APPENDIX C

Ecosystem Considerations for 2007

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

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SUMMARY OF MAJOR CHANGES

- Updated the following sections/contributions in November 2006:
    - Responses to comments of the Scientific and statistical committee (SSC)
    - Executive Summary
    - Ecosystem Assessment
    - North Pacific Climate Overview
    - Winter Mixed Layer Depths at GAK 1 in the Northern Gulf of Alaska
    - Eastern Bering Sea Temperature and Ice Cover
    - Summer Bottom and Surface Temperatures –Eastern Bering Sea
    - Variations in water mass properties during fall 2000-2004 in the eastern Bering Sea
    - HAPC Biota – Bering Sea
    - HAPC Biota – Aleutian Islands
    - Variations in phytoplankton and nutrients during fall 2000-2004 in the eastern Bering Sea
    - Distribution, diet, and energy density of age-0 walleye pollock, *Theragra chalcogramma*, in the Bering Sea and Chukchi Sea, Alaska
    - Variations in juvenile sockeye and age -0 pollock distribution during fall 2000-2004 in the eastern Bering Sea
    - Forage – Gulf of Alaska
    - Forage – Eastern Bering Sea
    - Forage – Aleutian Islands
    - Prince William Sound Pacific herring
    - Southeast Alaska Herring
    - Historical trends in Alaskan salmon
    - ADF&G Gulf of Alaska Trawl Survey
    - Gulf of Alaska Small Mesh Trawl Survey Trends
    - Stock-recruitment relationships for Bristol Bay red king crabs
    - Miscellaneous Species – Gulf of Alaska
    - Jellyfish – Eastern Bering Sea
    - Miscellaneous species - Eastern Bering Sea
    - Miscellaneous Species – Aleutian Islands
    - Marine Mammals
    - Seabirds

- New contributions in September 2006:
    - Gulf of Alaska Zooplankton
    - Distribution and abundance trends in the human population of the Bering Sea/Aleutian Islands
    - Fish Stock Sustainability Index was added to the contribution entitled: Fish Stock Sustainability Index and status of groundfish, crab, salmon and scallop stocks

- Updated the following sections/contributions in September 2006:
    - Responses to comments of the Scientific and statistical committee (SSC)
    - Executive Summary
    - Ecosystem Assessment
    - Pollock Survival Indices –FOCI
    - Seasonal rainfall at Kodiak
    - Wind mixing at the southwestern end of Shelikof Strait
    - Ocean Surface Currents – Papa Trajectory Index 2005
    - Exploring Links between Ichthyoplankton Dynamics and the Pelagic Environment in the Northwest Gulf of Alaska.
    - Togiak Herring Population Trends

  - Trends in Groundfish Biomass and Recruits per Spawning Biomass
  - Update on EBS winter spawning flatfish recruitment and wind forcing
  - Combined Standardized Indices of recruitment and survival rate
  - Bering Sea Crabs
  - Marine mammals -fishery mortality and native subsistence harvest levels
  - Time Trends in Bycatch of Prohibited Species
  - Time trends in groundfish discards
  - Areas closed to bottom trawling in the EBS/ AI and GOA
  - Hook and Line (Longline) fishing effort in the Gulf of Alaska, Bering, Sea and Aleutian Islands
  - Groundfish bottom trawl fishing effort in the Gulf of Alaska, Bering Sea and Aleutian Islands
  - Groundfish pelagic trawl fishing effort in the Eastern Bering Sea
  - Trophic level of the catch
  - Fish Stock Sustainability Index and status of groundfish, crab, salmon and scallop stocks
  - Total annual surplus production and overall exploitation rate of groundfish
  - Fishing overcapacity programs
  - Groundfish fleet composition

- Completed and posted a website for the Ecosystem Considerations report and underlying data for many of the contributions in the report on the internet: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

- Included month and year of the last update as well as contact information for each contribution.

- Excluded grenadiers contribution in September 2006, since this will be in a separate chapter.

RESPONSES TO COMMENTS OF THE SCIENTIFIC AND STATISTICAL COMMITTEE (SSC)

October 2006 SSC Comments

1. …further streamline the Executive Summary to a short, bulleted list that only highlights major physical and biological changes that affect the Northeast Pacific environment in 2006 and their potential significance.

Response:
The format of the Executive Summary was changed to a short, bulleted list of recent and pertinent updates contained in the full report.

2. We also seek clarification on page 39 under the target species status concerning which species are "overfished" or not.

This section was re-worded. The two species that are considered overfished are listed (Pribilof Island blue king crab and St. Matthew Island blue king crab). It is also stated that no groundfish stock or stock complex is considered overfished.

December 2005 SSC Comments

1. The SSC suggested that, if in the future the principal discussion of the Ecosystem Considerations chapter was to be conducted during the October SSC meeting, that there should be a brief review of the most salient points in December, with an emphasis on those findings that could impact decisions about the setting of ABCs.

Response:
A brief review of the most salient points, with an emphasis on those findings that could impact decisions about the setting of ABCs, will be provided to the SSC in December, 2006.

2. BSAI pollok SAFE: Given the recent very low abundances of zooplankton, especially the copepod Calanus marshallae, on the middle shelf of the southeastern Bering Sea, it would seem that there should be either moderate or high concern about these low levels. Either [in the BSAI pollock SAFE] or in the Ecosystem SAFE, it should be discussed whether warming temperatures in the southern Bering Sea are adversely affecting the production of large species of zooplankton.

Response:
Currently, it is not clear what is causing the anomalously low summer zooplankton biomass in the Bering Sea. As new information emerges on this issue, an update will be provided in the Ecosystem Considerations report. Interesting observations regarding this and its potential effects on pelagic productivity are summarized in the Ecosystem Assessment (under the heading of “Results” and “Bering Sea”).

