declined uniformly throughout all study areas in the GOA, with the most significant declines occurring after 1981 (Figure 1). 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*) have 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 shallow distributed members of pandalidae were more vulnerable to the climate change that was observed during the later part of the 1970s.

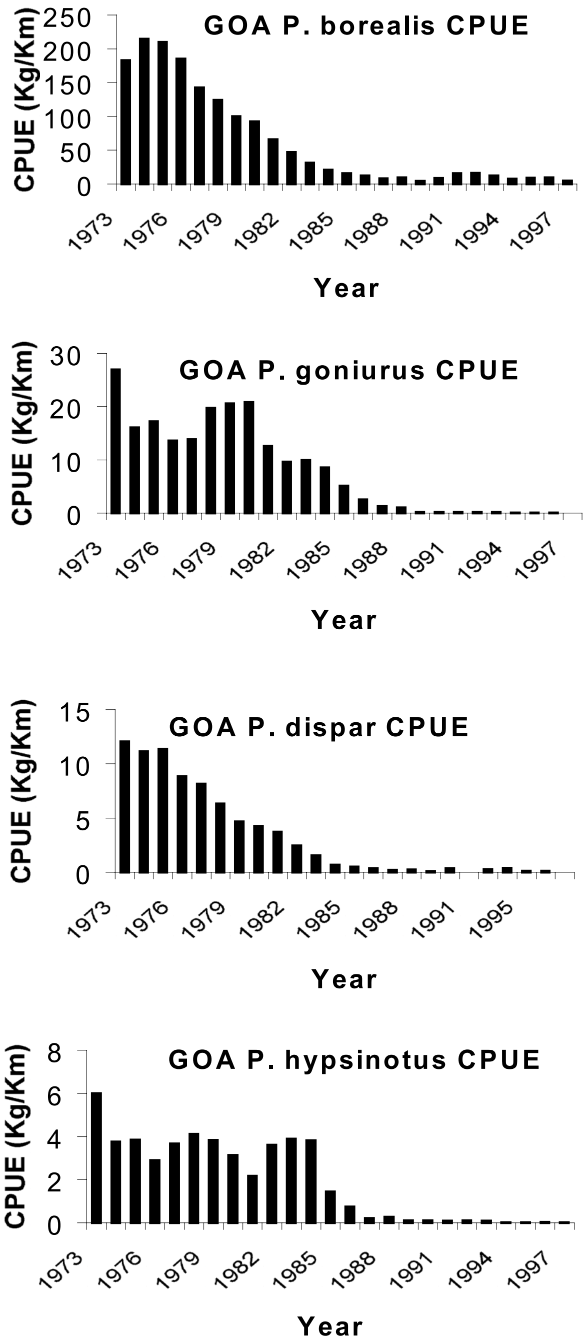



Figure 1.--Relative abundance of Pandalus borealis, P. goniurus, Pandalopsis dispar and Pandalus hypsinotus in the Gulf of Alaska 1973-1997 from small mesh trawl surveys (data smoothed with 3yr running avg.).

**Other Epibenthic Fishes**

Many epibenthic non-commercial 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 dicussed above. However since 1970 most of these species have been identified, enumerated, and weighed in small-mesh trawl surveys.

Among these species the most significant change since the early 1970s has been the decline of *Lumpenella longirostris*, long-snout prickleback (Figure 1). 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.

Other minor 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

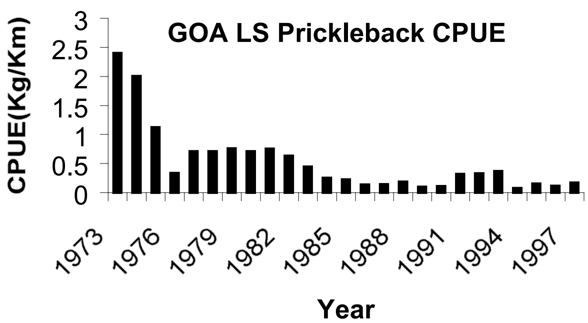



Figure 1.-- Longsnout prickleback abundance trends in the GOA from small-mesh trawl surveys, 1973-1997 (3 yr running avg.).

**Other Epi-benthic 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 sea-stars in survey catches is 0.8 kg/km (n=6,812) for 1972-97. Since 1991 catches have been substantially over this long-term index averaging 2.8 kg/km. 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 (Figure 1). 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, well above the overall average for years prior to 1980. It appears that 1980 was a pivotal year in jellyfish abundance in the GOA. This extremely high jellyfish biomass probably impacted primary productivity through predation. 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 species.

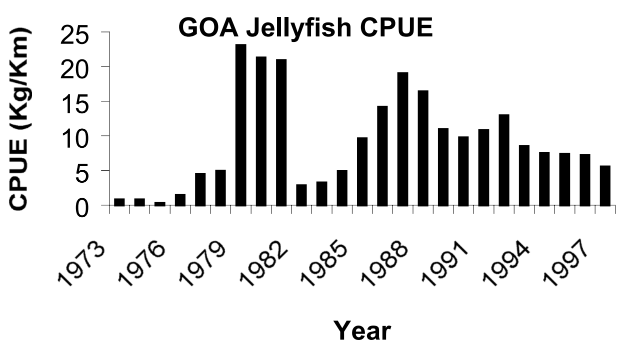



Figure 1.-- Jellyfish abundance trends in the GOA from small-mesh trawl surveys, 1973-1997 (smoothed with a 3yr avg.).

## Eastern Bering Sea

Contributed by Jerry Hoff

Non-commercial species are a significant portion of the fish fauna occuring in the Bering Sea, but, due to their small biomass or lack of marketability, are rarely harvested. However, these fishes may be valuable indicators of changes occuring to the Bering Sea ecosystem due to natural or man-made influences. Figure 1 shows the relative changes in population estimates from 1982 to 1997 of 12 non-commercial fish species common in the Eastern Bering Sea shelf region.

Studies have shown that environmental temperatures and fish populations co-vary in a cyclical pattern. Non-commercial fishes from the Bering Sea show similar cyclical fluctuations in population levels which may be linked to environmental changes such as temperature. However, specific mechanisms of how environmental changes can influence fish populations over long periods of time is often difficult to discern. For example, do environmental changes alter the fishes' habitat (substrate or structure) or does it act directly on some aspect of the fishes' biology (spawning time, egg viability, food availability).

The nature of future work in this regard will be to examine how environmental changes can influence fish population changes for non-commercial species in the Eastern Bering Sea. Important aspects of the biology of each species such as length at age, and length frequencies provide important information on fish longevity, growth rates and recruitment. By comparing the ecology and biology between each species, common life history aspects can help determine vulnerabilities to changing environmental conditions.

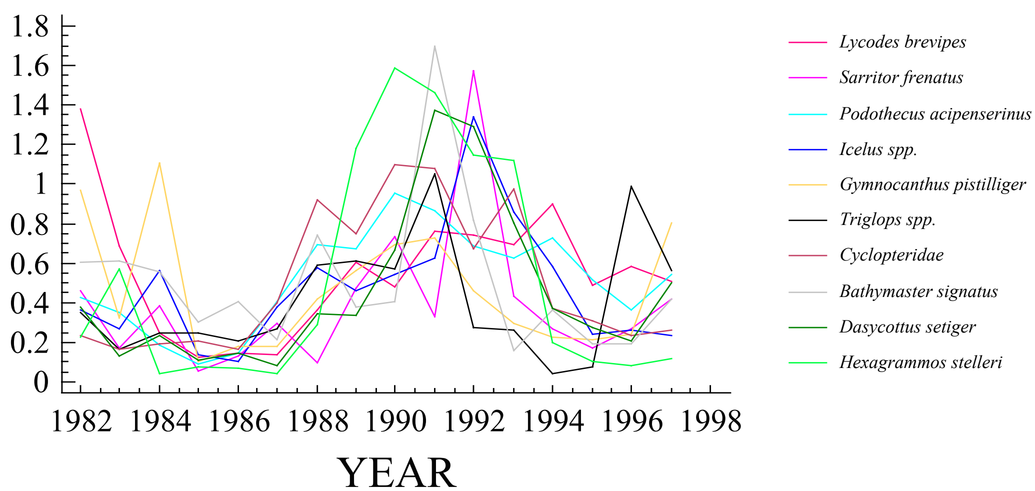



Figure 1.--Changes in population estimates for a variety of non-commercial species showing a similarity in trends. Species include sculpins, eelpouts, poachers, snailfish, ronquils and greenlings.

**Jellyfish**
Contributed by Ric Brodeur

Researchers at National Marine Fisheries Service examined catches of large medusae from summer bottom trawl surveys that sampled virtually the same grid station on the eastern Bering Sea shelf and used the same methodology every year from 1979 to 1998. This series shows a gradual increase in biomass of medusae from 1979 to 1989, followed by a dramatic increase in the 1990s (Figure 1). The median biomass increased ten-fold between the 1982-89 and 1990-97 periods. Most of this biomass was found within the Middle Shelf Domain (depths between 50 and 100 m). The greatest rate of increase occurred in the northwest portion of this domain. Whether this dramatic increase in biomass of gelatinous zooplankton has resulted from some anthropogenic perturbation of the Bering Sea environment or is a manifestation of natural ecosystem variability is unclear. However, several large-scale winter/spring atmospheric and oceanographic variables in the Bering Sea exhibited concomitant changes beginning around 1990, indicating that a possible regime change occurred at this time.

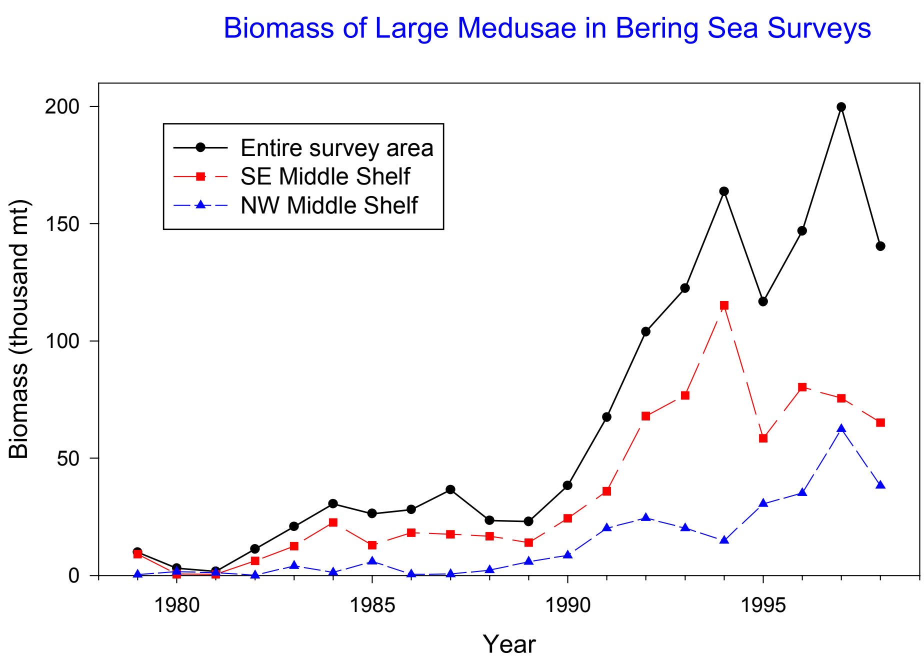



Figure 1.—Biomass of jellyfish medusae in the eastern Bering Sea from bottom trawl surveys, 1979-1998.

## ***Marine Mammals***

By NMFS National Marine Mammal Lab Staff

**Harbor seals--**The National Marine Mammal Laboratory conducted aerial assessment surveys for harbor seals (*Phoca vitulina richardsi*) in the southern portion of southeast Alaska, from Frederick Sound to the US/Canadian border in 1998. The northern portion of southeast Alaska was surveyed in 1997. Two observers worked out of Petersburg and 5 observers used Ketchikan as their base of operations. From 18-28 August, the entire coastline was surveyed from small, single-engine aircraft equipped with floats, at an altitude of 200-250 m (700-800 ft.). Observers estimated the number of seals hauled out and took photographs of all seal haulouts. Results from the two surveys will be combined to produce an overall estimate for Southeast Alaska.

When seals are censused from the air, an unknown number of seals are in the water and not present at the haulout sites. A companion project to the assessment surveys is development of a correction factor for each haulout type (rocky, sandy, and ice) to account for seals not present at the time of the census surveys. This is accomplished by capturing 20-40 seals and attaching a small VHF radio transmitter to the left rear flipper. The proportion of radio-tagged seals hauled during subsequent surveys should be representative of all seals at the haulout. The resulting correction factor is then applied to the population estimates derived in the assessment analysis. The estimates are then adjusted upwards to account for those seals not present during the aerial census surveys.

Correction factors have been developed previously for seals hauling out on rocky and sandy substrates. Little is known about the seals hauling out on glacial ice since no one has been able to successfully capture one. The NMML developed new capture techniques using a variety of net materials and types and net deployment methods. In early August, the NMML successfully captured 19 seals at Aialik and Peterson Glaciers in the Kenai Fiords National Park near Seward, Alaska. We tracked the movements of these radio-tagged seals from aircraft (22 August - 2 September) and remote data collection computers (19 August to about 8 October). Results from the assessment and correction factor surveys are currently being analyzed and will be used to estimate the number of harbor seals in Alaska and determine key components used in the NMFS annual stock assessment report.

**Northern fur seals--**Northern fur seals (*Callorhinus ursinus*) were listed as depleted in 1988 under the Marine Mammal Protection Act. Much of the research effort for fur seals takes place on the Pribilof Islands (St. Paul and St. George). The NMML conducts counts of adult males (bulls) annually, and counts of pups biennially. Analysis of the 1998 bull and pup counts indicate a continued slight decrease in fur seal numbers on both of the Pribilof Islands. From 1997 to 1998 the total number of adult males on the Pribilof Islands decreased by 1.6%. Because of the high variability in these counts, however, several more years of data are needed to determine if a trend exists. The estimate of the total number of pups born on St. Paul Island in 1998 was 179,149 (SE = 6,193); the standard error accounts for variance in the estimation of both live and dead pups. The total estimated number of pups born in 1998 was not significantly different (P = 0.82) from 1996, but was significantly less than the estimate in 1994 (P < 0.01). The total number of pups born on St. George Island and the approximate 95% confidence interval was 21,547 - 22,633. The 1998 estimate of pups born on St. George Island is significantly less (P < 0.01) than the number of pups born in 1996, but the estimate is not significantly different (P = 0.22) from the estimate of the number of pups born in 1994.

**Beluga whales--**The NMML flew aerial surveys of the isolated stock of beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, during June/July of 1993-98. This included nearly 100% of the coastal areas each year, and with the addition of offshore transects, systematic searches encompassed 13-29% of the entire inlet. Beluga whales were concentrated in a few dense groups in shallow areas near river mouths in the northern portion of upper Cook Inlet. Very few belugas occurred elsewhere. Over the past three decades, there have been decreases in sightings of beluga whales both in offshore areas and in lower Cook Inlet. Since 1995, there have been no sightings in our surveys south of the upper inlet. Results of these surveys and status of beluga whales will be reported in a stock assessment report in December 1999.

**Steller sea lions**--NMFS and ADF&G conducted surveys of Steller sea lion (*Eumetopias jubatus*) pups and non-pups during June and July 1998 from Southeast Alaska to the western Aleutian Islands. Numbers of sea lions counted during a "winter" or "non-breeding season" survey conducted in March 1999 are still being analyzed. In general, numbers of non-pups in the western stock (west of 144°W) continued to decline in 1998. In the Kenai to Kiska area, non-pup numbers at trend sites decreased by 12.8% from 1994 to 1998 (18,713 to 16,315) and 8.9% (17,900 to 16,315) from 1996 to 1998 (Table 2). This compares to a Kenai to Kiska decline of 4.6% from 1994 to 1996. The Aleutian Islands as a whole declined by 7.3% from 1996 to 1998, as compared to a marginal increase ( 1.1%) from 1994 to 1996. Combined, the western and central Gulf of Alaska declined 12.4% from 1996 to 1998, and 4.0% from 1997 to 1998. The central Aleutian Islands (Islands of Four Mountains to Kiska) was the one area that did show a marginal increase ( 4.2%) from 1996 to 1998.

Although the numbers for Southeast Alaska show a decline, only 18 sites were surveyed in 1998, and other indications, particularly pup count results (below) suggest that the population in this areas is stable. Survey coverage in the eastern Gulf of Alaska was too incomplete to provide a reliable trend for non-pups.

NMFS and ADF&G conducted counts of Steller sea lion pups at all rookeries in Alaska, from the Forrester Complex in Southeast Alaska to Attu Island in the western Aleutian Islands during 19 June to 5 July 1998. Since 1994, the last range-wide pup counts, pup numbers decreased by 10.8% (from 14,198 pups to 12,670) at all rookeries (Table 2). For the western stock (reflected by the counts from Kenai to Kiska) the decline was 19.1% over 4 years. In general, pup numbers were up slightly in parts of the central Aleutian Islands (8 rookeries from Seguam Island to the Delarof Islands), but down elsewhere. Rookeries in the western Aleutian Islands (particularly those in the Near

Islands: 3 rookeries at Attu and Agattu islands) were counted completely for the first time in 1997. Pup numbers at these three rookeries declined by 18.0% in one year (979 pups to 803 pups). The 2 rookeries in the eastern Gulf of Alaska declined 23.7% from 1994 to 1998, but increased 13% from 1997 (610 pups to 689). Pup numbers in Southeast Alaska have increased 12.3% from 1994, but showed little change from 1997 to 1998.

**Harbor porpoise and Dall's porpoise** - Researchers from the NOAA National Marine Mammal Laboratory conducted line transect aerial surveys for harbor porpoise (*Phocoena phocoena*) and Dall's porpoise (*Phocoenoides dalli*) from 27 May to 28 July 1998 in the Gulf of Alaska (offshore waters from Cape Suckling to Unimak Pass), Prince William Sound, and Shelikof Strait. The survey aircraft was a Twin Otter flown at an altitude of 500 ft and an airspeed of 100 knots. Sawtooth lines covered the offshore waters from Cape Suckling to Unimak Pass (offshore of Kodiak Island) from about 15 nm seaward to the 1,000 fathom line. A series of zigzag lines covered Shelikof Strait, between the Alaska Peninsula and Kodiak Island. Larger inlets and bays were also included in the survey. The survey in Prince William Sound consisted of two lines: one covering the central waters and one along the coast with extensions into selected inlets. Two primary observers surveyed from bubble windows on each side of the aircraft. A third observer, viewing directly beneath the aircraft from a belly window, recorded porpoises missed on the trackline by the primary observers.

Poor weather restricted the completion of the entire planned survey. Survey lines were completed in Prince William Sound and an adequate number of survey miles were completed offshore from Cape Suckling west along the Kenai Peninsula, offshore of Kodiak Island, west to Sutwik Island (Alaska Peninsula), and in Shelikof Strait. We flew a total of 5,722 nm, with sightings of 83 harbor porpoise, 69 Dall's porpoise, 13 killer whales, 47 humpback whales, 24 fin whales, 1 Cuvier's beaked whale, 1 northern right whale, 25 harbor seals, 20 Steller sea lions, and 1 northern fur seal. We will use these data to estimate annual abundance of harbor porpoise and Dall's porpoise, which is one of the key pieces of information needed to manage marine mammal-fishery interactions, as required under the Marine Mammal Protection Act. A report will be available by December 1999.