October 2005 SSC Comments:
1. The Ecosystem Considerations document includes an Executive Summary of Recent Trends that provides a useful and concise overview of recent conditions and trends in the stocks and the environment in the Bering Sea and Gulf of Alaska. The SSC encourages further development of this form of synthesis of the varied and numerous sources of information that comprise the main body of the document. It might be useful to frame the synthesis in terms of the effects that humans have on the ecosystem versus the effects of the ecosystem on humans.

Response:
The Executive Summary of Recent Trends was further developed to form a synthesis framed in terms of the effects that humans have on the ecosystem versus the effects of the ecosystem on humans.

2. Also because some of the information in the document will change infrequently, whereas other items will be updated regularly, each section of the report (and website) should indicate when it was last updated.

Response:
All sections now have the month and year that they were updated.

3. In the future the chapter (and website) should link stock assessment results with updates to the ecosystem assessment and consideration should be given to incorporating the climate information in to stock assessments and the ecosystem assessment.

Response:
We acknowledge that this is an important issue, and we strive and will continue to strive to attain this goal.

EXECUTIVE SUMMARY OF RECENT TRENDS

Human Effects on Ecosystems

- No significant adverse impacts of fishing on the ecosystem relating to predator/prey interactions, energy flow/removal, or diversity were noted, either in observed trends or ecosystem-level modeling results.

- The overall human population of BSAI fishing communities in 2000 was almost seven times larger than its 1920 population; however, the proportion of people living in those communities relative to the total Alaskan population has declined.

- Despite efforts by industry and regulators to control prohibited-species bycatch, both chinook salmon and “other salmon” (OS) bycatch have increased dramatically in recent years. Bycatch of “other salmon” was at a record high in 2005. To address these problems, the Council is considering means to control salmon bycatch. Between 2002 and 2004, herring bycatch increased dramatically, but was lower in 2005.

- The incidental take of seabirds decreased beginning in 1998 and, during 2002-2004, catch rates have been the lowest in the time series in the BS, AI, and GOA.

- Further examination of the trophic level of the catch supports the idea that fishing-down the food web is not occurring in Alaska, and there does not appear to be a serial addition of lower-trophic-level fisheries in the BS or GOA. In general, it appears that fishing events are episodic in the AI and GOA, and pollock dominate catches in the BS.

Ecosystem Effects on Humans

- The PDO was positive in 2006, is predicted to be negative in 2007/08, which would promote negative SST anomalies in the Northeast Pacific and is hypothesized to affect community structure and production of some fish species. Due to a probable El Niño event, a narrow strip of warmer than normal waters off the west coast of North America is likely to develop.

- Relative to the previous six years in the Bering Sea, 2006 spring months were colder, the ice extent was further south, and the ice retreat occurred later. May sea surface temperatures and summer bottom temperatures were the coldest since 1999, and there was a more extensive cold pool in the summer of 2006 than the previous 5 years.

- Despite the ice conditions in the Bering Sea in 2006, overall, there is a declining trend in March Arctic sea ice extent that has accelerated in the past four years. The implications of this trend for the North Pacific are likely to include a tendency for a shorter season during which intense cold-air outbreaks of arctic origin can occur.

- Physical data collected on the NMFS Gulf of Alaska bottom trawl survey indicate that summer temperatures in 2005 were the warmest on record. There has been a general warming of depths less than 50 m in the GOA through to 2005.

- Demersal groundfish species in the BSAI and GOA had above-average recruitments from the mid- or late 1970s to the late 1980s, followed by below-average recruitments during most of the 1990s. New results this year show there is an indication for above-average recruitment from 1994-2000 (with the exception of 1996).

- Annual groundfish surplus production in the EBS decreased between 1978 and 2004. Production in the GOA was much lower on average, less variable than that in the EBS, and decreased slightly from 1978 to 2004. Declines in production may be a density-dependent response to observed increases in biomass and aging populations of groundfish.

- Forage biomass in the eastern Bering Sea has dropped considerably since 1999, and pollock cannibalism also dropped abruptly in that year and has stayed low.

- Coinciding with the warm conditions during 2000-2004, summer zooplankton biomass was anomalously low in all four geographic domains of the BS.

- Jellyfish biomass, sampled in the EBS bottom trawl survey, was also low during 2001-2006 relative to the peak biomass that occurred in 2000. Jellyfish CPUE in the AI, however, was the highest on record in 2006.

- The ADFG/NMFS GOA small-mesh survey time series shows a transition from a community rich in shrimp and capelin to a community rich in groundfish following the 1976/1977 climate regime shift. Catches through 2005 do not show any significant deviation from the groundfish-dominated community state.

- The ADFG large-mesh trawl survey catch rates increased in recent years especially in 2006. There were record numbers of Tanner crab caught in Ugak Bay.

- Zooplankton time series in the central north GOA during 1998-2003 indicate zooplankton biomass was highest in 1998 and 2002, but varies with season and with habitat (shelf vs. slope as determined by local fronts and circulation).

- Also, in the GOA, analyses conducted on larval fish abundance data indicate that both basin- and local-scale environmental conditions appear to affect the spring abundance of larval fish.

- Prince William Sound herring biomass remains low. Southeastern Alaska herring biomass is expected to decrease due to low recruitment in 2004 and 2005.

- Generally, salmon catches in Alaska remain relatively high through 2005.

- Overall, seabird breeding chronology in 2003 was early or average, with early nesters predominate in the NB/C, SEBS, and SEAK. The highest number of late nesters was in SWBS. In 2003, there was a trend of above average or average seabird productivity in most regions, except in the southwest BS. Of the 96 seabird species-site samples, declining seabird populations comprised 22%, while 20% showed increasing trends, and the majority of samples showed no discernable change (58% of samples).

- In 2004, the number of northern fur seal pups born on the Pribilof Islands continued to decline.

- Although not all 1990s Steller sea lion trend sites in Alaska were surveyed in 2006, counts of non-pup sea lions on 1990s trend sites in the eastern and western Gulf of Alaska, and eastern Aleutian Islands were essentially unchanged between 2004 and 2006. Thus, the 2006 count indicates that the population of adult and juvenile Steller sea lions in these areas may have stabilized. In the western Aleutian Islands, non-pup counts on the 9 trend sites surveyed in 2006 declined 19% from 2004, suggesting that the decline observed in the western Aleutian Islands sub-area may be continuing.

INTRODUCTION

The Ecosystem Considerations appendix is comprised of three main sections:

i. Ecosystem Assessment
ii. Ecosystem Status Indicators
iii. Ecosystem-based Management Indices and Information.

The purpose of the first section, Ecosystem Assessment, is to summarize historical climate and fishing effects on the eastern Bering Sea/Aleutian Islands and Gulf of Alaska ecosystems using information from the other two sections and stock assessment reports. In future drafts, the Ecosystem Assessment section will also provide an assessment of the possible future effects of climate and fishing on ecosystem structure and function.

The purpose of the second section, Ecosystem Status Indicators, is to provide new information and updates on the status and trends of ecosystem components to stock assessment scientists, fishery managers, and the public. The goals are to provide stronger links between ecosystem research and fishery management and to spur new understanding of the connections between ecosystem components by bringing together many diverse research efforts into one document.

The purpose of the third section, Ecosystem-based Management Indices and Information, is 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.

Since 1995, the North Pacific Fishery Management Councils (NPFMC) Groundfish Plan Teams have prepared a separate Ecosystem Considerations section to the annual SAFE report. Each new Ecosystem Considerations section provides updates and new information to supplement the original section. The original 1995 section 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 section 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 section 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 section 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.

In 1999, a proposal came forward to enhance the Ecosystem Considerations section 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,
4) Provide a stronger link between ecosystem research and fishery management, and

5.) Provide an assessment of the past, present, and future role of climate and humans in influencing ecosystem status and trends.

The 2000-2006 Ecosystem Considerations sections included some new contributions in this regard and will be built upon in future years. Evaluation of the meaning of the observed changes needs to be done separately and in the context of how the indicator relates to a particular ecosystem component. For example, particular oceanographic conditions such as bottom temperature increases might be favorable to some species but not for others. Future evaluations will need to follow an analysis framework, such as that provided in the draft Programmatic groundfish fishery environmental impact statement that links indicators to particular effects on ecosystem components.

In 2002, stock assessment scientists began using indicators in this chapter to systematically assess ecosystem factors such as climate, predators, prey, and habitat that might affect a particular stock. Also, information regarding a particular fishery's catch, bycatch and temporal/spatial distribution will be used to assess possible impacts of that fishery on the ecosystem. Indicators of concern can be highlighted within each assessment and could be used by the Groundfish Plan Teams and the Council to justify modification of allowable biological catch recommendations or time/space allocations of catch.

It was requested that contributors to the ecosystem considerations chapter provide actual time series data or make it available electronically. Most of the time series data for contributions are now available on the web, with permission from the authors. It is particularly important that we spend more time in the development of ecosystem-based management indices. Ecosystem-based management indices should be developed to 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 nonextractive uses.
4. Maintain the concept that humans are components of the ecosystem.

The Ecosystem Considerations report and data for many of the time series presented in the report are now available online at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Past reports and all groundfish stock assessments are available at:
http://www.afsc.noaa.gov/refm/stocks/assessments.htm

If you wish to obtain a copy of an Ecosystem Considerations Chapter version prior to 2000, please contact the Council office (907) 271-2809.

ECOSYSTEM ASSESSMENT

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Introduction

Fish are only one component of a complex marine ecosystem. Removing fish for human consumption can potentially have broad impacts on the marine ecosystem unless safeguards are incorporated into fishery management plans. Fisheries can impact fish and ecosystems by the selectivity, magnitude, timing, location, and methods of fish removals. Fisheries can also impact ecosystems by vessel disturbance, nutrient cycling, introduction of exotic species, pollution, unobserved mortality, and habitat alteration. Climate variability can affect components of marine ecosystems by altering ocean conditions (e.g., temperature, currents, water column structure). In the Bering Sea and Gulf of Alaska, changes coincident with climate regime shifts have been observed that affect the survival and recruitment of pelagic and demersal fishes, the abundance of forage fish and shrimp, the amount of primary and secondary production, and the distribution of cold water species.

Ecosystem-based management strategies for fisheries are being developed around the world to address the larger impacts due to fishing, while incorporating climate impacts. Ecosystem-based fishery management aims at conserving the structure and function of marine ecosystems, in addition to conserving fishery resources. An ecosystem-based management strategy for marine fisheries is one that reduces potential fishing impacts while at the same time allowing the extraction of fish resources at levels sustainable for the ecosystem. Groundfish fisheries in the BSAI and GOA are managed with conservative single-species harvests, catch and bycatch monitoring and constraints, OY caps, areas closed to fishing for protection of other species, and forage fish protection (NMFS 2003). Evaluation of the present and likely future fishing effects of groundfish fisheries operating under these constraints from an ecosystem point-of-view may provide understanding of the possible implications of the current management approach. As noted by Carpenter (2002), a limitation of ecological forecasts includes the uncertainty of predictions because the future probability distributions of drivers such as climate may be unknown or unknowable. Development of possible future scenarios, expansion of our forecasting capabilities within the space/time constraints that are relevant to human action, and identification of management choices that are robust to a wide range of future states are possible ways this assessment can be broadened in the future.