**Table 1**.--Counts of **non-pup** Steller sea lions at Trend Sites (rookeries and haulouts) during aerial surveys in Alaska, 1994 to 1998.

| Region | Non-pup counts at Trend Sites | | | Percent change | |
|---|---|---|---|---|---|
| | 1994 | 1996 | 1998 | 1994-98 | 1996-98 |
| Western Aleutian Islands | 2,037 | 2,190 | 1,913 | -6.1 | -12.6 |
| Central Aleutian Islands | 5,790 | 5,528 | 5,761 | <- 1% | +4.2 |
| Eastern Aleutian Islands | 4,421 | 4,716 | 3,847 | -13.0 | -18.4 |
| Western Gulf of Alaska | 3,982 | 3,741 | 3,361 | -15.6 | -10.2 |
| Central Gulf of Alaska | 4,520 | 3,915 | 3,346 | -26.0 | -14.5 |
| Kenai to Kiska subtotal | 18,713 | 17,900 | 16,315 | -12.8 | -8.9 |

**Table 2**.--Counts of Steller sea lion **pups** in Alaska, 1994 to 1998.

| Region | No. of rookeries | 1994 | 1997 | 1998 | Percent change 94-98 | Percent change 97-98 |
|---|---|---|---|---|---|---|
| Western Aleutian Islands | 4 | | 979 | 803 | | -18.0 |
| Central Aleutian Islands | 16 | 3,162 | | 2,862 | -9.5 | |
| Eastern Aleutian Islands | 6 | 1,870 | | 1,516 | -18.9 | |
| Western Gulf of Alaska | 4 | 1,662 | | 1,493 | -10.2 | |
| Central Gulf of Alaska | 5 | 2,831 | | 1,876 | -33.7 | |
| Eastern Gulf of Alaska | 2 | 903 | 610 | 689 | -23.7 | +13.0 |
| Western Stock subtotal (Kiska to Seal Rocks) | 33 | 10,428 | | 8,436 | -19.1 | |
| Southeast Alaska | 3 | 3,770 | 4,160 | 4,234 | +12.3 | +1.8 |

### *Seabirds*

Contributed by: U.S. Fish and Wildlife Service, Migratory Bird Management Office, Anchorage, Alaska

Seabirds spend the majority of their life at sea rather than on land. Alaska's extensive estuaries and offshore waters provide breeding, feeding, and migrating habitat for approximately 100 million seabirds. Thirty-four species breed in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) regions and number 36 million and 12 million individuals, respectively. (Table 1). Another 6 species breed at other locations in Alaska. In addition, up to 50 million shearwaters and 3 albatross species feed in Alaskan waters during the summer months but breed farther south (Table 2).

Seabirds are a trust responsibility of the U.S. Fish and Wildlife Service, which assesses their status and works to mitigate problems. Data are being collected annually for selected species of marine birds at geographically dispersed breeding sites along the entire coastline of Alaska. A total of 12 sites (Fig.1) located roughly 300-500 km apart are scheduled for annual monitoring. In addition, colonies near the annual sites are identified for less frequent surveys to “calibrate” the information at the annual sites. Other research projects (i.e., those associated with evaluating the impacts of oil spills on marine birds) supplement the monitoring database. The objective of the monitoring is to provide long-term, time series data from which biologically-significant changes may be detected and from which hypotheses about causes of changes may be tested. The strategy for colony monitoring includes; estimating timing of nesting events, reproductive success, and population trends of representative species of various foraging guilds (i.e. off-shore diving fish-feeders, surface-feeding fish-feeders, diving plankton-feeders, etc.).

Seabirds are characterized by low reproductive rates, low annual mortality, and a long life span. Population trends can result from changes in either productivity or survival, but most trends that have been adequately investigated were attributed to changes in productivity. Breeding success in most species is variable among years, but in stable populations, poor success is compensated for by occasional good years. The natural factor most often associated with low breeding success is scarcity of food (Kuletz 1983, Murphy et al. 1987, Murphy et al. 1984, Springer 1991). The factors which influence availability of food to seabirds along with other threats to seabird populations (i.e., oil spills, incidental take in commercial fishing gear, and the introduction of alien predators) are discussed below.

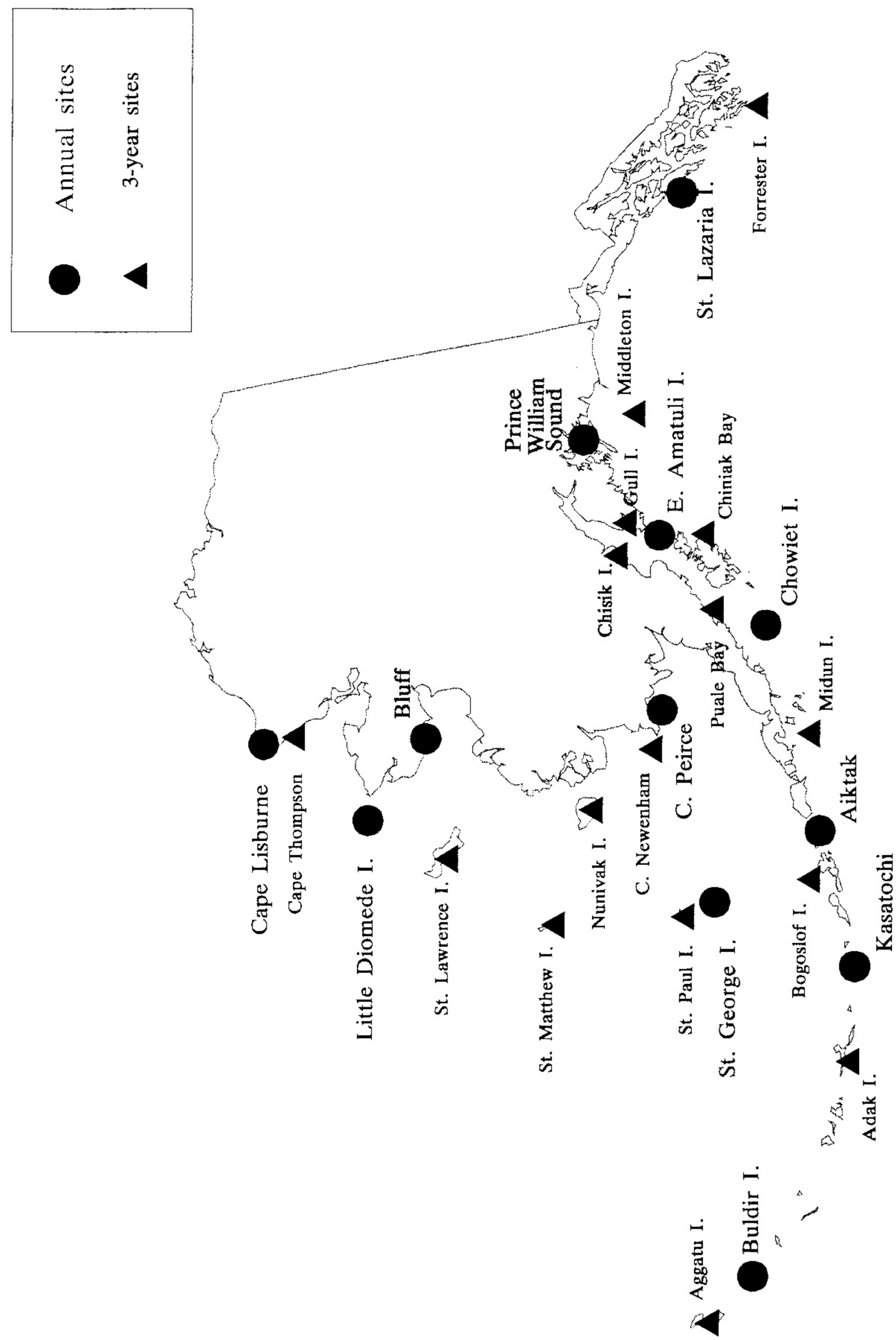



Figure 1. Map of Alaska showing the locations of seabird monitoring sites.

## SEABIRD STATUS AND POPULATION TRENDS

### Northern fulmar

Fulmars *(Fulmarus glacialis)* breed in Alaska from the Bering Sea to the Gulf of Alaska (USFWS 1999) and were counted at only one location in 1998; at Chowiet, in the Semidi Islands Group. Numbers there were lower than in previous years. This count does not necessarily mean populations are declining. Conditions for breeding at this colony in 1998 were poor (suggested by low reproductive rates of birds that did attend the colony) and possibly a smaller proportion of the breeders that normally would have been associated with this colony attended the cliffs. Populations had been increasing in the Semidis prior to the 1998 count (Byrd et. al 1999) and populations in the Bering Sea have increased gradually over the past two decades (Byrd and Dragoo 1997, Byrd et al. 1998).

### Storm-petrels

Two species of storm-petrels breed in Alaska: Leach's storm-petrel *(Oceanodroma leucorrhoa)* and the fork-tailed storm-petrel *(O. furcata)*. Both breed on islands from the western Aleutian Islands (AI) through the GOA, but not farther north (USFWS 1999). Populations are increasing in the southwest and southeast Bering Sea, and in southeast Alaska (Table 3) (Byrd et al. 1999).

### Albatrosses

The three North Pacific albatrosses are Laysan's *(Phoebastria immutabilis),* black-footed *(P. nigripes),* and short-tailed *(P. albatrus).* All three breed in the subtropics during winter: Laysan's and black-footed albatross breed in Hawaii and short-tailed albatross breed in Japan. Albatrosses spend the summer (approximately May through September) in Alaskan waters, although some nonbreeding birds may be encountered at any time. Laysan albatrosses are most abundant in the western Aleutian Islands, black-footed albatross are most abundant in the Gulf of Alaska. The breeding populations of Laysan's and black-footed albatrosses appear stable overall, based on monitoring in Hawaii, although the black-footed albatross declined at one major colony in the decade preceding 1995[1]. Trends in the nonbreeding part of the population (primarily subadults) are unknown. This is a problem for management of all seabird species, but it is especially serious for albatrosses, because one-half the population is nonbreeding.

The short-tailed albatross is seriously endangered. Its population was drastically reduced early in the century by commercial harvest (Hasegawa and DeGange 1982) and now numbers only 450 breeding birds; the total population is approximately 1200. The short-tailed albatross population is increasing, but it is still extremely vulnerable because of its small size and the fact that it breeds on only two islands[2].

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[1] E. Flint, U.S. Fish and Wildlife Service, Hawaii and Pacific Islands National Wildlife Refuge Complex, P.O. Box 50167, Honolulu, Hawaii 96850, unpublished data.

[2] H. Hasegawa, Biology Department, Toho University, Miyama, Funabashi, Chiba, 274 Japan; unpublished data.

**Shearwaters**
Short-tailed *(Puffinus tenuirostris)* and sooty *(P. griseus)* shearwaters breed in the subantarctic and visit Alaskan waters from May through September. Sooty shearwaters range primarily south of the Aleutian Islands and in the Gulf of Alaska, and short-tailed shearwaters are found in the Bering and Chukchi Seas (Gould et al. 1982, Hunt et al. 1981a). The population of short-tailed shearwaters (Table 2) is thought to be stable, based on monitoring in Australia (Skira et al. 1985). The populations of these two species in Alaskan waters in summer are almost as large as those of all other seabirds combined.

**Cormorants**
Four species of cormorants breed in Alaska. The pelagic cormorant *(Phalacrocorax pelagicus)* breeds on all coasts of Alaska, the red-faced cormorant *(P. urile)* west of Prince William Sound, and the double-crested cormorant *(P. auritus)* in the Aleutian Islands and GOA. Brandt's cormorant (*P. penicillatus)* primarily breeds south of Alaska but has a small colony in southeastern Alaska (USFWS 1999). Cormorant populations are difficult to monitor because birds move among colonies frequently. Pelagic cormorant numbers are stable or increasing at Cape Peirce in Bristol Bay, the western Aleutian Islands, and southeast Alaska, but are declining at other sites in the Aleutian Islands and at Chiniak Bay on Kodiak Island. Red-faced cormorants are stable in the southwest Bering Sea but are declining in the southeast Bering Sea and on Kodiak Island (Table 3) (Byrd et al. 1999).

**Jaegers**
The three species of jaegers; long-tailed jaeger (*Stercorarius longicaudus),* parasitic jaeger *(S. parasiticus),* and pomarine jaeger *(S. pomarinus),* forage on shore during the summer and are primarily present in Alaskan marine waters during their spring and fall migrations. They winter in the Southern Hemisphere. Population trends are unknown.

**Gulls**
Six species of gulls are common in Alaska. Two large species are common at sea in all seasons: the glaucous *(Larus hyperboreus)* and glaucous-winged *(L. glaucescens)* gulls. Glaucous gulls breed from Bristol Bay northwards, and glaucous-winged gulls breed from the central Bering Sea southeastwards. Herring gulls *(L. argentatus)* are also present locally near the Bering Straits and in the GOA. The principal small gulls in Alaskan waters are the mew gull *(L. canus)* found south of the Bering Strait, and Sabine's gull *(Xema sabini)* from Bristol Bay northwards (USFWS 1999). Glaucous-winged gulls are monitored in some areas; they are stable in the Aleutian Islands, northern GOA, and southeastern Alaska (Table 3) (Byrd et al. 1999).

**Kittiwakes**
The black-legged kittiwake *(Rissa tridactyla)* breeds throughout Alaska except for the southeast. Red-legged kittiwakes *(R. brevirostris)* are restricted to 4 colonies in the BSAI (USFWS 1999).

Kittiwake population trends differ among regions of the state. Populations of both species declined steeply on the Pribilof Islands after 1976 (the year when monitoring began); red-legged kittiwakes declined to approximately half their original numbers. Both species are now stable or increasing slightly (Byrd and Dragoo 1997). In contrast, both species have increased steadily in the western Aleutian Islands until the present. Black-legged kittiwakes are increasing in Prince William Sound, stable or increasing in the northern Bering Sea/Chukchi Seas, are stable in the southeast and southwest Bering Sea, and parts of the northern GOA; they are declining in Cook Inlet, and the Semidi Islands (Table 3) (Byrd et al. 1999). Declines and population shifts have been ascribed to lack of sufficient food during the breeding season (Springer et al. 1986, Suryan et al. 1998b). The red-legged kittiwake is a Species of Management Concern for the U.S. Fish and Wildlife Service, because 80% of its worldwide population nests in only one colony on St. George Island in the Bering Sea, and because its recent severe decline has not been explained (USFWS 1995).

**Terns**
Arctic *(Sterna paradisaea)* and Aleutian *(S. aleutica)* terns breed in most marine regions of Alaska (USFWS 1999). The Arctic tern migrates to the subantarctic for the winter; the wintering grounds of the Aleutian tern are at sea, but the location is unknown. Populations are not monitored in Alaska.

**Murres**
Common murres *(Uria aalge)* breed in all marine regions of Alaska; thick-billed murres (*U. lomvia) are* found primarily in the Aleutian Islands, Bering Sea islands, and north of the Bering Strait (USFWS 1999). Birds from colonies north of the Bering Strait winter in the central Bering Sea (Hatch et al. 1996, Shuntov 1993).

Murre population trends differ among regions. Both species are monitored together in some areas. Common murres are stable or increasing in the northern Bering/Chukchi Seas, southeast Bering Sea (mid-Aleutian Islands), southwest Bering Sea, most locations in the northern GOA, and in southeast Alaska; declines have continued at Duck Island in Cook Inlet and at Cape Peirce in Bristol Bay (Table 3) (Byrd et al. 1999). Thick-billed murres have increased north of the Bering Strait, at the Semidi Islands in the northern Gulf of Alaska, and in the western Aleutian Islands. (Table 3) (Byrd et al. 1999).

**Guillemots**
The pigeon guillemot *(Cepphus columba)* breeds in most marine areas of Alaska south of the Bering Strait. The black guillemot *(C. grylle)* breeds north of the Bering Strait (USFWS 1999) and winters in the Bering Sea. Populations are monitored only for pigeon guillemots in the northern GOA, where they have declined over the past two decades, possibly due to reductions in prey availability (Agler et al. In press), Hayes and Kuletz 1997).

**Auklets**
The abundance and diversity of small auks is much higher in the Bering Sea than elsewhere in the world, owing to the large-scale advection of oceanic zooplankton onto the shelf in areas such as the Aleutian passes and Bering Strait (Springer and Roseneau 1985). Least *(Aethia pusilla),* crested *(A. cristatella),* and parakeet *(A. psittacula)* auklets

breed from the Bering Strait to the Aleutian Islands and western GOA. Cassin's auklets *(Ptychoramphus aleutica)* breed in the Aleutian Islands and western Gulf of Alaska; whiskered auklets *(A. pygmaea)* breed in the Aleutian Islands only. Least and crested auklets are the most abundant seabirds in the state (USFWS 1999). Population trends of auklets are poorly known at present because monitoring of their underground nests is difficult. Currently there is no known method of monitoring parakeet or whiskered auklets. Least auklets are declining in the central Aleutian Islands (Table 3). In 1998, crested auklets were monitored only at Kasatochi in the Aleutian Islands, where there has been no obvious population trend since the early 1990s (Table 3). It has been suggested that auklet trends are due in part to food-chain changes following reductions in plankton-eating whales or other predators (Springer 1991, Springer 1992, Springer et al. 1993).

**Murrelets**

Kittlitz's murrelets *(Brachyramphus brevirostris)* breed from north of the Bering Strait to southeastern Alaska; marbled *(B. marmoratus)* and ancient *(Synthliboramphus antiquus)* murrelets breed from the Aleutian Islands eastwards. Trends are known only for Prince William Sound. Kittlitz's murrelets have declined there during the 1990s; marbled murrelets remained stable during this decade, after a decline in the 1980s (Agler et al. (In press), Agler and Kendall 1997, Klosiewski and Laing 1994). Marbled and Kittlitz's murrelets are Species of Management Concern of the U.S. Fish and Wildlife Service due to population declines (USFWS 1995).

**Puffins**

Horned *(Fratercula corniculata)* and tufted *(F. cirrhata)* puffins breed throughout marine areas of Alaska. The rhinoceros auklet *(Cerorhinca monocerta;* a misnamed puffin) breeds in the Aleutian Islands and GOA (USFWS 1999). Most winter south of the state over the deep ocean. Tufted puffin populations have increased slightly in the southeast Bering Sea, and southeastern Alaska; they have been stable in the northern GOA during the 1990s (Table 3) (Byrd and Dragoo 1997, Byrd et al. 1999). Trends of horned puffins and rhinoceros auklets are unknown.

FACTORS THAT INFLUENCE THE AVAILABILITY OF FOOD TO SEABIRDS

Successful foraging by seabirds depends on adequate stocks of prey, and foraging also is limited by conditions that make prey available to the birds. All seabirds depend on specific oceanographic processes to concentrate their prey at the necessary place, time, and position in the water column. Partial information on the factors that influence prey availability near seabird colonies has been gained through recent research. These factors include oceanographic characteristics of the environment and the ecology and food-web relationships of forage species. The value of prey also depends on its nutritive content.

Much more information is needed on factors that limit seabird prey availability. Data are lacking for some species groups, for many areas of Alaska, and for almost all species in winter. Most critical is the absolute lack of information on how events beyond a seabird's foraging range may influence the availability of its prey. Such events may include environmental changes, fluctuations in region-wide stocks of forage and non-forage species, and commercial harvests.

Factors that limit the availability of food to seabirds have been investigated primarily during the past 10 years, and directed research is recent. Intensive work has taken place in the southeastern Bering Sea (short-tailed shearwaters, kittiwakes, and murres) (Schneider et al. 1990, Springer et al. 1986)); northern Bering and Chukchi Seas (murres, kittiwakes, and auklets) (Springer et al. 1987)); the western AI (auklets) (Hunt et al. 1993)); and Cook Inlet and Prince William Sound (murres, kittiwakes, pigeon guillemots, and tufted puffins) (Hayes and Kuletz 1997, Kuletz 1983, Ostrand et al. 1998, Piatt et al. 1998, Suryan et al. 1998a, Suryan et al. 1998b)). In each place, only part of the factors affecting seabird forage availability have been explored. All studies were restricted to summer. Limiting factors in areas that have not yet been studied are likely to differ in type and importance, and they may be completely different in winter, when forage species and locations are different.

**Oceanographic factors**

Physical characteristics of the water column and ice cover concentrate the prey of seabirds and make it available to each species. Bird species differ in their requirements and preferred habitats, depending on the birds' size, shape, and foraging method (surface-feeding or diving, nearshore or offshore, etc.). The oceanographic phenomena that influence seabird foraging habitat primarily are on the scale of hundreds of meters to hundreds of kilometers (Hunt and Schneider 1987). Different combinations of factors limit the availability of prey for different seabird species. Factors also differ among areas of the state (Byrd et al. 1997). The influence of these factors, (i.e., fronts and upwellings, stratification of the water column, currents, changing ice conditions, temperatures, eddies, and regime shifts) is unknown.

**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 1 or 2 are typically available to seabirds in a given area (Springer 1991): sand lance in most of the Bering Sea (Springer 1991, Springer et al. 1996), pollock and formerly capelin in the Pribilof Islands (Decker 1995, Hunt et al. 1981, Springer et al. 1986), capelin and pollock on the Alaska Peninsula (Hatch and Sanger 1992, Springer 1991), and capelin, sand lance, and herring in the northern Gulf of Alaska (Hatch and Sanger 1992, Piatt et al. 1998, Suryan et al. 1998b). The availability of forage species often varies within small areas, such as Prince William Sound, Cook Inlet, and island groups in the Aleutian Islands (Byrd et al. 1997, Piatt et al. 1998, Suryan et al. 1998b). The preferred forage species in each area usually is essential for successful seabird reproduction (Baird 1990, Golet 1998, Piatt et al. 1998, Piatt and Anderson 1996, Springer et al. 1987, Springer et al. 1986, Suryan et al. 1998a, Suryan et al. 1998b).

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.

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 et al. 1998a). For instance, breeding success of black-legged kittiwakes in Cook Inlet varied with local stocks of capelin (Piatt et al. 1998), and success of black-legged kittiwakes in Prince William Sound was correlated with overall density of forage species within the birds' foraging range (Irons et al. 1986). No information is available for most seabird species or areas on the relationship between forage stocks and breeding success.

Presence of forage species in a bird's feeding range is not enough. Schools or swarms must be of sufficient size and density for seabirds to exploit them efficiently (Hunt et al. 1990, Piatt and Roseneau 1998). Schools also must be available in the correct habitat for each seabird species, including at a depth which the seabird can reach. No information exists on the influence of stock size on the availability of forage schools to seabirds.

Stocks of many forage species may expand and contract with overall abundance. Colonies near the periphery 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. Data are totally lacking on the relationships of overall stock sizes to forage availability in local areas.

Movements and schooling behavior of forage species often determine whether the species will be available at a suitable place and time suitable for seabird foraging. Densities of foraging seabirds are often correlated with densities of their prey (Hunt 1990). 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 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 (Blackburn and Anderson 1997, Hunt et al. 1990, Piatt and Roseneau 1998). Breeding success and population trends of kittiwakes in the northern Bering Sea and of pigeon guillemots in Prince William Sound are correlated with years when schools of sand lance are available (Hayes and Kuletz 1997, Springer et al. 1987). Schools must be at or near the surface in order for kittiwakes and terns to reach them; these birds are usually observed feeding on schools of sand lance in years when reproductive success is high (Baird 1990). Factors that influence movements of forage species are poorly known.

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. No information is available on the magnitude or direction of these links, nor even on the existence of some hypothetical links.

The energy content of prey has recently been found to influence its value to birds. 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 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 et al. 1998, Roby et al. 1998).

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 Pribilofs, where capelin and sand lance are less available (Hunt et al. 1981b, Schneider and Hunt 1984) and they are able to raise chicks. However, breeding success of kittiwakes is relatively low in these colonies compared with other parts of Alaska (Hatch et al. 1993). 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.

Predation pressure of seabirds on forage stocks has been estimated for a few commercial fish species. The fraction of total exploitable stocks in the EBS that are consumed by seabirds has been estimated at 3% for pollock and less than 1% for herring (Livingston 1993), which is similar to an estimate of 4% 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 because the birds are concentrated there during summer (Springer et al. 1986). Fifteen to 80% of the biomass of juvenile forage fish may be removed by birds each year near breeding colonies (Furness 1978, Logerwell and Hargreaves 1997, Springer et al. 1986, Wiens and Scott 1975). 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. The availability of forage fish to seabirds also depend on the rate of fish immigration, and on factors that limit the ability of birds to capture the fish present in the area.

Estimates of predation pressure by seabirds on forage stocks are based on incomplete data. Almost all information on diet, consumption, and energetics of Alaskan seabirds has been obtained during the breeding season (Tables 1 and 2). Broad assumptions must be made about the other 9 months of the year and about the nonbreeding component of seabird populations (roughly 30-50% 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 (Croxal 1987). Diets, feeding habitats, energy requirements, and distributions outside the breeding season have been studied very little for most seabird species[3]. Predation pressure of birds on forage fish stocks is unknown for most stocks and areas. Predation pressure on noncommercial forage species cannot be estimated at all, because no information exists on stock sizes for these species.

Almost a complete lack of information exists on region-wide conditions that may influence local prey availability. Climate and food-web changes can occur over the entire Bering Sea or GOA, but information to determine how these changes affect local prey availability for seabirds is unavailable.

SEABIRD RESPONSES TO CHANGES IN FORAGE AVAILABILITY

The availability of food resources to seabirds depends not only on the forage species and their physical environment, but also on the response of each bird species to prey availability. Bird species differ in their foraging adaptations, the 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 Gulf of Alaska. Information is needed on limiting prey densities for most Alaskan species (the prey densities at which breeding success is insufficient to maintain populations).

**Foraging behavior and flexibility**

Foraging behavior and flexibility limit each species' responses to changing conditions. In general, diets consist of fish or squid 5-15cm long or large zooplankton (Tables 1 and 2).

[3]P. J. Gould, U.S. Geological Survey, Biological Resource Division, 101 I E. Tudor Rd, Anchorage, AK 99503, personal communication.

Diets and foraging ranges are most restricted during the breeding season, when high-energy food must be delivered efficiently to nestlings. 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 et al. 1999).

Seabirds differ 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 times when it is too deep for surface-feeders (Baird 1990). 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 marine mammals**

Seabird interactions with each other and marine mammals influence their populations. 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 et al. 1986). Seabirds that feed in flocks may benefit by interactions within and among species; surface-feeding birds may attract others to aggregations of prey, while diving birds appear to drive subsurface prey within reach of surface-feeders (Hatch 1993). Bottom-feeding marine mammals such as gray whales also increase the availability of prey and detritus to surface-feeding birds (Hunt 1990).

<u>POPULATION RESPONSES OF SEABIRDS TO CHANGES IN FORAGE AVAILABILITY</u> Trends in seabird populations are ultimately the result of forage availability and food-web changes. Depending on their 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 upon fluctuations in forage availability. Trends are likely to differ among seabird species in the same area and time period, because "forage availability" means different things to each species.

The responses of seabird populations to forage supplies 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. Over a range of 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 does not increase breeding success or population growth further (Cairns 1990).

The relationships between forage abundance and seabird population trends differ among species. Some species can maintain themselves while foraging on relatively low prey densities, while others in the same place require much higher densities. Examples include: puffins exploiting lower densities of capelin than murres in Newfoundland (Piatt 1990), and preliminary data that suggest murres may be able to subsist on lower densities of sand lance in Cook Inlet than kittiwakes (Piatt et al. 1998).

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. Bycatch of seabirds in groundfish fisheries has been monitored by fishery observers since 1990. Since 1993, observers have been trained by USFWS and NMFS to identify birds to genus or species. Birds found in the observers' random samples of fishery hauls are reported on standard bycatch forms. In addition, short-tailed albatrosses are reported whenever they are caught or observed and bird strikes are reported on daily log sheets.

The presence of “free” food in the form of offal and bait attracts many birds to fishing operations. In the process of feeding, birds sometimes come into contact with fishing gear and are accidentally killed. For example, most birds taken during hook-and-line operations are attracted to the baited hooks when the gear is being set. These birds become hooked at the surface, and are then dragged underwater where they drown. The probability of a bird being caught is a function of many interrelated factors including: type of fishing operation and gear used; length of time fishing gear is at or near the surface of the water; behavior of the bird (feeding and foraging techniques); water and weather conditions (e.g., sea state); size of the bird; availability of food (including bait and offal); and physical condition of the bird (molt, migration, health). Almost any species which occurs in these waters is susceptible to interactions with fishing gear.

**Bycatch on longlines**

Based on fishery by-catch observer data, Stehn et al.[4] estimate that the total annual mortality of seabirds in the Alaskan hook-and-line groundfish fisheries was 14,000 birds between 1993 and 1997 ranging from 9,400 birds in 1993 to 20,200 birds in 1995. Approximately 83% of the take occurred in the BSAI region. Northern fulmars represented about 67% of the total bycatch of all bird species, gulls contributed 18%, while Laysan albatrosses accounted for 5 % and black-footed albatrosses were about 4 % of the total. Several short-tailed albatrosses were reported caught in the longline fishery since 1990: two in 1995, one in October 1996, and two in September 1998.

[4] R. A. Stehn, K.S. Rivera, and K. D. Wohl. (In review). Proceedings of an International Symposium of the Pacific Seabird Group. Seabird Bycatch: Trends, Roadblocks and Solutions. E. F. Melvin and J. Parrish (Eds.). Semi-ah-moo, Washington, 2/99.

Details of the 1998 incidents are reported in the 98-108 National Marine Fisheries Service (NMFS) Information Bulletin.

Measures to deter birds from approaching longline gear have been required for Alaskan groundfish fisheries since April 1997 [50 CFR 679.24(e); FR 62(32):23176-23084]. However, no information is available on the effectiveness of bycatch deterrent measures in Alaskan fisheries. As follow-up to a NMFS deterrent study plan (1998), research on the effectiveness of various deterrents began in 1999.

**Bycatch in trawls**
Trawls primarily catch seabirds that dive for their prey, probably 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 trawl gear is currently available for 1993 and 1995[5]. The principal bird species caught in trawls were northern fulmars, auks (primarily unidentified auklets or murrelets) and shearwaters. Small numbers of other species also were caught.

**Vessel strikes**
Striking of vessels by birds in flight is reported by fishery observers, but bird-strike data have not yet been analyzed statistically. Some birds that strike vessels fly away without injury, and 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. Species that commonly strike vessels include storm-petrels, auklets, and shearwaters[6]. Albatrosses have been observed striking the vertical cables from which sonar transducers of trawlers are suspended[7]. Almost no information is available on the problem of transducer cables.

PROCESSING WASTES AND DISCARDS
Fish deheading and processing provide food directly to a few seabird species whose foraging behavior includes scavenging on dead material. These species include northern fulmars, large gulls, black-footed albatrosses, and possibly black-legged kittiwakes (Furness and Ainley 1984, Gould et al. 1997, Patten and Patten 1982). Fulmars and albatrosses feed on wastes and discards at sea; gulls feed at sea, near shore, and on land.

Scavenging by gulls can influence population trends in either direction. Scavenged processing wastes and other artificial foods are not adequate foods for rearing chicks

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[5] S. Fitzgerald, National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115; unpublished data.

[6]Kent Wohl, U.S. Fish and Wildlife Service, Migratory Bird Management, 1011 E. Tudor Rd, Anchorage, AK 99503; unpublished data.

[7]Kent Wohl, U.S. Fish and Wildlife Service, Migratory Bird Management, 1011 E. Tudor Rd., Anchorage, AK 99503; unpublished data.

successfully (Baird and Gould 1986, Irons et al. 1986, Murphy et al. 1984, Sanger 1986). On the other hand, abundant scavenging during winter may increase gull populations because survival of immature birds is enhanced (Patten and Patten 1982). Larger gull numbers can reduce local populations of other birds through increased competition for nest sites and predation pressure on their young, although disagreement exists as to the magnitude of this problem (Spaans and Blokpoel 1991).

## EFFECTS OF VESSELS ON SEABIRDS

Fishing vessels can affect seabird populations whether or not the vessels are engaged in fishing or processing activities. Fishing vessels, like all other types of vessels, can influence seabird habitats. Two potential impacts are oil spills and introductions of rats onto seabird nesting islands.

### Oil spills

The threat of oil spills to seabirds is well-known and oil and fuel spills in the North Pacific have increased during the past two decades (Burger and Fry 1993). A dramatic accident like the *Exxon Valdez* oil spill may kill hundreds of thousands of seabirds (Piatt and Anderson 1996). However, much more common are chronic small spills of a few gallons caused by accidents during routine activities such as fuel transfer operations and bilge cleaning. Chronic spills may be a greater threat to seabirds than the occasional large spill (Burger and Fry 1993), especially in sheltered areas where both vessels and seabirds assemble in large numbers.

A large oil spill can reduce local populations of vulnerable species for several years. For instance, several diving seabirds were reduced significantly by the *Exxon Valdez* oil spill (Piatt and Ford 1996). Murre populations and its breeding success have taken several years to recover (Piatt and Anderson 1996, Roseneau et al. 1998).

### Rat introductions onto nesting islands

Rats *(Rattus norvegicus)* pose the greatest predator threat at present to Alaskan seabirds. Rats are voracious predators because they can burrow, enter crevices, and climb cliffs with great agility (Jones and Byrd 1979). They also can kill small adult birds (Bailey 1993).

Rats are not native to Alaska. They have become established on 22 Alaskan islands. Rats probably jumped or swam ashore at islands with ports; they also are prone to invade any island on which a vessel is wrecked (Bailey 1993, Brechbill 1977, Jones and Byrd 1979). The effects of rat invasions on local seabird populations are not known in Alaska, because no islands have been monitored before and after their arrival. However, for most islands in other parts of the world where rats have invaded, seabird populations have declined or gone extinct (Burger and Gochfeld 1994, Jones and Byrd 1979, Moors et al. 1992). It is not known what proportion of fishing vessels carry rats. The threat to seabird populations, therefore, cannot be quantified. However, rats are a major management concern and the USFWS in Alaska has an extensive program to reduce the threat of new rat invasions.

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

| | Population [1,2] | | |
|---|---|---|---|
| Species | BSAI | GOA | Diet [3,4] |
| 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,l |
| 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,P,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,l |
| Horned Puffin *(Fratercula corniculata)* | 500,000 | 1,500,000 | C,S,P,F,Q,Z,l |
| Total | 36,000,000 | 12,000,000 | |

[1] Source of population data for colonial seabirds that breed in coastal colonies: modified from USFWS 1999. Estimates are minimal, 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; 1, 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: reviewed in: USDC, National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS). 1998. "Groundfish Total Allowable Catch Specifications and Prohibited Species Catch Limits Under the Authority of the Fishery Management Plans for the Groundfish Fishery of the Bering Sea and Aleutian Islands Area and Groundfish of the Gulf of Alaska". Final Supplemental Environmental Impact Statement. Juneau, AK. pp.162-169.

[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/Aleutian Islands and Gulf of Alaska regions.

| | Population[2] | | |
|---|---|---|---|
| Species | BSAI | GOA | Diet[3,4] |
| Short-tailed Albatross *(Phoebastria albatrus)* | Rare | Rare | Q,F |
| Black-footed Albatross *(Phoebastria nigripes)* | Common | Common | Q,M,F,I,D |
| Laysan Albatross *(Phoebastria 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,l |
| 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 1999. 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 $\geq 10^6$; 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; 1, 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: reviewed in: USDC, National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS). 1998. "Groundfish Total Allowable Catch Specifications and Prohibited Species Catch Limits Under the Authority of the Fishery Management Plans for the Groundfish Fishery of the Bering Sea and Aleutian Islands Area and Groundfish of the Gulf of Alaska". Final Supplemental Environmental Impact Statement. Juneau, AK. pp.162-169.

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

Table 3. Seabird population trends compared within regions.

| | | Storm-petrel | Cormorant | Gull | Kittiwake | Murre | Puffin |
|---|---|---|---|---|---|---|---|
| **Region** | **Site** | FTSP/LHSP | PECO/RFC | GWGU | BLKI/RLKI | COMU/TBM | TUPU |
| N. Bering/Chukchi Sea | | | | | | | |
| | C. Lisburne | | | | =/* | +[a] | |
| | Bluff | | | | +/* | =/* | |
| | Nunivak | | | | =/* | =/* | |
| SE Bering Sea | | | | | | | |
| | C. Peirce | | +/* | | =/* | --/* | |
| | Aiktak | +[a] | --[a] | = | | =[a] | = |
| SW Bering Sea | | | | | | | |
| | Buldir | | | | =/+ | */+ | |
| | Kasatochi | | =[a] | = | | =/* | |
| | Koniuji | | | | =/+ | +[a] | |
| | Ulak | +[a] | | | | +[a] | |
| N. Gulf of Alaska | | | | | | | |
| | Semidis | | | | --/* | +[a] | |
| | Chiniak Bay | | --/-- | | =/* | | |
| | Barrens | | | = | =/* | =/* | |
| | Gull | | | | =/* | +/* | |
| | Duck | | | | --/* | --/* | |
| | Chiswells | | | | =/* | | |
| | P. William | | | | +/* | | |
| Southeast Alaska | | | | | | | |
| | St. Lazaria | +[a] | +/* | = | | =[a] | = |

Codes: Species are only reported if poulations were counted at > 1 site in the region in 1998.

"--" indicates negative population trend for the site or region.

"=" indicates no discernable trend.

"+" indicates positive population trend.

"*" indicates the species (in particular species pairs) was not present or was not monitored in 1998.

Source: Byrd, G.V. et al. 1999. Breeding status and population trends of seabirds in Alaska in 1998. U.S. Fish and Wildl. Serv. Rept. AMNWR 99/02.

## *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

**Historical Accounts of Ecosystem Change in the Eastern Aleutians**
Contributed by Glenn Merrill

There are limited historical accounts of natural variability in the Eastern Aleutians. One of the earliest and most complete reports is *Notes from the Unalashka District* by Russian Orthodox priest Ivan Veniaminov. Veniaminov lived and traveled extensively throughout the Aleutians from 1824 through the 1850's. He made personal observations and recorded local Aleut accounts of the local environment. Although some of these accounts are not verifiable, Veniaminov provides numerous examples, both observed and anecdotal, of changes in species abundance.

Veniaminov recorded significant decreases in cod, salmon, and other marine fish abundance beginning in the mid 1820's lasting through the mid 1830's. Fluctuations in cod populations are reflected in the Eastern Aleut name for the fish, which translates as "the fish that stops" (Black, 1993). Veniaminov also recorded decreases in sea otter, sea lion, and seal populations during the mid 1820's. Traditionally, crab and shrimp were not part of the Aleut diet and good information on their abundance is difficult to obtain from historical observations.

Cod stations were established in the late 1880's throughout the Aleutians to exploit the abundant resource—an indication that the cod population increased substanitally since Veniaminov's observations in the 1830's (Alaska Geographic, 1980). Cod stocks decreased in the mid 1910's and many of the cod stations closed.

More recently, older residents of Sand Point and King Cove noted sudden decreases in marine fish and mammal species in the late 1940's and mid-1950's. The patterns of decreased population in the cod and salmon are similar to those observed by Veniaminov in the early 1800's. These observations seem to reflect more recent scientific findings linking fish abundance to climatological conditions (e.g., Anderson and Piatt, 1999).