The primary intent of this assessment is to summarize and synthesize historical climate and fishing effects on the shelf and slope regions of the eastern Bering Sea/Aleutian Islands and Gulf of Alaska from an ecosystem perspective and to provide an assessment of the possible future effects of climate and fishing on ecosystem structure and function. The Ecosystem Considerations section of the Groundfish SAFE provides the historical perspective of status and trends of ecosystem components and ecosystem-level attributes using an indicator approach. For the purposes of management, this information must be synthesized to provide a coherent view of ecosystems effects in order to clearly recommend precautionary thresholds, if any, required to protect ecosystem integrity. To this end, the assessment summarizes recent trends by distinct ecosystem properties that require consideration (Table 1).

The eventual goal of synthesis is to provide succinct indices of current ecosystem conditions reflecting these ecosystem properties. In order to perform this synthesis, a blend of data analysis and modeling will need to be employed to place measures of current ecosystem states in the context of history and past and future climate. In this year’s assessment, an extended analysis of **forage production and predation vs. fishing mortality** combines model results with data; it is the intent that in successive years, different focus areas will be used to develop a set of indices that can be used to clearly communicate ecosystem status and the direction of future interactions.

Methods

Assessment Approach: Effects categories, indicators, thresholds

Ecosystems consist of populations and communities of interacting organisms and their physical environment that form a functional unit and have some characteristic trophic structure and material cycles (i.e., how energy or mass moves among the groups). Evaluation of the effects of fishing on ecosystems should include these characteristics of ecosystems: populations, communities, physical environment, trophic structure and material (or energy) cycles.

Fishing may alter the amount and flow of energy in an ecosystem by removing energy and altering energetic pathways through the return of discards and fish processing offal back into the sea and through unobserved mortality of organisms not retained in the gear. The recipients, locations, and forms of this returned biomass may differ from those in an unfished system. Selective removal of species and/or sizes of organisms that are important in marine food web dynamics such as nodal prey species or top predators has the potential to change predator/prey relationships and community structure. Removals at concentrated space and time scales may impair the foraging success of animals tied to land such as pinnipeds or nesting seabirds that may have restricted foraging areas or critical foraging times that are key to survival or reproductive success. Introduction of non-native species may occur through emptying of ballast water or introduction of hull-fouling organisms from ships from other regions (Carlton 1996). These species introductions have the potential to cause large changes in community dynamics. Fishing can alter different measures of diversity. Species level diversity, or the number of species, can be altered if fishing essentially removes a target or nontarget species from the system. Fishing can alter functional diversity if it selectively removes a trophic or other type of functional guild member and changes the evenness with which biomass is distributed among a trophic guild. Fishing gear may alter bottom habitat and damage benthic organisms and communities that serve important functional roles as structural habitat or trophic roles. Fishing can alter genetic level diversity by selectively removing faster growing fish or removing spawning aggregrations that might have different genetic characteristics than other spawning aggregations.

Significance thresholds for determining the ecosystem-level impacts of fishing would involve both population-level thresholds that have already been established for species in the system (minimum stock size thresholds -MSST for target species, and fishing induced population impacts sufficient to lead to listing under the Endangered Species Act or fishing induced impacts that prevent recovery of a species already listed under ESA for nontarget species) and community or ecosystem-level attributes that are outside the range of natural variability for the system (Table 1). These community or ecosystem-level attributes are more difficult to measure directly and the range of natural variability of those attributes is not well known. We may also lack sufficient data on population status of target or nontarget species to determine whether they are above or below MSST or ESA-related thresholds. Thus, indicators of the strength of fishing impacts on the system will also be used to evaluate the degree to which any of the alternatives may be having a significant ecosystem impact relative to the baseline.

A great deal of literature has been written on possible indicators of ecosystem status in response to perturbations (eg., Pauly et al. 1998, Rice and Gislason 1996, Murawski 2000). These indices can show changes in energy cycling and community structure that might occur due to some external stress such as climate or fishing. For example, fisheries might selectively remove older, more predatory individuals. Therefore, we would expect to see changes in the size spectrum (the proportion of animals of various size groups in the system), mean age, or proportion of r-strategists (faster growing, more fecund species such as pollock) in the system. These changes can increase nutrient turnover rates because of the shift towards younger, smaller organisms with higher turnover rates. Total fishing removals and discards also provide a measure of the loss and re-direction of energy in the system due to human influences. Total fishing removals relative to total ecosystem energy could indicate the importance of fishing removals as a source of energy removal in an ecosystem. Changes in scavenger (animals that consume offal, such as northern fulmars) populations that show the same direction of change as discards could be an indicator of the degree of influence discards have on the system. Discards as a proportion of total natural detritus would also be a measure that could indicate how large discards are relative to other natural fluxes of dead organic material. Levels of total fishing removal or fishing effort could also indicate the potential for introduction of non-native species through ballast water in fishing vessels. Fishing practices can selectively remove predators or prey. Tracking the change in trophic level of the catch may provide information about the extent to which this is occurring (eg., Pauly et al. 1998). Thus, we will use measures of total catch, total discard, and changes in trophic level of the catch to indicate the potential of fishing to impact ecosystem energy flow and turnover.