Quotes from *Notes from the Unalashka District*

Sea Otters:

"In the time of the private companies [early 1800's], for instance, over a thousand sea otters were taken in this district but now [mid-late 1830's] from 70 to 150 (in the years 1832 and 1833, 175 and 200 were taken, something that has not happened for a long time); and there was a time (1826) when, in the entire district, the catch was only 15…. [p. 39]"

Caribou:

On Unga Island, anywhere from 30 to 200 head of caribou were taken at a time by the drive method; nowadays in the course of a whole year half a score may be obtained.  Other animals have also decreased to a larger or greater extent, such as foxes, sea lions, seals, wolves, and others…. [p. 39]"

Marine Fish:

"In the principal village of Unalashka, for instance, in spring they caught cod from baidaras [traditional kayaks], and caught up to several hundred fish (every day).  But in the years 1825 and 1826 there was not a single cod fish.  At the same time it was noticed that there was a decrease of other fish also.  In Makushin village [Unalaska Island], for instance, the seasonal migrating fish [e.g., salmon, dolly varden] used to have been taken by the hundreds of thousands.  Now [mid-late 1830's] they scarcely catch twenty thousands.  The same situation obtains everywhere…. [p. 39]"

Unalashka – Marine Mammals

"Formerly…animals were numerous—seals, sea otters, fur seals, and sea lions.  There are now [mid-late 1830's] so few that barely 100 are taken.  Sea otters are found only on the South side, close to shore, arriving from the sea in very small numbers (quantity); and the sea lions are found in even smaller numbers, and only in one locality, on the South side, not far from Usov Bay…. The fur seals used to come into the local channels until about the time of the discovery of the Pribylov Islands [1781], or somewhat later.  Now not a single one is to be found….  [p. 89]

Alaska Peninsula (Near Port Moller) -- Foxes

"But there have been instances, as in 1827, when there was an extraordinary number of foxes, a (phenomenon) called locally a *prival*, so that a huner, ordinarily obtaining 3 to 15 foxes, in such season procures from 50 to 60 of them.  But such *privaly* are very rare….  [p. 118]"

**Traditional Knowledge and Wisdom**
Contributions of Alaskan Native Community members summarized in the WisdomKeeper's Conference Report

In order to promote and organize active Native participation in the collective decision-making involving the Bering Sea ecosystem, the Bering Sea Coalition and the Whirling Rainbow Center held the first International Indigenous People's Summit Conference on the Bering Sea, March 16-20, 1999. This conference, entitled "WisdomKeepers of the North: Vision, Healing and Stewardship for the Bering Sea" (Bering Sea Coalition, 1999), was intended to:

- Be rooted in process-oriented Alaska native traditional gathering models rather than the goal-oriented Western convention model,
- Provide coastal communities with a widely representative forum to review the current research on the Bering Sea ecosystem and its components,
- Consider models of native environmental management and community development to strengthen their collective stewardship role,
- Create an opportunity for the Traditional Knowledge and Wisdom of Bering Sea native peoples to be heard beyond the confines of the villages,
- Promote the utilization of Traditional Knowledge and Wisdom of indigenous peoples in scientific, resource management and responsible use policies affecting the Bering Sea.

Talking circles at the meeting elicited many observations on the state of the Bering Sea by Alaska natives and others. Here is a summary of some of those observations:

- The cyclical nature of things was pointed out.
- The ice on the Bering Sea used to be three to four (feet) thick; now, it is only six to eight inches thick.
- The weather is changing and is much warmer than in the past.
- The number of fish has decreased.
- In one area, it was noted beaver are moving much further up the streams and constructing dams and blocking off movement of fish.
- An increased presence of worms in king salmon was noted.
- Dumping of bycatch into the sea is a shocking abuse of cultural mores. We never waste anything we take for food and we always share. When you hunt, only get what you need to eat.
- Herbs and wild celery are brown from pollution in the atmosphere.
- Salmon have spots on them and their flesh is different.
- Our fish are coming, but they are not as good-looking as they used to be. Our seals are thinner and the fish have gashes on them from the trawl nets.
- The bird eggs are fragile now. You touch them and they break. Something is happening to them that is not good, and we need help to find out what it is.
- Sheefish is a beautiful fish and that's being ruined now too. Why are they less today?
- Cold weather has something to do with the survival of some sea mammals. Now the tides are changing because the climate is warming up, and this has something to do with the animal declines because the ice is thinning. The animals need thick ice.
- Sports fishermen and trawlers throw fish away that they catch. This wanton use of our animals and fish is part of the reason for their declines.

- I eat the sea lion but we can’t eat its liver because it has mercury.
- We are taking too much from Mother Earth and the animals without giving anything back. The greed is ruining us.
- Changes have occurred in the whale population/migration and appearance.

Six WorkTeams were formed at the conference to promote discussions and develop recommendations for the future. These teams were:

1. Traditional Knowledge and Wisdom and Local Observations
2. Global Warming, Contaminants, Human Health in the Bering Sea
3. Transboundary Issues and Perspectives: Russian Science & Traditional Knowledge and Wisdom and New Initiatives
4. Pockets of Hope: Solutions From Around the World
5. Personal Healing, Community Wellness, Health and Stewardship: How and Why they are Connected
6. Partnerships and Alliances with and for Bering Sea Peoples

Over a hundred recommendations were made and many relate to improving communication among native communities and between native communities and scientists and agencies. Some projects along these lines are progressing. One very advanced example of this type of integration of Native knowledge is the “Traditional Knowledge and Radionuclides Project,” (http://www.alaskool.org/knowledge/db/). This project is adding to its database on contaminant measures, harvests and consumption of Native foods, nutritional values of Natie foods, cultural values associated with Native harvest, and Native knowledge about environmental change on a daily basis. This project has developed a regional meeting system, in which meetings are conducted according to Native ways of knowing and Native ways of building consensus in order to gather and share information. The process also includes scientists and collectively identifying points of shared knowledge and priorities and points where continuing differences in perspecties are important to respect.

**Local Knowledge of Changes**
Contributed by Ivan Vining

This year there were two observations provided from the fishing fleet. The first was from Charles Bronson of the F/V Great Pacific, out of Dutch Harbor. In February of 1999, he and his observer sighted Pacific white-sided dolphins (*Lagenorhyncus obliquidens*) twice in Unalaska Bay between Constantine Bay and Priest Rock. There were an estimated 100-150 dolphins each time. Similar to most of last years sightings, this observation was not outside the animals known range, however the observation did occur in February, which is not the normal time Pacific white-sided dolphins are spotted in this area (usually the summer months). Also, according to Mr. Bronson, he has never seen Pacific white-sided dolphins inside Unalaska Bay, though he has seen them several times in Unimak Pass.

The other observation was from Sitka Sound by Ben Mitchell of the F/V AK4079F from the summer of 1998. He reported a complete absence of Pacific herring (*Clupea harengus*) in the inner west Sitka Sound. He also reports other forage fish seem to be lacking in this area. He also observed that only a few king salmon (*Oncorhynchus tshawytscha*) and coho salmon (*Oncorhynchus kisutch*) migrate through this area of recent and the few that are caught in the area have empty stomachs. He further notes that this phenomenon is not unique to the summer of 1998, and the forage fish have been declining since 1992 or 1993.

## Spatial and temporal patterns in the Gulf of Alaska groundfish community in relation to the environment

Contributed by Franz Mueter

This is a report on the spatial and temporal trends in the Gulf of Alaska, based on the triennial NMFS surveys (1984-1996) and the ADF&G shrimp trawl survey (1976-1995) (Mueter, 1999). Unfortunately, the first triennial surveys used a number of different gear types with different selectivities, making comparisons somewhat problematic. Trends in species richness (# of species per haul) and species diversity (Shannon-Wiener index) (Figure 1) were developed along with trends in total biomass and indices of species composition. After adjusting for the effects of other important covariates (depth, location, date of sampling, area swept, gear type) there was a significant difference in these indices among years. However, these differences may be due to problems with species identification (in the early years) and differences in the time of sampling and the average tow length (in 1996). Although every effort was made to include only taxa that were consistently identified to the same level, many of the uncommon species were not always correctly identified and were often lumped in with other species/taxa in the early surveys. Hence, a lower species richness and diversity was seen in 1984. Species richness and diversity apparently also decreased from 1993 to 1996, but this may be a spurious trend either because (1) the 1996 survey was conducted much earlier in the year and (2) tow times were reduced in 1996 , thus area swept was generally much smaller. Both of these trends are confounded with year and thus it is difficult to tell whether the lower species richness and diversity in 1996 is due to the time of sampling or shorter tows, or whether it reflects a true decrease in diversity.

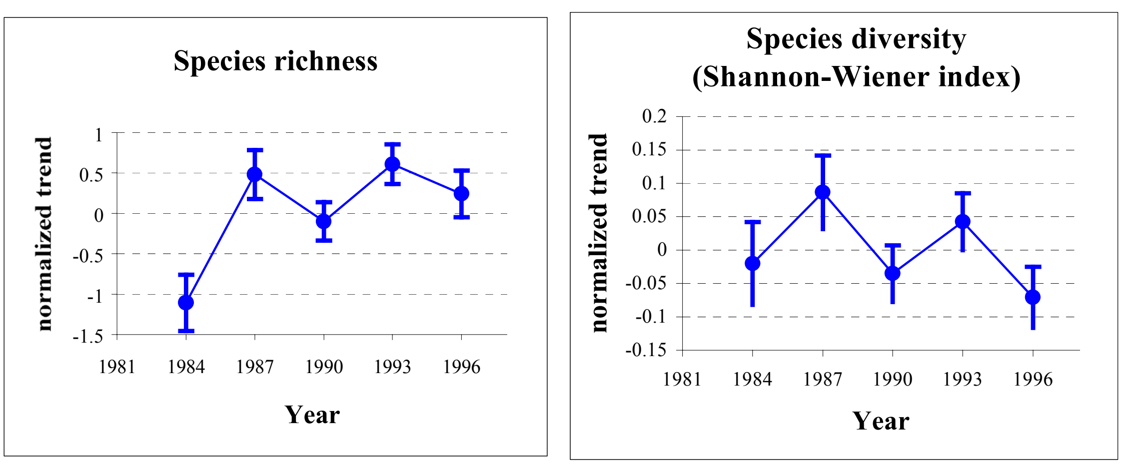



Figure 1.—Estimated trends in species richness and diversity on the Gulf of Alaska shelf and upper slope, 1984-1996.

Trends in total biomass (CPUE) from the NMFS triennial surveys and two indices of species composition are summarized below:

**Total groundfish biomass**

Two indices of trends in the combined CPUE of all groundfish species are included:

The first (Fig. 2) is an estimate of the combined gulf-wide average CPUE for 72 groundfish taxa (excluding invertebrates and strictly pelagic species). CPUEs from Japanese trawl gear used in 1984 and 1987 were adjusted to the US standard trawl gear using fishing power coefficients for the most abundant species (from Tables 28 and 31 in Munro and Hoff 1995). Following standard NMFS methodology, estimated CPUEs were averaged by stratum, the averages were weighted by stratum area, and were combined to obtain gulf-wide averages. The time trend indicates a significant increase in total CPUE between 1984 and 1996. The combined CPUE of all groundfish species included in the analysis increased from a gulf-wide average of 14,786 $kg/km^2$ in 1984 to 20,600 $kg/km^2$ in 1996, representing an increase of 40%. (The trends by species are summarized in Table 1).

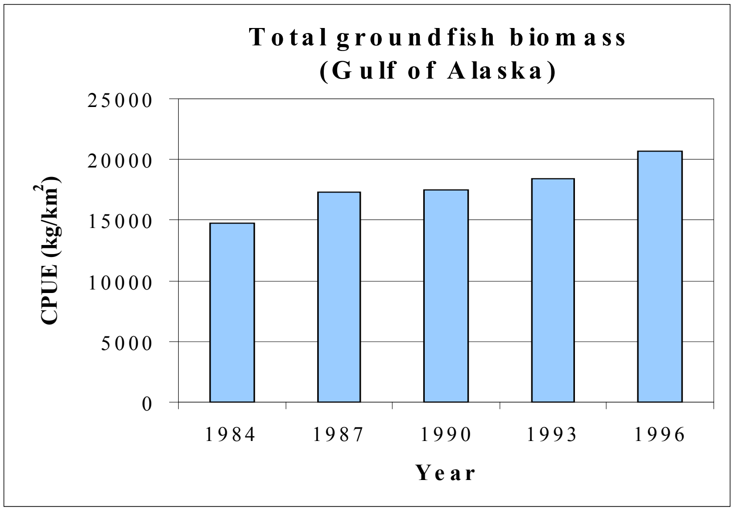



Figure 2: Estimated trend in the combined CPUE of 72 groundfish taxa from 1984 - 1996, averaged over Gulf of Alaska shelf and upper slope to 500 m.

The second index (Fig. 3) is based on a generalized additive model with log(CPUE) as dependent variable and depth, a location variable (alongshore distance), Julian day, gear, and year as independent variables. The trend shown in Figure 2 is the normalized trend over time after adjusting for the effects of depth, location, time of sampling and gear type. The trend is very similar to that in Fig. 2 and shows a significant increase from 1984 to 1996, based on the approximate 95% confidence intervals. The increase appears to be leveling off and the change from 1993 to 1996 was not significant.

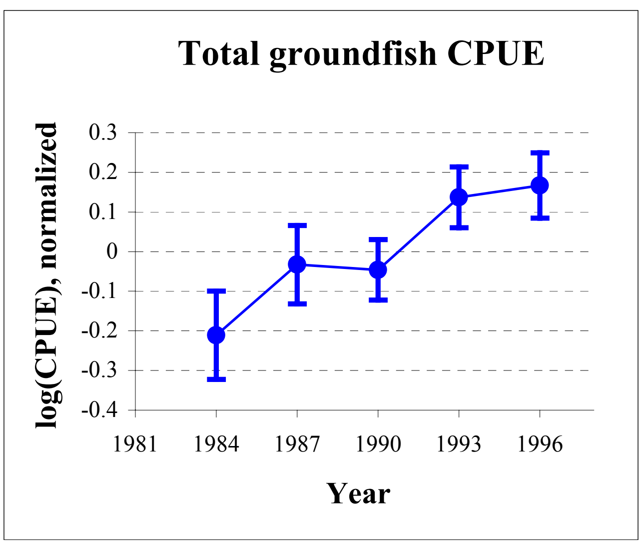



Figure 3: Trend in the combined log-transformed CPUE of 72 groundfish taxa from 1984 to 1996 with approximate 95% confidence intervals.

**Index of species composition for the nearshore groundfish community around Kodiak Island.**

This index (Fig. 4) is based on ADF&G shrimp trawl surveys conducted in seven areas around Kodiak Island between 1976 and 1995 (Marmot Bay, Marmot Island, Chiniak Bay, Ugak Bay, Kiliuda Bay, Twoheaded Gully, and Alitak Bay), at depths ranging from 10 to 110 m. The index represents the first ordination axis from an ordination (nonmetric multi-dimensional scaling of pairwise Bray-Curtis dissimilarities) of a site-by-taxon matrix of abundances ($CPUE^{0.25}$ in kg $km^{-2}$ for 32 taxa from 1035 hauls). The index accounts for approximately 30% of the overall variation in species composition and shows a strong trend over time with a sharp drop off in the early 1980s. High values of the index reflect high abundances of shrimp and several small forage fishes (capelin, Pacific herring, Pacific sandfish) and low abundances of two gadid (Pacific cod, walleye pollock) and two flatfish species (arrowtooth flounder, flathead sole), low values reflect low abundances of shrimp and forage fishes and high abundances of gadids and flatfishes.

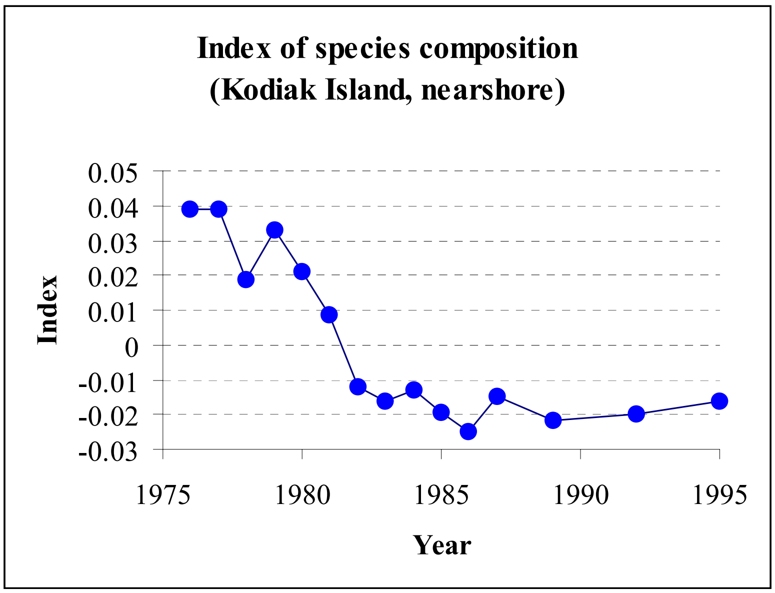



Figure 4: Trend in index of species composition for nearshore groundfish community around Kodiak Island.

**Index of species composition for the groundfish community on Gulf of Alaska shelf and upper slope.**

This index is based on the estimated CPUE of 72 groundfish taxa from NMFS triennial groundfish surveys. CPUEs were averaged by sampling stratum (48 strata, excluding 0-100 m stratum in Southeast Alaska) and year. The stratum-by-taxon matrix of abundances ($CPUE^{0.25}$) was used in an ordination (nonmetric multi-dimensional scaling of pairwise Bray-Curtis dissimilarities) and the ordination axis that had the highest correlation with year was used as an index of changes in species composition over time (Fig. 5).

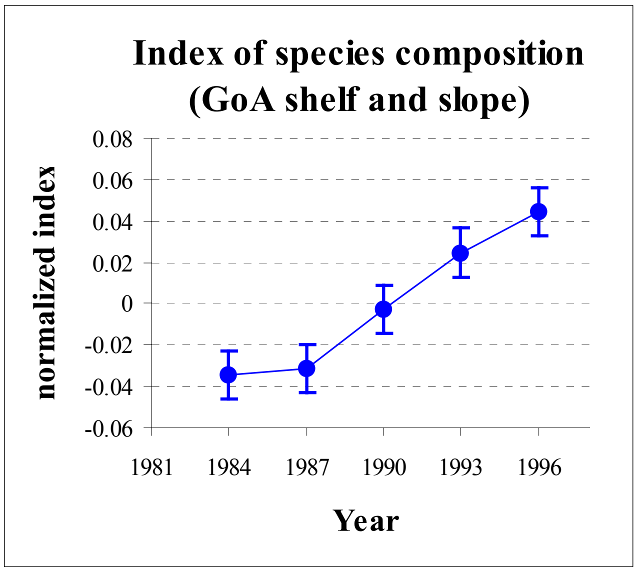



Figure 5: Trend in index of species composition based on ordination of species abundance data from 5 triennial surveys on Gulf of Alaska shelf and slope with approximate 95% confidence interval.

The index shows a sharp increase after 1987 and some indication of leveling off after 1993 (Fig. 5). The index reflects a significant change in species composition from 1984 to 1996 that is associated with significant long-term increases in the frequency of occurrence and/or CPUE-where-present of at least eight species, and significant long-term decreases in the frequency of occurrence of at least three species of groundfishes. Skates were most strongly associated with the index and showed a widespread increase in CPUE and frequency of occurrence, particularly in the Chirikof, Kodiak, and Yakutat areas. Another elasmobranch (Pacific sleeper shark, *Somniosus pacificus*), two osmerids (capelin, *Mallotus villosus*, and eulachon, *Thaleichthys pacificus*), three flatfish species (Dover sole, rex sole, and arrowtooth flounder), and one rockfish species (Pacific Ocean perch, *Sebastes alutus*) increased significantly in one or more areas and depth strata. The frequency of occurrence of capelin in the trawl survey increased significantly, while CPUE-where-present did not change or, in some cases, decreased significantly. Dover sole increased primarily in the eastern GoA (Yakutat and Southeast), rex sole increased most strongly in the Chirikof area. In contrast, arrowtooth flounder increased in all areas, but only in the 0-100 m depth stratum. While all three of the flatfish species increased significantly over time, estimates of their gulf-wide average CPUEs were highest in 1990 and declined from 1990 to

1996 (see Appendix 1). Both the frequency of occurrence and CPUE-where-present of Pacific Ocean perch increased strongly in the Chirikof area, while frequency of occurrence decreased in the Yakutat area.

The frequency of occurrence of these three taxa decreased significantly from 1984 to 1996: bigmouth sculpin (*Hemitripterus bolini*), *Myoxocephalus* spp., and *Lepidopsetta* spp.

For more details on these and other trends see:

Mueter, F.J. 1999. Spatial and temporal patterns in the Gulf of Alaska groundfish community in relation to the environment. Ph.D. Dissertation. University of Alaska, Fairbanks, AK. 195 pp.

Mueter, F.J., and Norcross, B.L. in review. Changes in species composition of the demersal fish community in nearshore waters of Kodiak Island, Alaska. Can. J. Fish. Aquat. Sci.