Total catch and trophic level of the catch will also provide information about the potential to disrupt predator/prey relationships through introduction of non-native species or fishing down the food web through selective removal of predators, respectively. Pelagic forage availability will be measured quantitatively by looking at population trends of pollock and Atka mackerel, target species that are key forage for many species in the BSAI and GOA. Bycatch trends of nontarget species such as the managed forage species group and herring will also be used as indicators of possible fishery impacts on those pelagic forage groups. Angermeier and Karr (1994) also recognized that an important factor affecting the trophic base is spatial distribution of the food. The potential for fishing to disrupt this spatial distribution of food, which may be particularly important to predators tied to land, will be evaluated qualitatively to determine the degree of spatial and temporal concentration of fishery removals of forage. We will evaluate these factors to determine the potential of fishing to disrupt predator/prey relationships.

The scientific literature on diversity is somewhat mixed about what changes might be expected due to a stressor. Odum (1985) thought that species diversity (number of species) would decrease and dominance (the degree to which a particular species dominated in terms of numbers or biomass in the system) would increase if original diversity was high while the reverse might occur if original diversity was low. Significance thresholds for species level diversity due to fishing are catch removals high enough to cause the population of one or more target or non-target species to fall below minimum biologically acceptable limits: either minimum stock size threshold (MSST) for target species, one that would trigger ESA listing, or that would prevent recovery of an ESA-listed species. Genetic diversity can also be altered by humans through selective fishing (removal of faster growing individuals or certain spawning aggregations) (see review in Jennings and Kaiser 1998). Accidental releases of cultured fish and ocean ranching tends to reduce genetic diversity (Boehlert 1996). Significance thresholds for genetic diversity impacts due to fishing would be catch removals high enough to cause a change in one or more genetic components of a target or non-target stock that would cause it to fall below minimum biologically acceptable limits. More recently, there is growing agreement that functional (trophic or structural habitat) diversity might be the key attribute that lends ecosystem stability (see review by Hanski 1997). This type of diversity ensures there are sufficient number of species that perform the same function so that if one species declines for any reason (human or climate-induced), then alternate species can maintain that particular ecosystem function and we would see less variability in ecosystem processes. However, measures of diversity are subject to bias and we do not know how much change in diversity is acceptable (Murawski 2000). Furthermore, diversity may not be a sensitive indicator of fishing effects (Livingston et al. 1999, Jennings and Reynolds 2000). Nonetheless, we will evaluate the possible impacts that fishing may have on various diversity measures.

Table 1. Significance thresholds for fishery induced effects on ecosystem attributes.

Issue	Effect	Significance Threshold	Indicators
Predator-prey relationships	Pelagic forage availability	Fishery induced changes outside the natural level of abundance or variability for a prey species relative to predator demands	Population trends in pelagic forage biomass (quantitative - pollock, Atka mackerel, catch/bycatch trends of forage species, squid and herring)
	Spatial and temporal concentration of fishery impact on forage	Fishery concentration levels high enough to impair the long term viability of ecologically important, nonresource species such as marine mammals and birds	Degree of spatial/temporal concentration of fishery on pollock, Atka mackerel, herring, squid and forage species (qualitative)
	Removal of top predators	Catch levels high enough to cause the biomass of one or more top level predator species to fall below minimum biologically acceptable limits	Trophic level of the catch Sensitive top predator bycatch levels (quantitative: sharks, birds; qualitative: pinnipeds) Population status of top predator species (whales, pinnipeds, seabirds) relative to minimum biologically acceptable limits
	Introduction of nonnative species	Fishery vessel ballast water and hull fouling organism exchange levels high enough to cause viable introduction of one or more nonnative species, invasive species	Total catch levels

Energy flow and balance	Energy re-direction	Long-term changes in system biomass, respiration, production or energy cycling that are outside the range of natural variability due to fishery discarding and offal production practices	Trends in discard and offal production levels (quantitative for discards) Scavenger population trends relative to discard and offal production levels (qualitative) Bottom gear effort (qualitative measure of unobserved gear mortality particularly on bottom organisms)
	Energy removal	Long-term changes in system-level biomass, respiration, production or energy cycling that are outside the range of natural variability due to fishery removals of energy	Trends in total retained catch levels (quantitative)
Diversity	Species diversity	Catch removals high enough to cause the biomass of one or more species (target, nontarget) to fall below or to be kept from recovering from levels below minimum biologically acceptable limits	Population levels of target, nontarget species relative to MSST or ESA listing thresholds, linked to fishing removals (qualitative) Bycatch amounts of sensitive (low potential population turnover rates) species that lack population estimates (quantitative: sharks, birds, HAPC biota) Number of ESA listed marine species Area closures

	Functional (trophic, structural habitat) diversity	Catch removals high enough to cause a change in functional diversity outside the range of natural variability observed for the system	Guild diversity or size diversity changes linked to fishing removals (qualitative) Bottom gear effort (measure of benthic guild disturbance) HAPC biota bycatch
	Genetic diversity	Catch removals high enough to cause a loss or change in one or more genetic components of a stock that would cause the stock biomass to fall below minimum biologically acceptable limits	Degree of fishing on spawning aggregations or larger fish (qualitative) Older age group abundances of target groundfish stocks

Model and data synthesis in assessing ecosystem effects of fishing

With the increased call for Ecosystem Approaches to Management (EAM) for marine resources, the development of multispecies population dynamics (i.e. predator/prey) models has passed from the debate stage (e.g. Hollowed et al. 2000a) through stages of theoretical development (e.g. Walters and Martell 2004, Yodzis 1998) and the models have undergone proliferation and initial evaluation (e.g. Plagányi and Butterworth 2004). These models are now reaching the point of establishing statistical rigor comparable with single-species assessment techniques (e.g. Mori and Butterworth 2005; Jurado-Molina et al. 2005) and providing management guidance (e.g. Dorn et al. 2005).