Finally, Figure 6 shows the relative composition of the groundfish community over time. It includes data from earlier surveys done in the 60s and 70s based on the report by Ronholt et al. (1978). Data from the early surveys has to be interpreted carefully because the sampling design, gear, and the spatial coverage of these surveys differs from the surveys done in the 1980s and 1990s. In particular, no stations below 400 m or east of 136°W were sampled in the 60s and 70s. Nevertheless, the trends for most taxa are believable. However, although POP were very abundant in the early 60s based on stock assessment at catch rates, for some reason they did not show up in the 1961 survey in large numbers. Another interesting trend apparent in the figure is the decrease in the relative abundance of sculpins, which declined from about 8% in the early 1960s to less than 0.1% in the 1980s and 1990s. The decline in sculpins apparently continued throughout the 1980s and 1990s as the index above and the numbers in Table 1 suggest.

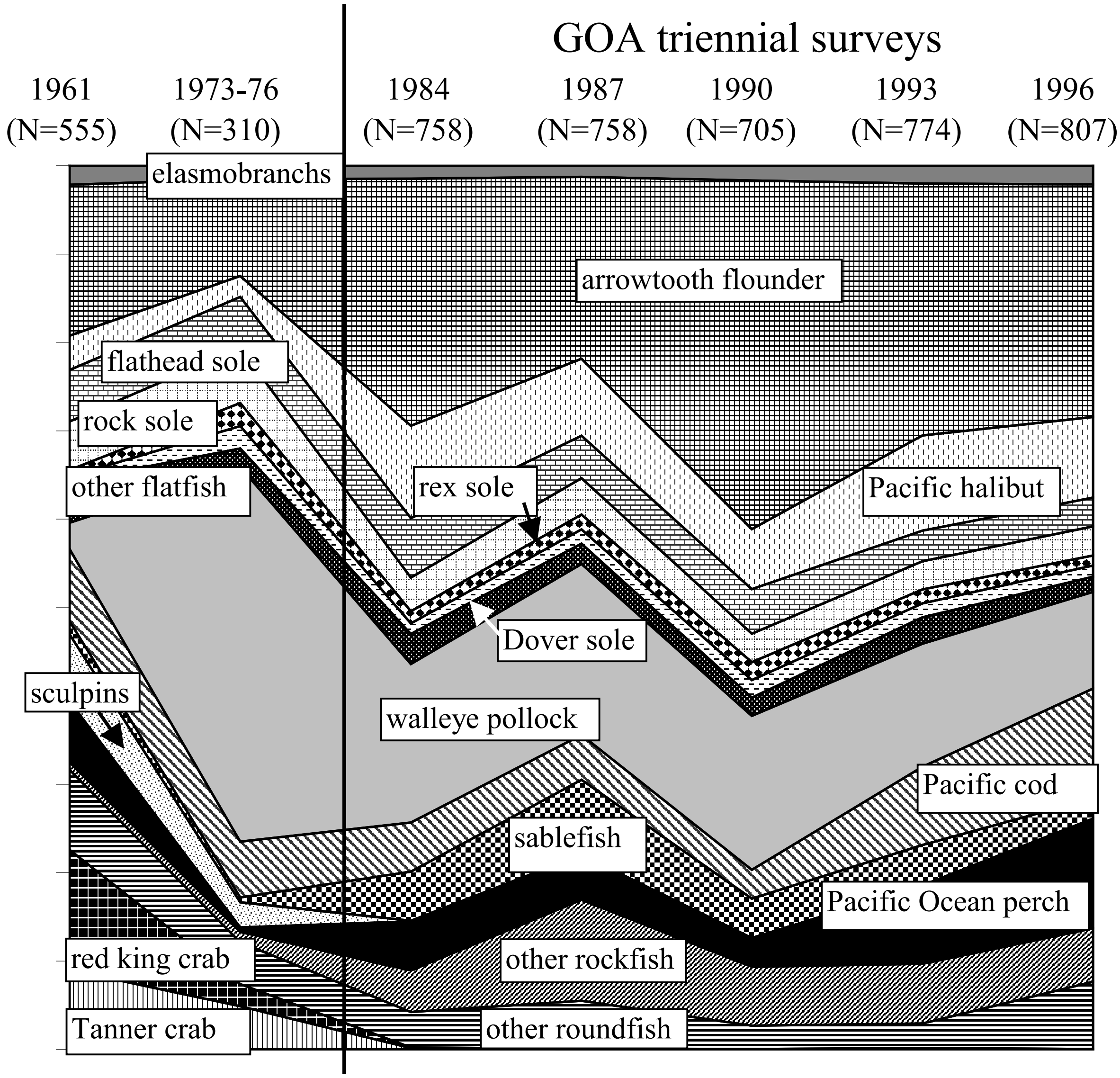



Figure 6: Relative species composition for major groundfish taxa in the Gulf of Alaska from 1961 - 1996.

Table 1: All groundfish taxa included in analysis and their estimated average CPUE (kg/km$^2$) by year and for all years combined. CPUEs were computed for each haul, averaged by stratum, weighted by stratum area, and combined to obtain area-wide averages. FO denotes overall frequency of occurrence for all years combined in percent.

| Scientific name | Common name | 1984 | 1987 | 1990 | 1993 | 1996 | Mean | FO |
|---|---|---|---|---|---|---|---|---|
| *Atheresthes stomias* [1] | arrowtooth flounder | 3790 | 3339 | 6499 | 5298 | 5574 | 4900 | 91 |
| *Theragra chalcogramma* [1] | walleye pollock | 2431 | 3139 | 2873 | 2586 | 2320 | 2670 | 74 |
| *Gadus macrocephalus* [1] | Pacific cod | 1876 | 1516 | 1424 | 1397 | 1821 | 1607 | 73 |
| *Hippoglossus stenolepis* [1] | Pacific halibut | 1415 | 1410 | 1118 | 2007 | 1936 | 1577 | 77 |
| *Sebastes alutus* [1] | Pacific Ocean perch | 753 | 823 | 535 | 1649 | 2629 | 1278 | 40 |
| *Anoplopoma fimbria* [1] | sablefish | 753 | 1379 | 731 | 844 | 492 | 840 | 52 |
| *Hippoglossoides elassodon* [1] | flathead sole | 912 | 783 | 828 | 643 | 689 | 771 | 57 |
| *Lepidopsetta* spp. [1] | rock sole spp. | 515 | 668 | 531 | 590 | 695 | 600 | 44 |
| *Sebastes polyspinis* [1] | northern rockfish | 135 | 475 | 365 | 356 | 337 | 334 | 20 |
| *Pleurogrammus monopterygius* | Atka mackerel | 153 | 98 | 101 | 73 | 1179 | 321 | 5 |
| *Glyptocephalus zachirus* [1] | rex sole | 187 | 269 | 335 | 297 | 245 | 266 | 67 |
| *Microstomus pacificus* [1] | Dover sole | 164 | 263 | 329 | 291 | 266 | 263 | 55 |
| *Limanda aspera* [1] | yellowfin sole | 313 | 192 | 196 | 277 | 162 | 228 | 7 |
| *Sebastes ciliatus* [1] | dusky rockfish | 87 | 505 | 91 | 194 | 255 | 227 | 20 |
| *Sebastes aleutianus* [1] | rougheye rockfish | 153 | 227 | 165 | 212 | 156 | 183 | 34 |
| Rajidae unident. | skate unident. | 139 | 129 | 164 | 205 | 274 | 182 | 33 |
| *Clupea pallasi* | Pacific herring | 186 | 511 | 60 | 53 | 3 | 163 | 8 |
| *Sebastes zacentrus* | sharpchin rockfish | 23 | 274 | 131 | 81 | 220 | 146 | 10 |
| *Albatrossia pectoralis* | giant grenadier | 115 | 96 | 81 | 155 | 175 | 124 | 3 |
| *Sebastolobus alascanus* | shortspine thornyhead | 126 | 127 | 68 | 114 | 177 | 122 | 24 |
| *Sebastes variegatus* | harlequin rockfish | 9 | 247 | 60 | 32 | 68 | 83 | 11 |
| *Thaleichthys pacificus* | eulachon | 24 | 56 | 95 | 119 | 110 | 81 | 32 |
| *Isopsetta isolepis* [1] | butter sole | 80 | 71 | 59 | 102 | 71 | 77 | 7 |
| *Platichthys stellatus* [1] | starry flounder | 50 | 63 | 35 | 137 | 93 | 76 | 5 |
| *Sebastes borealis* | shortraker rockfish | 59 | 137 | 43 | 69 | 69 | 75 | 8 |
| *Sebastes proriger* | redstripe rockfish | 18 | 90 | 92 | 101 | 51 | 71 | 4 |
| *Squalus acanthias* | spiny dogfish | 34 | 34 | 65 | 114 | 96 | 69 | 16 |
| *Hemilepidotus jordani* | yellow Irish lord | 49 | 46 | 40 | 40 | 61 | 47 | 27 |
| *Sebastes brevispinis* | silvergray rockfish | 16 | 18 | 48 | 65 | 82 | 46 | 7 |
| *Ophiodon elongatus* | lingcod | 15 | 32 | 35 | 53 | 80 | 43 | 10 |
| *Hemitripterus bolini* | bigmouth sculpin | 54 | 35 | 29 | 19 | 14 | 30 | 18 |
| *Lamna ditropis* | salmon shark | 27 | 43 | 42 | 26 | 11 | 30 | 1 |
| *Myoxocephalus* spp. | | 37 | 23 | 18 | 22 | 30 | 26 | 9 |
| *Parophrys vetulus* [1] | English sole | 11 | 28 | 26 | 28 | 15 | 22 | 7 |
| *Somniosus pacificus* | Pacific sleeper shark | 1 | 1 | 6 | 29 | 72 | 22 | 1 |
| *Zaprora silenus* | prowfish | 13 | 24 | 15 | 28 | 23 | 21 | 11 |
| *Pleuronectes quadrituberculatus* [1] | Alaska plaice | 7 | 16 | 20 | 9 | 17 | 14 | 4 |

[1] Catches for 1984 and 1987 were adjusted using fishing power coefficients in Tables 28 and 31 in Munro and Hoff (1995). Other flatfishes were adjusted using rock sole coefficients.

Table 1: continued

| Scientific name | Common name | 1984 | 1987 | 1990 | 1993 | 1996 | Mean | FO |
|---|---|---|---|---|---|---|---|---|
| *Microgadus proximus* | Pacific tomcod | 5.03 | 34.67 | 6.32 | 9.01 | 5.78 | 12.16 | 2 |
| *Sebastes babcocki* | redbanded rockfish | 4.88 | 6.21 | 11.20 | 12.53 | 15.54 | 10.07 | 11 |
| *Hydrolagus colliei* | spotted ratfish | 13.06 | 8.16 | 6.32 | 7.08 | 12.65 | 9.45 | 6 |
| *Hexagrammos decagrammus* | kelp greenling | 3.89 | 8.17 | 13.87 | 8.21 | 6.69 | 8.16 | 8 |
| *Sebastes reedi* | yellowmouth rockfish | 1.69 | 0.89 | 6.39 | 12.14 | 3.15 | 4.85 | 1 |
| *Sebastes ruberrimus* | yelloweye rockfish | 2.10 | 10.17 | 3.29 | 3.88 | 3.70 | 4.63 | 3 |
| *Sebastes helvomaculatus* | rosethorn rockfish | 1.99 | 5.12 | 2.50 | 2.54 | 7.71 | 3.97 | 4 |
| *Sebastes melanops* | black rockfish | 1.14 | 3.75 | 4.65 | 0.86 | 7.89 | 3.66 | 1 |
| *Bathymaster signatus* | searcher | 2.08 | 2.05 | 5.39 | 3.04 | 4.38 | 3.39 | 15 |
| *Trichodon trichodon* | Pacific sandfish | 7.56 | 3.71 | 2.45 | 1.76 | 0.52 | 3.20 | 3 |
| *Malacocottus* spp. | | 4.33 | 2.97 | 2.40 | 3.55 | 1.63 | 2.97 | 14 |
| *Cryptacanthodes giganteus* | giant wrymouth | 0.76 | 3.26 | 3.98 | 1.17 | 2.77 | 2.39 | 1 |
| *Lycodes palearis* | wattled eelpout | 0.86 | 1.75 | 3.10 | 3.16 | 2.30 | 2.23 | 11 |
| *Eopsetta jordani* | petrale sole | 0.97 | 0.83 | 0.61 | 2.77 | 3.68 | 1.77 | 2 |
| *Mallotus villosus* | capelin | 1.47 | 0.17 | 0.51 | 0.42 | 4.98 | 1.51 | 7 |
| *Lycodes brevipes* | shortfin eelpout | 0.13 | 0.84 | 0.79 | 2.41 | 2.17 | 1.27 | 8 |
| *Dasycottus setiger* | spinyhead sculpin | 1.33 | 0.49 | 0.89 | 1.88 | 0.83 | 1.08 | 11 |
| *Aptocyclus ventricosus* | smooth lumpsucker | 0.74 | 1.29 | 1.77 | 0.37 | 0.56 | 0.95 | 2 |
| *Podothecus acipenserinus* | sturgeon poacher | 0.19 | 0.42 | 1.23 | 2.34 | 0.33 | 0.90 | 5 |
| *Sebastes elongatus* | greenstriped rockfish | 0.05 | 0.22 | 0.59 | 0.91 | 1.20 | 0.59 | 1 |
| *Sebastes wilsoni* | pygmy rockfish | 0.00 | 1.38 | 0.30 | 0.01 | 0.96 | 0.53 | 1 |
| Myctophidae | lanternfish unident. | 0.19 | 0.19 | 0.11 | 1.52 | 0.53 | 0.51 | 4 |
| *Triglops* spp. | | 0.37 | 0.32 | 0.68 | 0.40 | 0.61 | 0.48 | 6 |
| Stichaeidae | prickleback unident. | 0.58 | 0.05 | 0.51 | 0.70 | 0.41 | 0.45 | 4 |
| *Sebastes crameri* | darkblotched rockfish | 0.02 | 0.13 | 0.59 | 0.99 | 0.41 | 0.43 | 1 |
| *Hexagrammos stelleri* | whitespotted greenling | 0.17 | 0.56 | 0.64 | 0.33 | 0.27 | 0.39 | 1 |
| *Lyopsetta exilis* | slender sole | 0.10 | 0.07 | 0.29 | 0.77 | 0.59 | 0.37 | 5 |
| Cyclopteridae (Liparidinae) | snailfish | 0.30 | 0.23 | 0.30 | 0.28 | 0.04 | 0.23 | 3 |
| *Hemilepidotus hemilepidotus* | red Irish lord | 0.07 | 0.29 | 0.05 | 0.32 | 0.10 | 0.16 | 1 |
| Cottidae | sculpin unident. | 0.25 | 0.00 | 0.28 | 0.08 | 0.01 | 0.12 | 1 |
| *Gymnocanthus* spp. | | 0.16 | 0.03 | 0.00 | 0.06 | 0.06 | 0.06 | 1 |
| *Eumicrotremus orbis* | Pacific spiny lumpsucker | 0.02 | 0.08 | 0.03 | 0.07 | 0.04 | 0.05 | 2 |
| *Lycodes diapterus* | black eelpout | 0.08 | 0.05 | 0.00 | 0.01 | 0.02 | 0.03 | 2 |
| *Sarritor frenatus* | sawback poacher | 0.03 | 0.03 | 0.01 | 0.04 | 0.04 | 0.03 | 2 |
| *Bathyagonus nigripinnis* | blackfin poacher | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 1 |
| *TOTAL* | | 14786 | 17286 | 17436 | 18400 | 20662 | 17714 | |

## Multispecies Forecasting of the Effects of Fishing

Contributed by Jesus Jurado-Molina and Pat Livingston

For several years, the groundfish plan teams have expressed specific ecosystem concerns with regard to the effects of fishing on species composition. In particular, the plan teams have noted that large differences exist in the harvest rates of groundfish species off Alaska. Some groundfish (such as pollock, cod, sablefish, and rockfish) are harvested at or close to their Fabc levels, while other species (such as flatfish) are harvested at substantially lower levels. The plan team has requested analysis of the long-term implications of disproportionate harvest rates.

In order to address this concern, we have used results from a multispecies virtual population analysis (MSVPA) model for the eastern Bering Sea(Livingston and Jurado-Molina, 1999) , which has been updated to reflect the information from the 1998 stock assessments. The outputs from the MSVPA model have been used to produce the following forecast of the long-term multispecies effects of harvesting groundfish.

The multispecies forecasting model (MSFOR) incorporates information on predation interactions derived from MSVPA, which allows the assessment of the future dynamics of populations of the species under analysis. This model is based on the same equations as the MSVPA model. In addition to the catch equation and population equations, MSVPA and MSFOR estimates the predation mortality M2 of prey *p* caused by a predator *i* using the following equation:

$$M2_{p,i} = \frac{\overline{N}_i R_i S_{p,i}}{\sum_j N_j W_j S_{j,i}} \qquad (1)$$

where the denominator represents the total suitable biomass available to predator *i*. $R_i$ is the annual food consumption of the predator. $W_j$ is the weight of the prey *p* and $S_{j,i}$ is the suitability coefficient. This last parameter is a measure of the suitability of prey *p* as food for predator *i* and its estimation is based on stomach content data. The total mortality of the prey is the sum on all predators:

$$M2_p = \sum_i M2_{p,i} \qquad (2)$$

A system of eight species was defined for the eastern Bering Sea and modelled in a multispecies VPA (Livingston and Jurado-Molina, 1999) and multispecies forecast. Four species played the role of both predator and prey including walleye pollock (*Theragra chalcogramma)*, Pacific cod (*Gadus macrocephalus*), Greenland turbot (*Reinhardtius hippoglossoides* ) and yellowfin sole (*Pleuronectes asper*). Rock sole (*Lepidopsetta bilineata*) and Pacific herring (*Clupea harengus pallassi*) were considered only as prey. Finally, arrowtooth flounder (*Atheresthes stomias* ) and northern fur seal (*Callorhinus ursinus*) were considered “other predators. The “other predators” are considered external predators within the MSVPA because their populations are not estimated within the MSVPA, instead, they are provided externally from other sources. For the forecasting of eastern Bering Sea, it was assumed that the population of northern fur seal remained constant.

However the model is implemented in such way that increasing or decreasing population scenarios can be explored later. For arrowtooth flounder, we followed the same assumptions on recruitment and fishing mortality as the rest of the species. Figure 1 shows the biomass flow for the system defined for the eastern Bering Sea.

The forecasting model requires several inputs for each species. Some inputs are the same as used in the MSVPA model including weight at age, predator's annual consumption, assumption on the "other food" and maturity at age. Some results from the MSVPA, initial population at age in 1998 and quarterly mean suitabilities, are used as inputs to the MSFOR model. The quarterly suitabilities are transformed to annual values using a weighted average with the seasonal rations as the weights. Two inputs, future fishing mortality and recruitment are discussed in the following paragraphs.

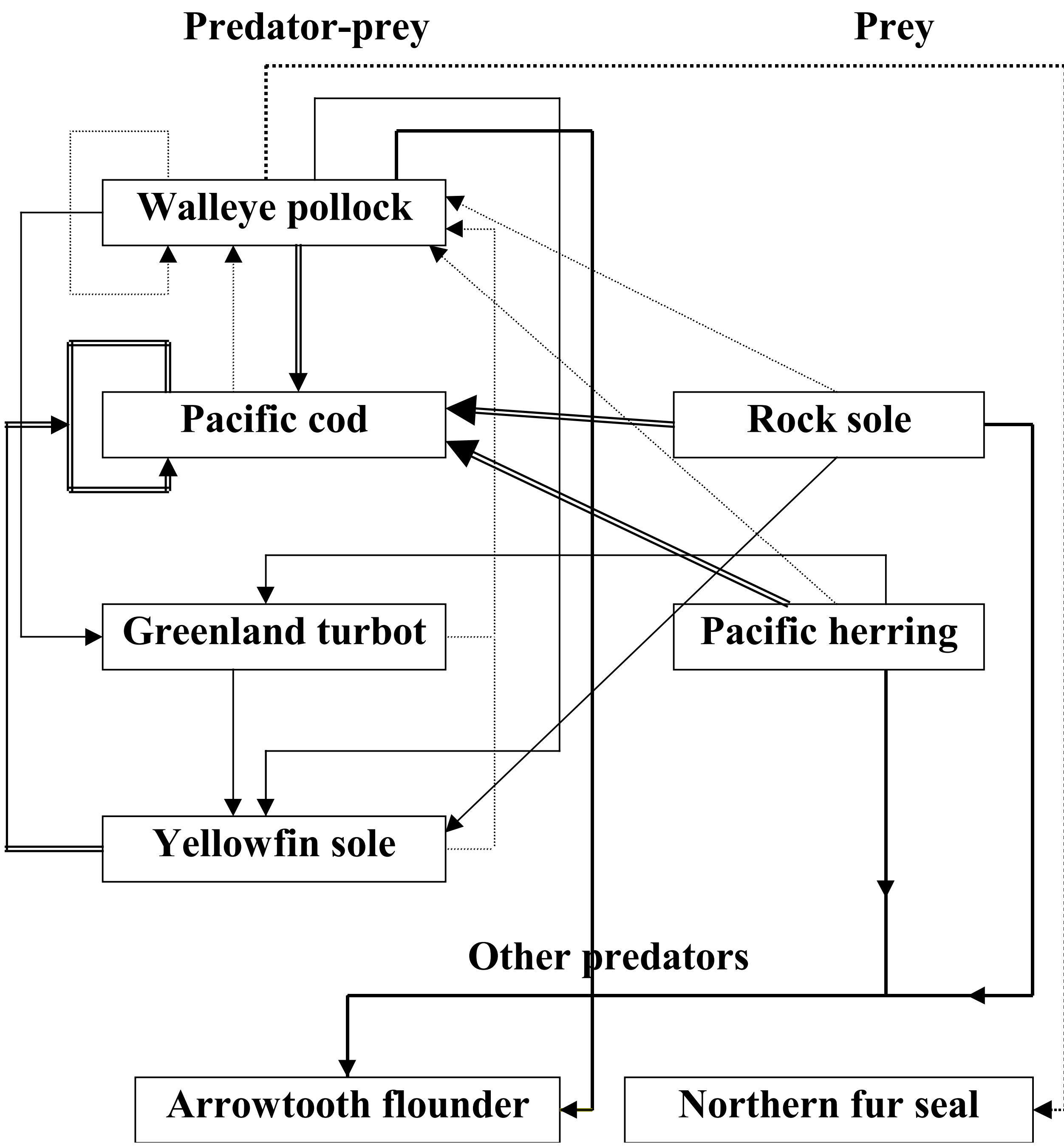



Figure 1. Biomass flow of the system defined for the eastern Bering Sea.

Recruitment of age-0 fish in the MSFOR takes place in the third quarter of each year since we only consider predation losses of fish in the juvenile stage and beyond. The easiest way to include recruitment in the deterministic model is to assume that it is constant. The constant value used for each species was calculated as the average of the estimated recruitment in the MSVPA from 1979 to 1998.

In order to address the plan teams' concerns about the multispecies effects of fishing on species composition, three levels of fishing mortality were used in the deterministic multispecies forecasting models. The first level known as the "reference F" was calculated as the average of the last three years (1996-1998) of the fishing mortality estimates from the MSVPA models. This level represents the actual level of fishing mortality that has been realized in recent years. For the second level of future fishing mortalities, the level of fishing mortality producing the *Acceptable Biological Catch* ($F_{ABC}$) in the 1998 stock assessments was selected. The values for the $F_{ABC}$ and the selectivity patterns for each species were taken from the 1998 SAFE report with the exception of Pacific herring. For this species, 20% of the exploitable biomass has historically been used as the management criterion. One last scenario of no fishing mortality ($F$ = 0) was implemented for comparisons with the last two options of future fishing levels. Figure 2 shows the levels of future fishing mortality $F_{ref}$ and $F_{ABC}$ applied to the forecasting of groundfish population trends of the species of the Bering Sea.

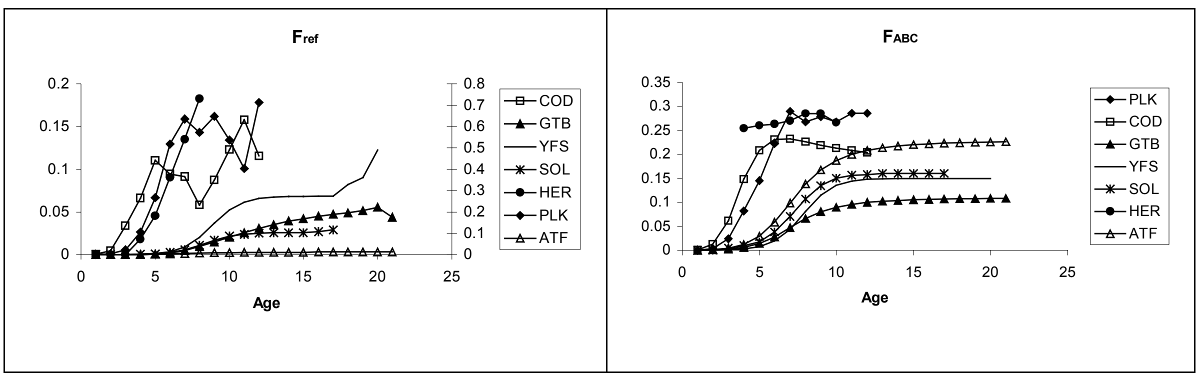



Figure 2. Levels of future fishing mortality used in the MSFOR model for the species of the Bering Sea. In the left figure, the right y-axis corresponds to walleye pollock. (PLK- walleye pollock, COD- Pacific cod, GTB – Greenland turbot, YFS – yellowfin sole, SOL – rock sole, HER – Pacific herring, ATF – Arrowtooth flounder)

The options on fishing mortality allow exploring three scenarios for the implementation of the deterministic MSFOR model. In addition, The corresponding single species models were also implemented to compare with the multispecies results. In Table 1, the models implemented for the eastern Bering Sea and their characteristics are shown.

Table 1. List of the combinations of fishing mortality and recruitment use to implement the deterministic MSFOR models for the eastern Bering Sea.

| Model | F | |
|---|---|---|
| Fordetb | $F_{ref}$ | Multispecies |
| Fordetb1 | $F_{ABC}$ | Multispecies |
| Fordetb2 | No | Multispecies |
| Fordetc | $F_{ref}$ | Single species |
| Fordetc1 | $F_{ABC}$ | Single species |
| Fordetc2 | No | Single species |

Results

A total of three deterministic MSFOR models and three single species models were set up to analyze the equilibrium dynamics of the system defined for the eastern Bering Sea. All models were set for a period of time of forty years. Three indicators were chosen as outputs of the deterministic MSFOR models, including yield, total biomass and spawning biomass. We compare the relative performance of these indicators with respect to $F_{ref}$. The relative percentage change of an indicator *I* was defined as the difference between the indicator under $F_{ABC}$ and the results under $F_{ref}$ divided by the indicator under Fref as equation (3) shows:

$$\%\ change\ of\ I = \frac{(I(F_{ABC}) - I(F_{ref}))}{I(F_{ref})} x100 \qquad (3)$$

As shown in figure 2, the $F_{ABC}$ regime is characterized by a decrease for fishing mortality under the $F_{ABC}$ regime ($F_{ABC} < F_{ref}$) for walleye pollock. For the rest of the species $F_{ABC}$ is larger than $F_{ref}$, except for herring that is managed with a 20% constant harvest rate. This trend is reflected in the results for the relative percentage change of yield shown in Figure 3 for the multispecies and single species models. The general trend in the relative % yield change is characterized by a decrease in the long-term yield of pollock and herring when $F_{ABC}$ is implemented in the model compared to the yield obtained under the $F_{ref}$ regime. The opposite case is found for the rest of the species, which showed increases in the long-term yield. Rock sole presented the largest yield change. Single species results followed the same pattern as the multispecies model (Figure 3). The difference between the single species and the multispecies predictions are less than 10% except for rock sole. For this species, the multispecies model predicts a larger increase in yield than predicted by the single species forecast, with the difference presumably caused by predation interactions (particularly with cod) not taken in account in the single species model.

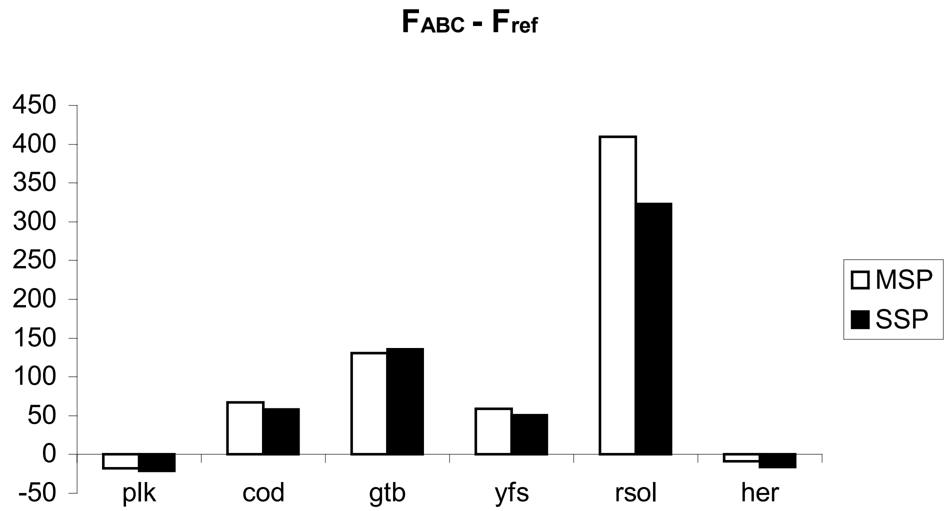



Figure 3. Results of the change in relative percentage yield from the MSFOR and the single species model between the reference level and the $F_{ABC}$ fishing level.

Figure 4 shows the results for the relative percentage change for spawning biomass and total biomass for the multispecies and the single species models under three levels of fishing mortality. Figures on the left side of Figure 4 show the results of the multispecies (top) and from single species (bottom) forecasts when $F_{ABC}$ and $F_{ref}$ are compared. Both models (multispecies and single species) predict almost the same trend for the relative percentage change of biomass and spawning biomass, despite the fact that in the multispecies case a relative large decline in the arrowtooth flounder population which preys on pollock. Possibly, increasing cannibalism due to increasing adult pollock biomass and the decrease in arrowtooth flounder predation are offsetting factors. When $F_{ABC}$ is implemented, the biomass and spawning biomass of pollock increases due to a reduction of fishing mortality to the $F_{ABC}$ level. Total biomass and spawning biomass decreased for cod, yellowfin sole, Greenland turbot and rock sole. This decrease in biomass and spawning biomass results from the increase of fishing mortality under the $F_{ABC}$ regime. Once again the multispecies and single species changes are similar with the exception of rock sole, in which the multispecies model predicts a decrease of 15% in the long-term total biomass if the $F_{ABC}$ is adopted while the single species predicts a bigger decrease (28%) for that parameter. The multispecies and the single species models also predict slightly different results for Pacific herring. MSFOR predicts a small increase for the total biomass and the spawning biomass while the single species model predicts a small decrease for total biomass and the spawning biomass. These differences could be explained by the population decrease of predators of rock sole and Pacific herring.

The right side of Figure 5 presents the results from the single and multispecies models for the no fishing scenario. Single species forecast predicts that, in absence of fishing mortality, all species populations grow. Walleye pollock, Pacific cod and yellowfin sole had the greatest increases in biomass and spawning biomass (Figure 5). The changes for rock sole, Pacific herring and Greenland turbot and arrowtooth flounder are smaller than 15%. The multispecies model predicts different results. Multispecies forecasts predict increasing biomass and spawning biomass for most of the species, except for rock sole, which had a small decrease in those indicators. This decreasing trend for rock sole could be explained by the increase of the biomass of rock sole predators. Another difference is the relative increase of biomass and spawning biomass. The increases predicted by the single species are significantly bigger than the predictions from multispecies forecasts. For pollock biomass, single species forecasts an increase of 61% while multispecies predicts an increase of just 9.5%. The cases for the rest on the species are similar (Figure 5).

The previous results from MSFOR and the single species forecasts predict almost the same trends for the relative changes of yield biomass and spawning biomass under the $F_{ABC}$ regime. However two species are the exception. Rock sole and Pacific herring seem to respond slightly differently because of predation interactions. More detailed analysis of the results is being pursued at present. Particularly, we want to better understand the possible interaction between arrowtooth flounder predation on pollock and pollock cannibalism in these scenarios. Although a simple assumption of recruitment was implemented, the MSFOR model provided valuable information on the possible consequences in the long-term indicators analyzed. In the future, more realistic assumptions on recruitment will be added to the model. It is also possible to include stochastic terms to the recruitment that could provide additional information on the future consequences of the implementation of future levels of fishing mortality in the eastern Bering Sea. These other recruitment assumptions are presently being explored.

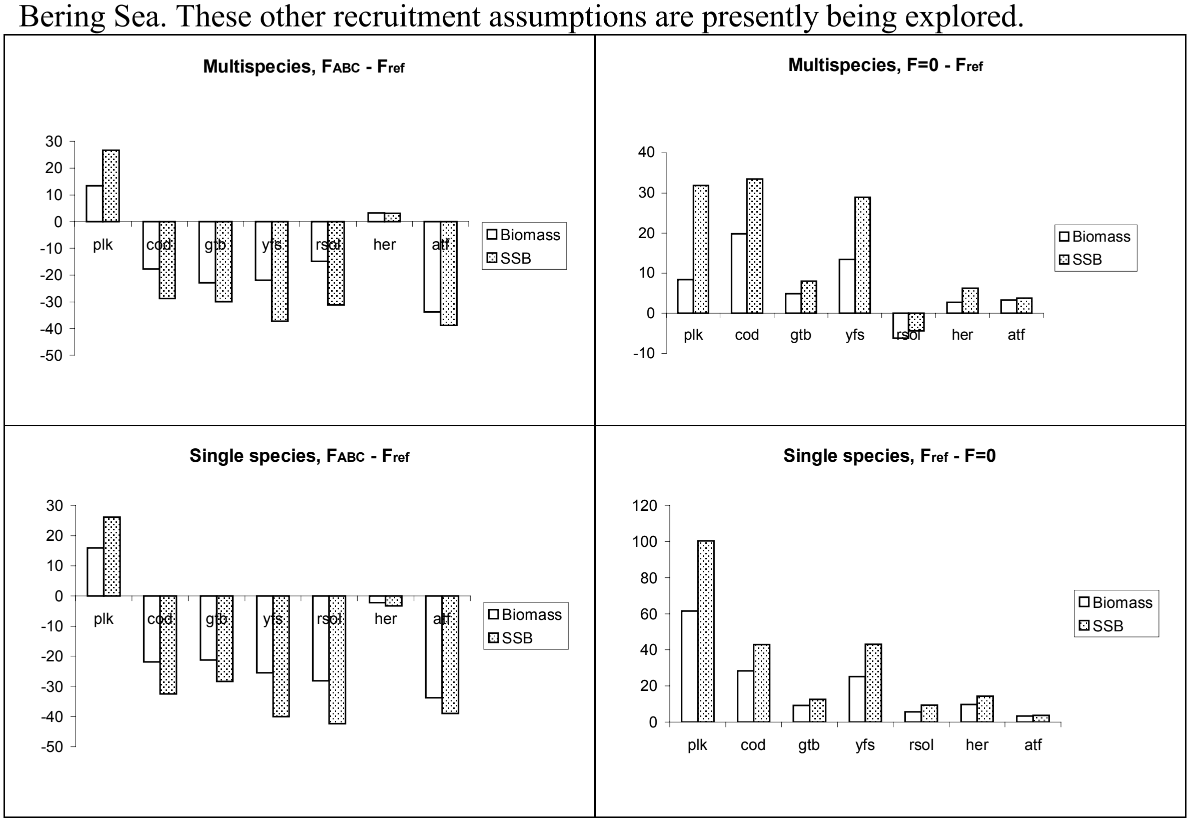



Figure 5. Results from the multispecies and single species model for the relative percentage change of total biomass and spawning biomass under the assumption of constant recruitment and three levels of fishing mortality. The left side compares the $F_{ref}$ and $F_{ABC}$ levels. The right side corresponds to the $F_{ref}$ and no fishing comparison.

## Ocean Surface Current Modeling Update

Contributed by W. James Ingraham, Jr.

Recently, ocean surface current modeling has been used increasingly to understand the 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 package "Ocean Surface CURent Simulations, OSCURS ". With this numerical model just pick your own input: 1) a start-point on the graphic chart; 2) any start-day from January, 1946 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 the "Live Access Server", for an actual model run.

Development of OSCURS was motivated by the need in fisheries research for indices that describe variability in ocean surface currents. 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) 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 feedback is welcome at **jim.ingraham@noaa.gov**.

# 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.

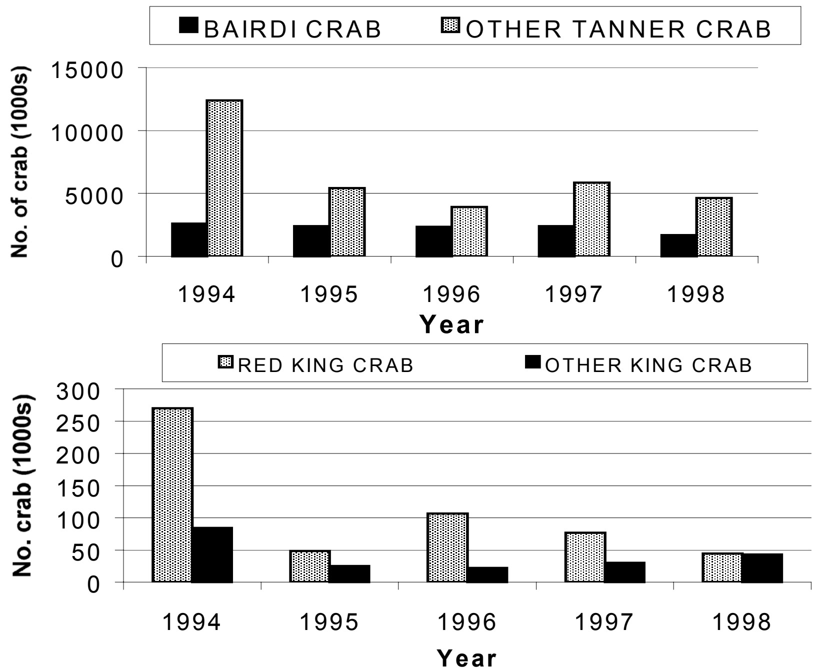



Figure 1.--Tanner and king crab bycatch in groundfish fisheries off Alaska, 1994-98.

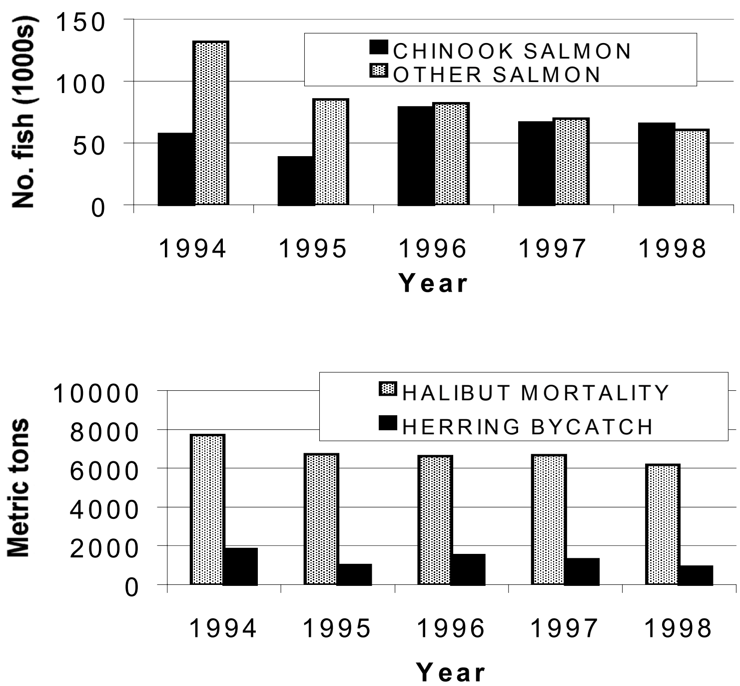



Figure 2. Bycatch of salmon, halibut, and herring in the groundfish fisheries off Alaska, 1994-98.