In this year's assessment, we focus on integrating data and models to show historical trends in forage fish abundance, based on point estimates (maximum likelihood estimates) of predator/prey functional responses derived from food web (ECOPATH) models of the eastern Bering Sea and Gulf of Alaska (Aydin et al,. in review). These results are then used to provide an index of fishing vs. predation mortality for development of future ecosystem-level thresholds for fishing. These fitting procedures, described in detail in Appendix 1, represent a significant advance in providing point estimates of quantities of interest from ecosystem models.

However, while the development of statistical rigor may improve model precision, the question of accuracy remains open. In particular, are current multispecies models evaluated in such a way that reported uncertainty (i.e. error ranges) sufficiently brackets ecological hypotheses to capture the potential surprising consequences of indirect trophic effects? While management advice from multispecies models is currently limited to advisory or strategic evaluation roles rather than to stock assessment, the need to evaluate the uncertainty in the models remains. In particular, models used to investigate strategic alternatives (for example, trading off marine mammals against fish harvesting) may require a different standard from stock assessments. Such a standard is not necessarily "higher"; rather, it should focus on different criteria. A quota-setting, single-species, management model requires setting a single value with the highest possible likelihood; in a tactical sense, model error or bias can be confronted in an adaptive manner with sufficiently regular (e.g. annual) corrections or updates.

On the other hand, a model built for strategic evaluation exists to define a broad policy infrequently; for example, it may be used to define long-term sustainable reference levels, overfishing limits, set asides of prey species for predators, or overall management plan structures. It should be expected that the managerial, scientific, and political will for strategic decisions informed by these models will only be correctable on the scale of a decade or more. For such models, emphasis should be placed not on the single outcomes with the highest likelihoods, but on reporting the "reasonable range of possibilities" with emphasis on looking for surprises or undesirable outcomes that have a moderate probability of occurring.

To date, two general approaches have been taken to investigate multispecies models in specific marine management contexts; either to start with a single species and work outwards, adding complexity when necessary, or to start with the whole ecosystem and work inwards, reducing complexity when unnecessary. Each approach is adapted to solving a very different type of problem.

The first approach is to start with a detailed, single-species model, and to add predator/prey components only as necessary to focus on key interactions. Provided it is known that the majority of species interactions for the target species are covered by a few, strongly-linked species, such models can be extended to improve assessments for multiple predators and prey simultaneously. Multispecies Virtual Population Analysis (MSVPA; Sparre 1991, Jurado-Molina et al. 2005) is perhaps the most well-known model in this category. Minimum realistic models in operation today can provide specific and significant statistical improvements to the performance of single-species models, but only when used in the context of estimating parameters such as natural mortality that are already a part of those models (e.g. Hollowed et al. 2000b).

The second approach is to start from the "big picture"; that is, to build and investigate models of "the whole ecosystem" or, in a predator/prey context, the whole food web. This method has been made extremely popular in recent years by the dissemination of the software package Ecopath with Ecosim (EwE; Christensen et al. 2005), but in the direct context of marine ecosystem management, such approaches have been used extensively for over 30 years (e.g., for Georges Bank; Cohen et al. 1982 or for the Bering Sea; Levaestu and Livingston, 1980). The quantification of food web interactions has been listed as an important component of developing "Ecosystem Approaches" to management (EPAP1998; NRC 2006).

The strength of whole ecosystem approaches does not lie in producing point estimates of quantities of interest, but rather in examining management alternatives across a range of moderate or highly likely ecosystem parameter sets. In this sense, Occam's Razor may not be the best world view from which to examine Ecosystem Approaches to Management. Even when a "single most likely" explanation for a historical phenomenon may be uncovered, its historical context may limit its informative power for the future (Gaichas 2006). Ecosystem models should focus on avoiding management "surprises" (such as trophic cascades to undesirable species), whether the surprises would arise from not understanding the past, or from having insufficient imagination about the future. To this end, it is important to include sufficient complexity both in food web structure (topology) and in functional relationships (responses) in the development an ecosystem approach. Even if this expands the range of data uncertainty (observation error), the limitation of bias and resulting unexpected results through the inclusion of a range of possibilities should have priority over producing a point estimate of any one outcome.

Results

Model Synthesis: Forage and Predation in the Bering Sea and Gulf of Alaska

Total production in a marine ecosystem is a product of both bottom-up and top-down forces. Ultimately, the total production for a single trophic level within an ecosystem is limited by the total photosynthetic energy available in an ecosystem, less 80% or more respirative losses occurring at each trophic level (bottom-up control). However, top-down control through fishing or environment, or competition within a single trophic level may have significant impacts on the structure of individual trophic levels. If the control of production shifts within an ecosystem, long-term expectation of fisheries yield and the impact of fisheries on ecosystem structure and function may shift as well, whether through natural or anthropogenic causes. This is important to evaluate in Alaska as fisheries are managed under an optimal yield (OY) cap which set an expectation for the total fisheries production of an ecosystem.