## 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.

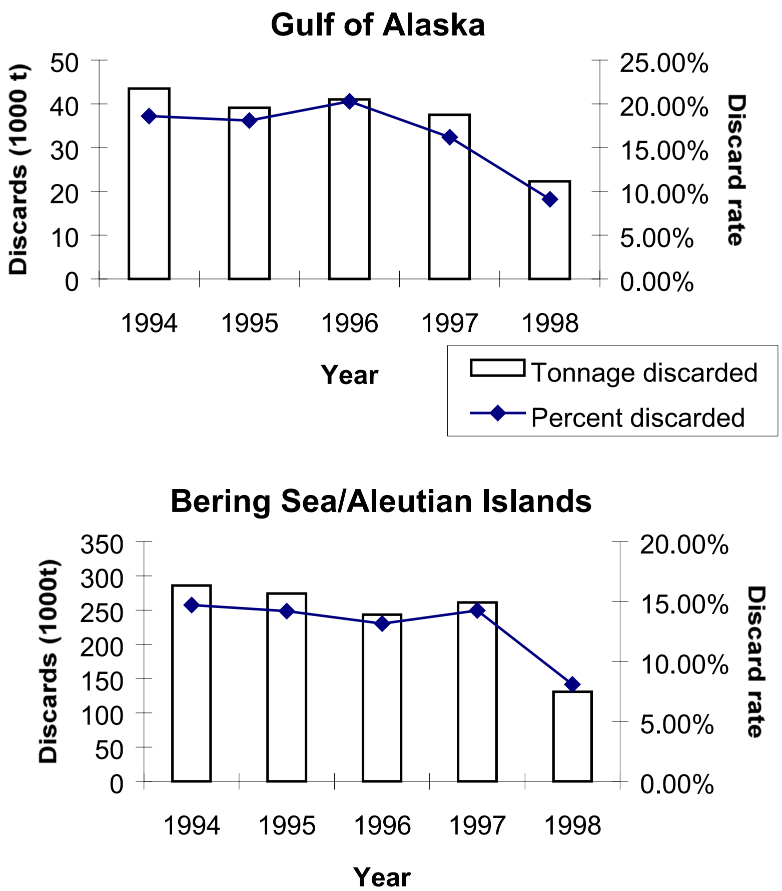



Figure 1. Total biomass and percent of total catch biomass of managed groundfish discarded in the GOA and BS/AI areas 1994-98. (Includes only catch counted against Federal TACS.)

## *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

Since 1987, the NPFMC has put many different groundfish trawl closures into effect (Table 1). Some of the closures are year-round while others may only last a few months. A measure of time*area closure for each major area was derived by putting each closure into units of sq km*months in each year and adding these separate closure measures together within each year and area (Figure 1). Starting in 1995, there has been an increase in the amount of area*time groundfish trawl closures in both the EBS/AI and GOA. The amount of sq km months closed per year in each area can be compared with an estimate of total potential sq km months in each year that could be closed. The latter estimate was derived by multiplying by 12 (months) the shelf and slope area estimates of the EBS/AI and GOA that are surveyed by NMFS bottom trawl surveys. This amounts to approximately 1.89 million sq nmi. months that could potentially be closed for the EBS/AI area and 1.05 million sq. nmi months for the GOA (including southeast). As of the end of 1998, about 28.9% of the potential on shelf total sq. nmi. months in the EBS/AI are closed to groundfish trawling and 18% of the potential on shelf total in the GOA are closed.

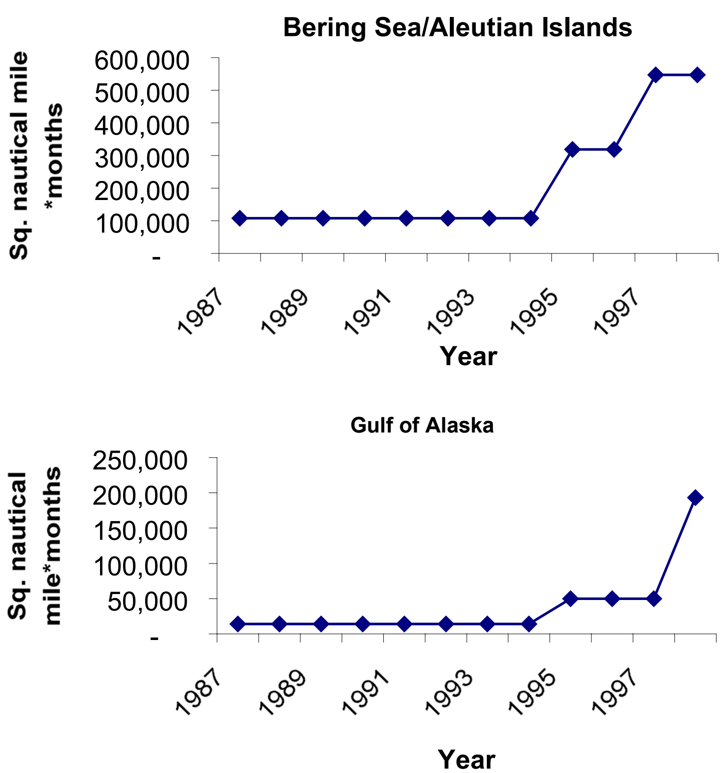



Figure 1.--Estimates of time*area closures to groundfish trawling in the Bering Sea/Aleutian Islands and Gulf of Alaska, 1987-1998. (Not including trigger closures or seasonal extensions around selected sea lion rookeries.)

**Table 1. Time series of groundfish trawl closure areas in the BSAI and GOA, 1995-1999.**

CSSA = chum salmon savings area
CHSSA = chinook salmon savings areas
HSA = herring savings area
RKCSA = red king crab savings area
SSL = Steller sea lion
COBLZ = C. opilio bycatch limitation zone

**Bering Sea / Aleutian Islands**

| Year | Location | Season | Area size | Notes |
|---|---|---|---|---|
| 1995 | Area 512 | year-round | 8,000 $nm^2$ | closure in place since 1987 |
| | Area 516 | 3/15-6/15 | 4,000 $nm^2$ | closure in place since 1987 |
| | CSSA | 8/1-8/31 | 5,000 $nm^2$ | re-closed if 42,000 chum salmon bycaught |
| | CHSSA | trigger | 9,000 $nm^2$ | closed if 48,000 chinook salmon bycaught |
| | HSA | trigger | 30,000 $nm^2$ | closed to specified fisheries when trigger reached |
| | Zone 1 | trigger | 30,000 $nm^2$ | closed to specified fisheries when trigger reached |
| | Zone 2 | trigger | 50,000 $nm^2$ | closed to specified fisheries when trigger reached |
| | Pribilofs | year-round | 7,000 $nm^2$ | established in 1995 |
| | RKCSA | year-round | 4,000 $nm^2$ | established in 1995; pelagic trawling allowed |
| | Walrus Islands | 5/1-9/30 | 900 $nm^2$ | 12 mile no-fishing zones around 3 haul-outs |
| | SSL Rookeries | year-round | 5,800 $nm^2$ | 10 mile no-trawl zones around 27 rookeries |
| | SSL Rookeries | seasonal ext. | 5,100 $nm^2$ | 20 mile extensions around 8 rookeries |
| 1996 | same closures in effect as in 1995 | | | |
| 1997 | same closures in effect as in 1995 and 1996, with two additions: | | | |
| | Location | SeasonArea size | Notes | |
| | Bristol Bay | year round | 19,000 $nm^2$ | expanded area 512 closure |
| | COBLZ | trigger | 90,000 $nm^2$ | closed to specified fisheries when trigger reached |
| 1998 | same closures in effect as in 1995, 1996, and 1997 | | | |
| 1999 | Additional closures to protect Steller sea lion critical habitat. | | | |

**Gulf of Alaska**

| Year | Location | Season | Area size | Notes |
|---|---|---|---|---|
| 1995 | Kodiak | year-round | 1,000 $nm^2$ | closures in place since 1987 |
| | Kodiak | 2/15-6/15 | 500 $nm^2$ | closures in place since 1987 |
| | SSL Rookeries | year-round | 3,000 $nm^2$ | 10 mile no-trawl zones around 14 rookeries |
| | SSL Rookeries | seasonal ext. | 1,900 $nm^2$ | 20 mile extensions around 3 rookeries |
| 1996 | same closures in effect as in 1995 | | | |
| 1997 | same closures in effect as in 1995 and 1996 | | | |
| 1998 | same closures in effect as in 1995, 1996, and 1997, with one addition: | | | |
| | Location | Season | Area size | Notes |
| | Southeast AK | year round | 52,600 $nm^2$ (11,929 $nm^2$ is the area actually on the shelf) | adopted as part of license limitation program |
| 1999 | Additional closures to protect Steller sea lion critical habitat<br>A 3.1 $nm^2$ closure to all fishing gear on a pinnacle off Sitka | | | |

Proposed: A 7,000 $nm^2$ closure to bottom trawling in Cook Inlet

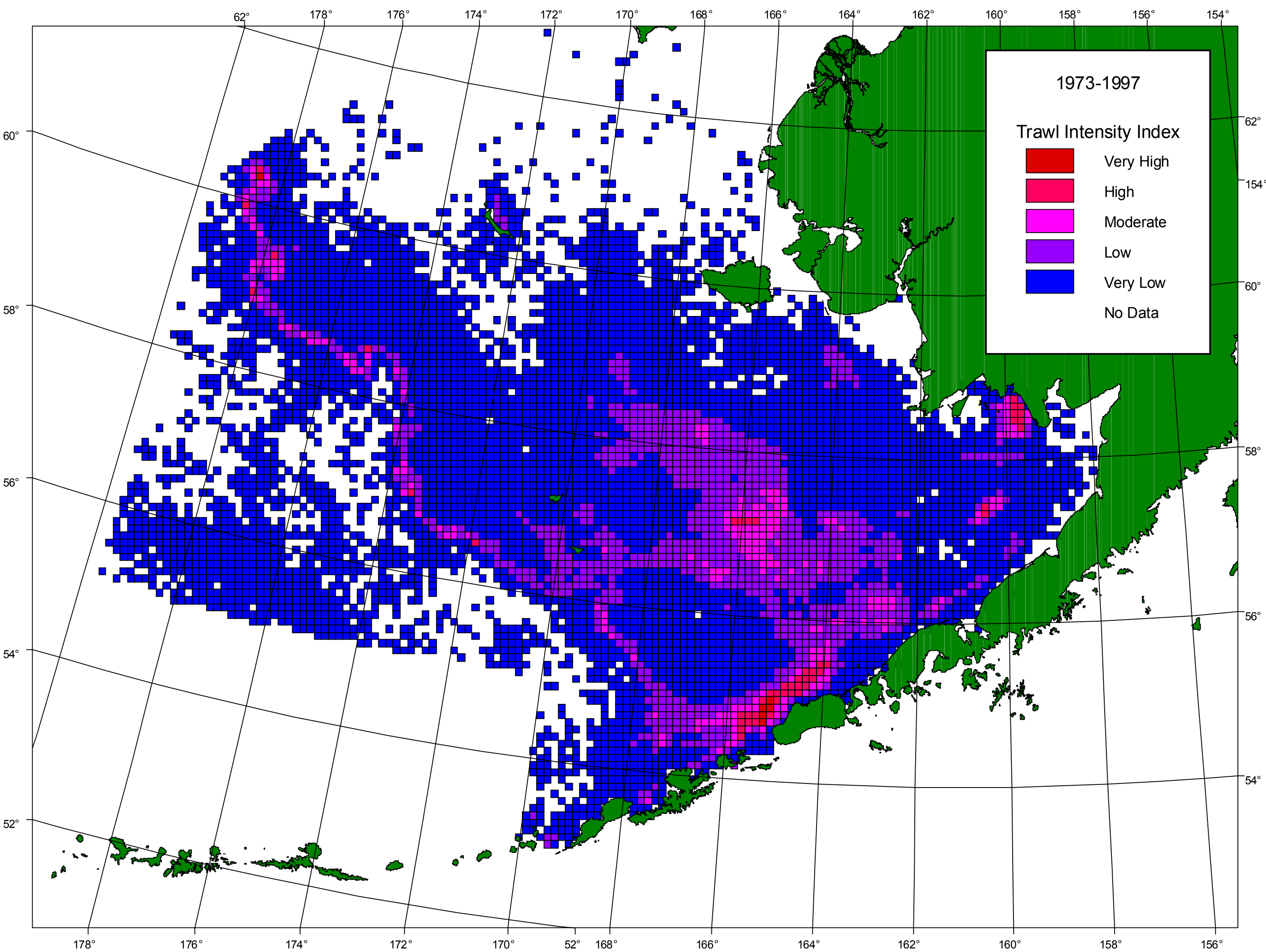
## Groundfish fishing effort in the eastern Bering Sea

Contributed by Bob McConnaughey

The Bering Sea (BS) has experienced rapid and intensive development of commercial bottom trawl fisheries. Because of good record keeping and the relatively brief history of fishing in the area, it is possible to reconstruct the spatial and temporal patterns of exploitation. For purposes of this discussion, the BS is comprised of catch reporting areas north of the Alaska Peninsula, excluding the western Aleutian Islands (areas 541, 542, 543).

For the period 1973-1997, a total of 412,040 records of bottom trawls in the BS were obtained from the NMFS Observer database (NORPAC). Bottom trawls by the domestic trawl fleet (1986-1997; n=182,705) were selected according to gear type information recorded in the field. Bottom trawls by the joint venture (1980-1990; n=101,376) and foreign (1973-1989; n=127,959) fleets were selected based on presence of benthic organisms (e.g. crabs, snails, sea stars) in the catch, because gear information is not available.

Two general spatial patterns are apparent when the historical trawl data are summarized on a 10 km grid (Fig.1). First, virtually all areas of the BS have experienced some degree of exposure to bottom trawls. Second, there is substantial variability in the intensity of exposure, when one considers the number of trawls made per unit area. These patterns reflect the non-random behavior of fishing fleets, which is based on historical patterns of performance and regulatory restrictions. Relatively heavy trawling has occurred along the shelf edge, along the Alaska Peninsula near Unimak Island and in Togiak Bay. The primary composition of the catch in these three areas was pollock, Pacific cod and Greenland turbot; Pacific cod and pollock; and yellowfin sole (Fritz *et al*. 1998).


1973-1997
Trawl Intensity Index
Very High
High
Moderate
Low
Very Low
No Data
62°
178°
176°
174°
172°
170°
168°
166°
164°
162°
160°
158°
156°
154°
60°
58°
56°
54°
52°

To better understand the long-term effects of fishing on the benthos a study was conducted on megafauna populations in a shallow (48m average) soft-bottom area of the eastern Bering Sea in 1996 (McConnaughey et al, 1999). Samples of 92 taxa (reduced for analysis) were collected at 84 1nm$^2$ sites straddling a closed area boundary. Multi- and univariate statistical tests and raw patterns in the data support the following generalizations: (1) sedentary megafauna (e.g., anemones, soft corals, sponges, whelk eggs, ascidians), neptunid whelks and empty shells were more abundant in the unfished (UF) area; (2) mixed responses were observed in motile groups (e.g., crabs, sea stars, whelks) and infaunal bivalves, suggesting the importance of life history considerations, such as habitat requirements and feeding mode; and (3) overall diversity (Figure 2) and niche breadth of sedentary taxa were greater in the UF area. A significant difference in diversity and niche breadth of sedentary organisms (e.g., sponges, anemones, soft corals, stalked tunicates) indicates that long-term exposure to bottom trawling, at least in the experimental area, reduces diversity and increases patchiness of this epibenthic community.

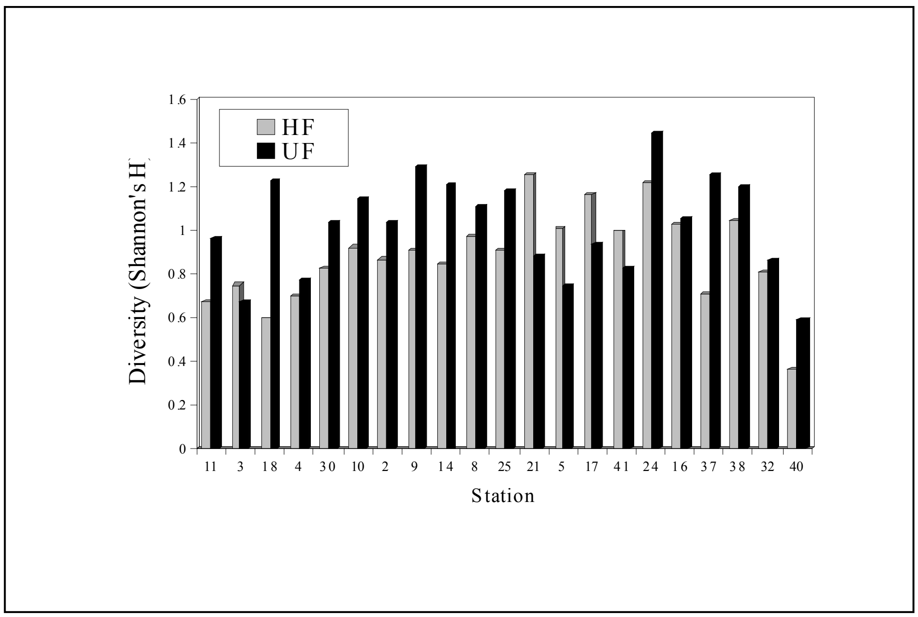



Figure 2. Species diversity of benthic invertebrate megafauna in heavily fished (HF) and unfished (UF) areas by station pairs in the eastern Bering Sea.

## Groundfish fishing effort in the Gulf of Alaska and Aleutian Islands

**Spatial and temporal patterns of bottom trawling in the Gulf of Alaska and Aleutian Islands during 1990-1998**
Contributed by Jon Heifetz and Cathy Coon

Coon et al. (1999) determined the spatial and temporal patterns of bottom trawl effort in the Gulf of Alaska and Aleutian Islands from 1990-1998 by analyzing domestic observer data. Areas of high bottom trawl effort within the Gulf of Alaska occur in the Kodiak region where there have been directed fisheries targeting Pacific ocean perch (*Sebastes alutus*), Pacific cod (*Gadus macrocephalus*), and flatfish (Figure 1). The Aleutian Islands has had high bottom trawl effort for Atka mackerel (*Pleurogrammus monopterygius*) and Pacific ocean perch (Figure 2). The total numbers of observed tows for the years 1990-1998 were 57,948 in the Gulf of Alaska and 35,498 for the Aleutian Islands. If expanded to include unobserved tows, the total number of trawls by were estimated to be 116,288 for the Gulf of Alaska and 41,015 for the Aleutian Islands. Total estimated bottom trawl effort in 24 hour days was 11,829 for the Gulf of Alaska, and 4,427 for the Aleutian Islands. The areas of the highest estimated number of bottom trawls were on the continental shelf at a depth of 101-200 m in both the Aleutian Islands and the Gulf of Alaska. Density values of trawling (number of trawls per $km^2$) for the Gulf of Alaska overall were $0.35/km^2$, with the highest density in the Kodiak region at $1.43/km^2$ in an area of 4,657 $km^2$ in 301-500 m depth. The highest bottom trawl duration in the Gulf of Alaska was at depth of 101-200 m, with the highest number of days trawled /$km^2$ in the Chirikof area at 0.74 days/$km^2$ in 301-500 m. Density of trawling in the entire Aleutian Island region was 0.56 trawls/$km^2$. The Eastern Aleutian area had the highest density 1.56 trawls/$km^2$ in an area of 7,909 $km^2$ in 101-200m depth. Overall there have been some temporal changes in bottom trawl effort (Figure 3). Bottom trawl effort in the Aleutian Islands declined from a peak in 1990 of 855 days to a low in 1997 of 321 days. In the Gulf of Alaska bottom trawl effort peaked at 1,710 days in 1990, declined to 739 days in 1994, increased to 1,490 days in 1996, and then declined to 934 days in 1998. Most of the changes in effort occurred in the Eastern Aleutian Islands and Eastern Gulf of Alaska. The reduction of fishing effort in these areas was related to fishery closures and reduction of total allowable catch quotas.

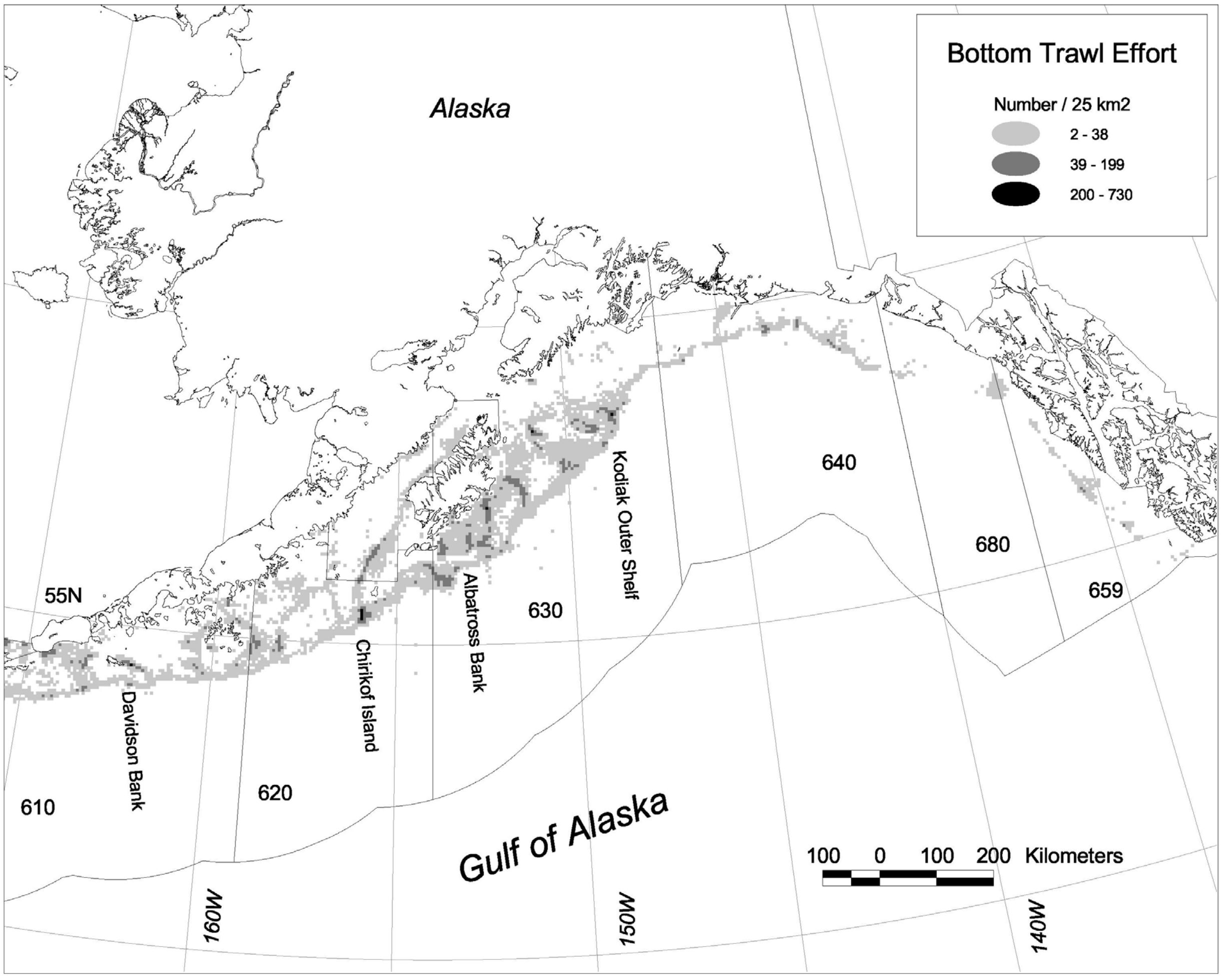



Figure 1. Spatial locations and density of bottom trawl effort in the Gulf of Alaska, 1990-98.

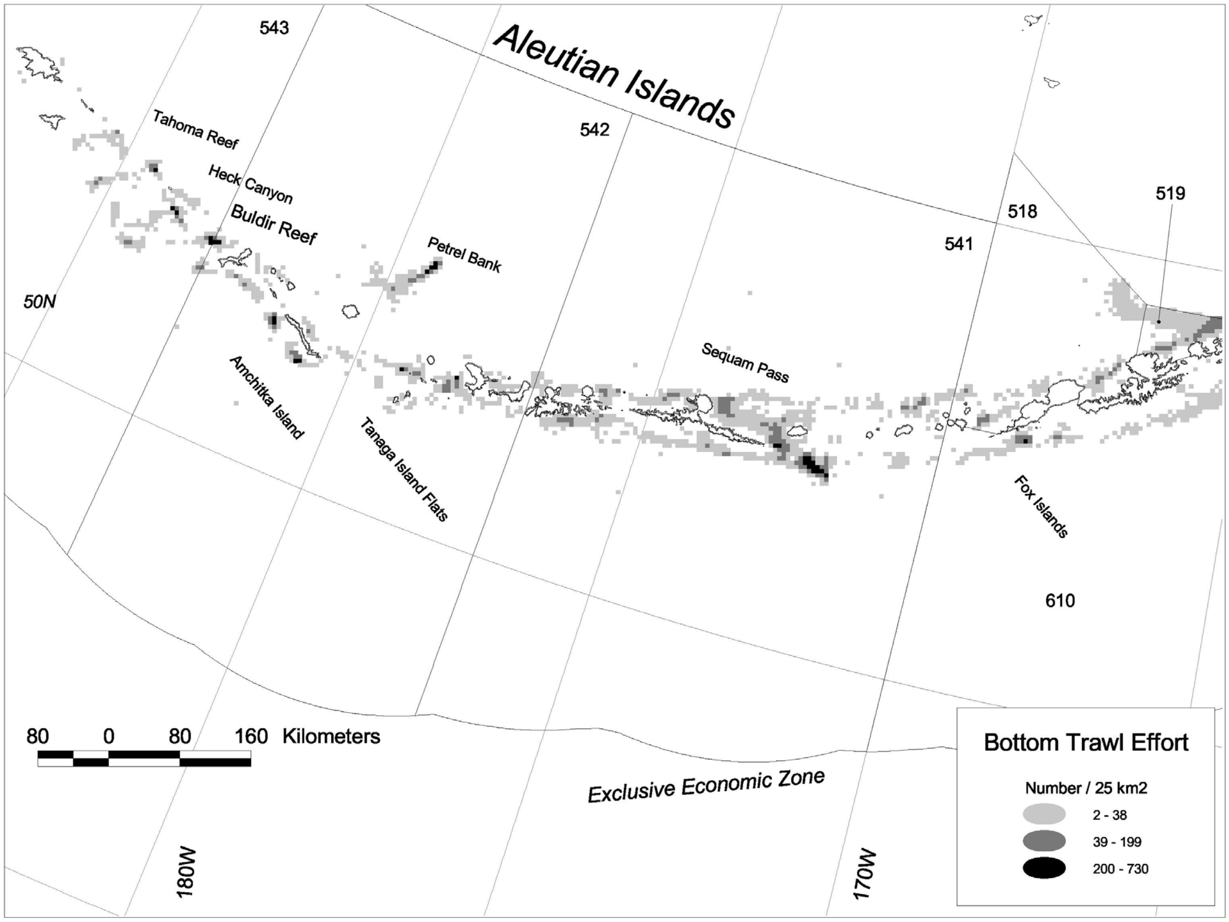



Figure 2. Spatial location and density of bottom trawl effort in the Aleutian Islands, 1990-98.

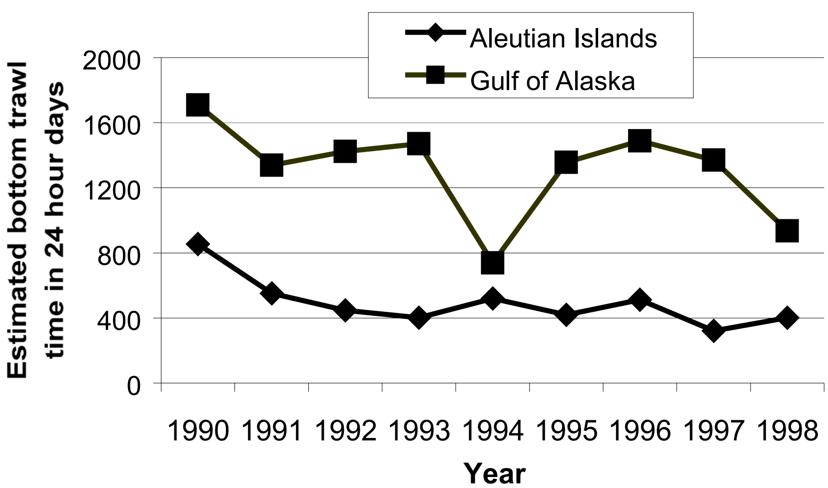



Figure 3. Estimated bottom trawl time in the Gulf of Alaska and Aleutian Islands during 1990-98.

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

## Trophic level of the catch

Contributed by Pat Livingston

To determine whether North Pacific fisheries were "fishing-down" the food web, the trophic level of the catch in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska areas was determined. The trophic level of each species in the catch was obtained from published accounts of diet for non-groundfish species and from the food habits data base of the Alaska Fisheries Science Center for groundfish species. Trophic level (e.g., 1 for phytoplankton, 2 for consumers of primary production, 3 for consumers of secondary production, etc.) of the total catch was determined by weighting the trophic level of each species in the catch by the proportion (by weight) of that species in the total catch and summing the weighted trophic levels in each year. Stability in the trophic level of the total fish and invertebrate catches in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska (Figure 1) are an indication that the "fishing-down" effect is not occurring in these regions. Catch biomass in the eastern Bering Sea has consisted mainly of pollock since the late 1960's. In the Aleutian Islands area catches were mostly Pacific ocean perch in the 1960's and walleye pollock, Pacific cod, and Atka mackerel in the late 1970's to the present. Gulf of Alaska catches in the 1960's were dominated by rockfish and moved to pollock dominated catches in the 1980's with declining contributions of pollock to the total catch in the 1990's Although, there has been a general increase in the amount of catch since the late 1960's in all areas, the trophic level of the catch has been high and stable over the last 25 years. A trophic level of four indicates the dominance of top-level predators in the catch.

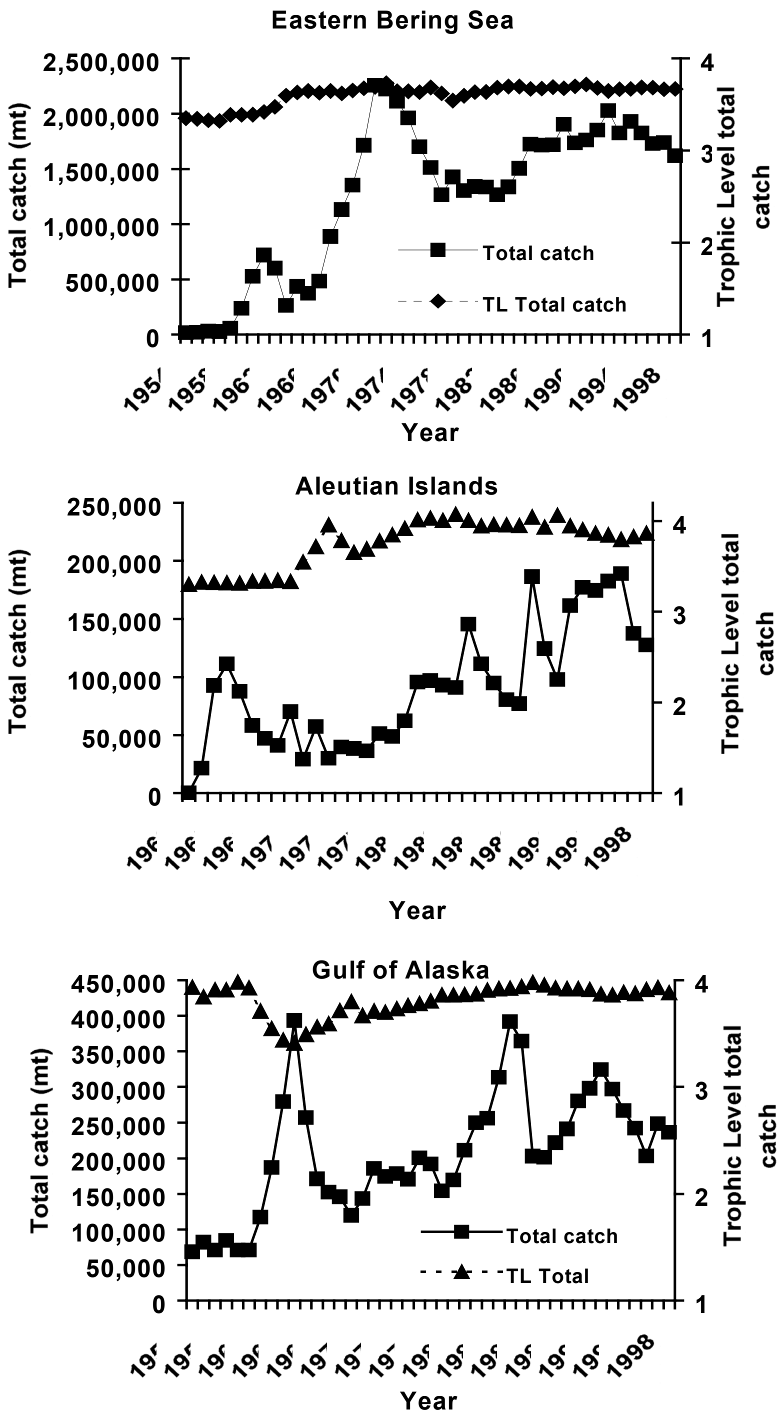



Figure 1. Historical estimates of the total groundfish (including halibut and herring) and shellfish catch and trophic level of the catch in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska.

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 |

## *Ecosystem Goal: Humans are part of Ecosystems*

Fishing overcapacity programs

Contributed by Dave Witherell

Overcapacity, wherein there are too many vessels to harvest the limited fisheries resources, is considered a problem in fisheries throughout the world. The problem is often manifested in short fishing seasons, increased enforcement problems, and reduced economic viability for vessel owners and crew members. Overcapacity can, under certain conditions, have grave implications for conservation as well.

The North Pacific Fishery Management Council has developed several programs to address overcapacity in the fisheries. Groundfish and crab management programs generally limit the number of vessels that are allowed to fish off Alaska. In addition, halibut and fixed gear sablefish are managed under an Individual Fishing Quota (IFQ) program, which does not limit the number of vessels, but instead, grants permission to individuals to harvest a specified percentage of the Total Allowable Catch (TAC) each year. Specific programs are reviewed below.

Moratorium on New Vessels

A moratorium on new vessel entry into the federally managed groundfish and crab fisheries was implemented in 1996. The program is considered a place holder while more comprehensive management measures are developed. Currently the owners of 1,853 groundfish and 664 crab vessels hold moratorium fishing rights. In addition to limiting the number of vessels the moratorium also restricted each vessel's length. Vessels that were less than 125' length overall may only be increased to 120 percent of their length on June 24, 1992, or up to 125', whichever is less; vessels that are 125' or longer may not increase their length. Increasing a vessel's length could add harvesting capacity without increasing the number of vessels.

License Limitation Program (LLP)

The LLP for groundfish and crab vessels is scheduled to be implemented on January 1, 2000, and will replace the vessel moratorium. The original LLP, approved in 1995, was intended as the second step in fulfilling the Council's commitment to develop a comprehensive and rational management program for fisheries off Alaska. Amendments to that program approved in 1998 tighten the LLP program and include additional restrictions on vessel numbers and fishery crossovers. Additional restrictions under development include an industry-funded license buyback program for the crab fisheries and further gear and species endorsement restrictions for the groundfish fisheries. Based on preliminary estimates of qualified vessels, the LLP should reduce the number of vessels eligible to participate in the Bering Sea/Aleutian Islands (BSAI) crab fisheries by more than 60% (down to approx. 283 licenses) compared to the current vessel moratorium. The number of vessels predicted to be eligible for groundfish licenses (N = 2,435) is slightly greater than the number currently holding moratorium permits (while the LLP carried stricter qualification standards, many moratorium permits were never claimed). However, the LLP will be more restrictive in terms of the areas a vessel can fish and the types of gear it can deploy. Also important to note is that the vast majority of the vessels qualifying for the LLP are longline vessels less than 60', and they are only eligible to participate in Gulf of Alaska fisheries. These vessels have typically had relatively small catch histories in past years.

Sablefish and Halibut Individual Fishing Quotas (IFQs)

The halibut and sablefish fisheries provide good examples of how the Council is working to control overcapacity in fisheries off Alaska. From 1975 to 1994 the Central Gulf of Alaska halibut fishing seasons decreased from approximately 125 days to single day openings, while catches increased. Faced with very short seasons and increasing fishing effort, the Council passed an IFQ program for both the halibut and fixed gear sablefish fisheries. These programs were initiated in 1995. After implementation, the fisheries changed from a short pulse fishery to one that extends over several months. IFQs have allowed participants to better match fishing capacity with the amount of fish they are allowed to harvest during a year. In recent years the numbers of vessels and persons have declined, even as the TACs have been increasing.

American Fisheries Act (AFA)

The AFA, passed in late 1998, among other things limited the number of harvesting and processing vessels that would be allowed to participate in the BSAI pollock fishery. Only harvesting and processing vessels that met specific requirements, based on their participation in the 1995-97 fisheries will be eligible to harvest BSAI pollock. Preliminary estimates indicate that 21 catcher/processors and 120 catcher vessels will qualify under the AFA. Nine large capacity catcher/processors were retired from the fishery by the AFA. Under the fishery cooperative structure now in place, not all 21 eligible catcher/processors fished during the 1999 late winter and early spring pollock seasons. The AFA also restricts eligible vessels from shifting their effort into other fisheries. "Sideboard" measures, as they have become known, prevent AFA eligible vessels from increasing their catch in other fisheries beyond their average 1995-97 levels. Sideboard restrictions reduce the likelihood that the fishing capacity of AFA eligible vessels will be increased to better compete in those fisheries.

## 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 916 in 1998 (Figure 1) and more than offset both a substantial increase in the number of pot vessels (231 in 1998 compared to 136 in 1994) and a modest increase in the number of trawlers (262 in 1998 compared to 256 in 1994). As a result, the total number of vessels decreased from 1,683 in 1994 to 1,273 in 1998 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 scheduled 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 |

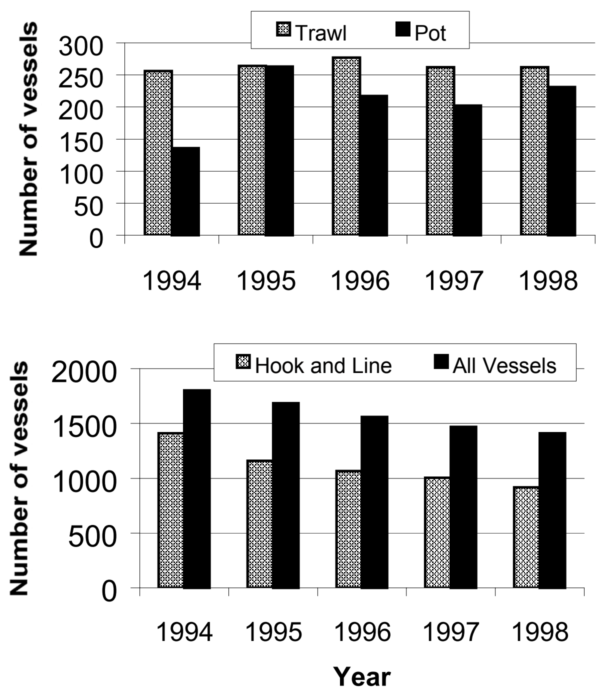



Figure 1.--Number of vessels participating in the groundfish fisheries in the EEZ off Alaska by gear type, 1994-98.

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