Measures of top-down control: fishing vs. predators

Current evidence suggests that the main sources of top-down control of forage fish in the Bering Sea and Gulf of Alaska ecosystems come from predatory fish rather than fishing, although individual top predators, such as Pacific cod, may be fully exploited by fisheries. Mueter (Figs. 155 and 157 this report) show that annual surplus production (ASP) of groundfish in the Bering Sea and Gulf of Alaska has dropped in recent years. He suggests that, rather than being a measure of ecosystem-level overfishing, this decline in ASP is due to density-dependence in large groundfish populations that are currently maintained above $B_{MSY..}$ This density-dependence may also be a function of aging populations of groundfish, especially in the Bering Sea, as seen in the size compositions of current groundfish populations according to recent stock assessments (Figure 1). Strong recruitment events for large predators in the late 1970s (Pacific cod) and mid 1980s (arrowtooth flounder, rock sole, and flathead sole) followed by lower recruitment in the 1990s has created a biomass of predatory fish that is currently dominated by individuals >50cm fork length (Figure. 1A-C). Walleye pollock has shown oscillations of size composition between smaller and larger fish with a period of 8-12 years, perhaps due to cycles of cannibalism (Figure 1D). It is worth noting that the most recent peak in size composition of smaller (<30cm fork length) walleye pollock in 2002-2003 was smaller than previous peaks in 1966-68, 1978-79, and 1991-92 (Figure 1D), perhaps due to the increasing importance of predation on pollock by other predators such as arrowtooth flounder. The trend in predator biomass for Gulf of Alaska is discussed under model reconstructions, below.

Another index that has been suggested as a measure of overall top-down control of the ecosystem due to fishing is the trophic level of the fishery; in particular, the notion of “fishing down the food web” has been popularized in recent years. The trophic level of the catch and the Fishery in Balance (FIB) indices have been monitored in the BS, AI, and GOA ecosystems to determine if fisheries have been "fishing-down" the food web by removing top-level predators and subsequently targeting lower trophic level prey. The FIB index was developed by Pauly et al. (2000) to ascertain whether trophic level catch trends are a reflection of deliberate choice or of a fishing-down the food web effect. This index declines only when catches do not increase as expected when moving down the food web (i.e., lower trophic levels are more biologically productive), relative to an initial baseline year. Although there has been a general increase in the amount of catch since the late 1960s in all three areas of Alaska, the trophic level of the catch has been high and relatively stable over the last 25 years (Figure 154). Unlike other regions in which this index has been calculated, such as the Northwest Atlantic, the FIB index and the trophic level of the catch in the EBS, AI, and GOA have been relatively constant and suggest an ecological balance in the catch patterns (Figure 154).

The single metrics of TL or FIB indices, however, may hide details about fishing events. We, therefore, plotted the trophic level of catches in the BS, AI, and GOA in a similar style to that recently published by Essington et al. (2006; Figure 2). This further examination supports the idea that fishing-down the food web is not occurring in Alaska, and there does not appear to be a serial addition of lower-trophic-level fisheries in the BS or GOA. In the AI, a decline in the overall trophic level of the catch may have been obscured by episodic fishing events. Catches of Atka mackerel (trophic level 3.64) began increasing in the mid-1980s. Pollock (trophic level 4.07) catches were relatively high in the 1980s and 1990s, but declined after 1998, at which point cod (trophic level 4.31) catches were much higher than they had been prior to 1992. The increase in cod catches may have offset any decrease in the observed trophic level of the catch as would have been expected with the generally increasing trend in Atka mackerel catches and decreasing catches of pollock over time. In general, it appears that fishing events on different species are episodic in the AI and GOA, while pollock steadily dominate catches in the BS throughout the period.

Measures of bottom-up control: Forage fish and predation

Forage fish abundance and availability to predators will have a major impact on the productivity of upper trophic levels. Changes in bottom-up productivity overall may be a current concern in the Bering Sea, as Napp and Shiga (Figure 56, this report) have noted that zooplankton biomass has been anomalously low in the Bering Sea since 2000. No long-term historical surveys exist that are specifically targeted towards forage biomass; the AFSC bottom trawl survey has a low (unknown) catchability for most forage species, as suggested by the fact that estimates of forage fish consumption by groundfish (e.g. capelin, Yang et al. 2005) are orders of magnitude higher than survey estimates of biomass for those species. At the same time, Survey Catch-per-unit-Effort (CPUE) indices for several forage fish (Figure 64; Lauth this report) may be useful as trends in selected forage fish abundances; on their own, the CPUE indices can not show whether the total production of forage fish has changed as a response to observed zooplankton trends.

However, it is possible to use these individual CPUE indices as a sum of total forage fish abundance by using the minimum consumption estimates to calculate the catchability of forage fish by the survey relative to the catchability of forage fish by predatory groundfish. For the eastern Bering Sea, we summed the CPUE indices of forage species shown in Figure 64 by calculating a catchability (q) for each forage species that is the ratio between CPUE of that species in a reference year and the consumption of that species by groundfish in the reference year as estimated from groundfish stomach contents data collected by the AFSC Trophic Ecology Laboratory (see Appendix 1 for calculation methods). This method requires that direct diet estimations be available for a large majority of the consumers of the forage species in question; 1991 was used as the reference year for this analysis due to the breadth of stomach collections performed during year. For walleye pollock and groundfish predators, for which age-structured stock assessments were available, the annual biomass estimates from each stock assessment were used directly.

For the Gulf of Alaska, the biomass required to support consumption was calculated across two reference survey years, 1990, and 1993 as for the Bering Sea, above. However, since trawl survey data was not available for each year, a historical reconstruction of forage fish abundance was performed for the years 1965-2005, using maximum likelihood estimation of predator/prey functional response parameters between groundfish and forage species, using the ELSEAS biomass dynamics model described in Appendix 1. Again, biomass estimates from age-structured stock assessment models were used directly when available.

The biomass of species are reported as biomass densities (t/km^2) to allow comparisons of structure and function between ecosystems. Biomass densities reported for the Bering Sea are assumed to be spread over the 495,000 km^2 of the Bering Sea shelf and slope survey area, including portions of the Aleutian Islands survey area that lie within the Bering Sea management region (management region 518, east of 170°W). Biomass densities for the Gulf of Alaska cover 292,000 km^2 of the western and central GOA shelf and slope (management regions 610-640, between 170°W and 140°W), but exclude the eastern Gulf of Alaska.

Bering Sea

Figure 3A shows the eastern Bering Sea stock assessment biomass of Age 2+ walleye pollock (Ianelli et al. 2005a) for the survey years 1982-2005, which ranged between 10 and 27 t/km^2 during this time period. The period between 1990 and 1992 was a low period with biomass densities less than 15 t/km^2. Biomass of several other forage species, calculated from CPUE and consumption estimates as described above, are shown in Figures 3B-C. Figure 3B includes shrimp as forage while Figure 3C shows the forage without shrimp. Squid are not shown as their catch rates were too variable within a single year to produce a meaningful estimation.

Two trends are worth noting in Figures 3B-C. First of all, the decline in pollock in 1990-93 was immediately followed by an increase in the total biomass of other forage species, including shrimp and capelin, in 1992-1994, peaking in 1993. For shrimp, pollock inflict a large proportion of their mortality, so this may represent a decrease in top-down control. However, pollock are not a major predator on capelin, sandlance, or other forage fish, suggesting that overall food supply of forage species (euphausiids and copepods) may be specifically limiting total forage fish production, and that a decrease in pollock production may lead to a release of other energy pathways for forage.

However, a more worrying trend, in terms of bottom-up production, may be seen in the latter years of these time series. In particular, sandlance biomass dropped abruptly between 1997 and 1998, and the years between 1999 and 2005 are the lowest since 1982. This drop suggests that the decline in zooplankton biomass noted by Napp and Shiga (this report) may indeed represent a decline in overall Bering Sea pelagic productivity since 1999-2000. If true, it is unclear if this is a drop in overall productivity or a shift in productivity to the benthos; there is no specific evidence of increases in benthic productivity in the ecosystem.

Another trend of concern in the Bering Sea is the recent increase in arrowtooth flounder biomass; in the Gulf of Alaska, the increase in predation by arrowtooth flounder may have been instrumental to the decline in pollock since the early 1990s. However, as shown in Figure 4A, the total biomass of groundfish predators, according to stock assessment results, has declined since a peak in 1987, primarily due to a decrease in Pacific cod biomass. Point estimates of summer consumption from the AFSC bottom trawl surveys (e.g. Lang et al. 2005) show a more complex picture between 1985-2003 (Figure 4B). Up until 1997, cannibalism was the main source of predation mortality for pollock; in 1998, cannibalism abruptly dropped and has remained low since. While arrowtooth flounder accounted for half of pollock consumption in 2003, the total consumption in these later years is lower than it was prior to 1998. Still, as arrowtooth flounder and Pacific cod consume larger pollock than do pollock themselves, this represents a shift to higher predation on older pollock.

Gulf of Alaska

Surveys in the Gulf of Alaska are more infrequent and insufficient to show year-to-year changes, so we rely on inferences made from historical reconstructions of forage demand made from food web models. The disadvantage of this method is that it relies on extrapolations of forage fish abundance to periods when no data is available; however, an advantage is that this extrapolation method is calibrated in years in which data exists, and can then be extended backwards provided a limited number of time series exist to drive the model through the covered period. In this case, we were able to extend reconstructions from 1965-2005 based on stock assessment and catch data.

The detailed methods for the extrapolation are discussed in Appendix 1. Briefly, a food web (ECOPATH) model, constructed for the time period 1990-1993, was taken as the starting point for fitting predator/prey functional responses used for a biomass dynamics model. Also included are time series of catches for whales and crabs to attempt to reconstruct historical biomass levels that would have been required to obtain historical harvest levels.

While the food web is a static matrix of energy flows, each predator/prey link (functional response) in the resulting biomass dynamics model a three-parameter function of predator and prey biomass (Appendix 1) that allows for dynamic foraging behavior such as prey switching within the model, creating the possibility of multiple equilibrium points and phase shifts ("regime" shifts) within the modeled biota. To perform a historical reconstruction and fitting procedure, biomass in the food web is "spun up" for 20 modeled years to allow the model to equilibrate to 1965 stock assessment biomass levels. The model is then run forward for the period 1965-2005 applying reported catches by gear and a gear-specific bycatch catchability matrix based on data from the years 1997-2001. Parameters for the functional response are fit using maximum likelihood estimation as discussed in the Appendix 1.

The dimensionality of these functional responses (three parameters for each of 2000+ predator/prey pairs) is reduced by splitting each functional response into predator- and prey- specific components, resulting in six parameters for each of 119 species in the model. Additionally, base respiration rates determining production (P/B) from consumption and residual, non-predation mortality ("M0") are fit for each species, so each species is governed by a total of 8 parameters. Age-structured species in the model have additional parameters such as age-of-maturation and growth rate; these parameters are not currently subjected to fitting.

Figure 5 shows the resulting maximum likelihood estimates for the biomass of forage species in the Gulf of Alaska. Walleye pollock, Pacific herring, and rockfish trends are directly from the single-species stock assessments, while other species biomasses are responding to changes in groundfish biomass through the functional responses. Figure 5A includes shrimp as forage, while Figure 5B shows forage species without shrimp. Shrimp, in particular, are an important forage species in the Gulf of Alaska for piscivorous groundfish such as arrowtooth flounder but are less important to pelagic foragers such as Steller sea lions.

If shrimp are included as forage species (Figure 5A), the reconstruction indicates that forage biomass in the Gulf of Alaska was highest in the late 1960s at 65t/km^2**,** dropped to a minimum in the early 1980s as pollock increased, then returned to nearly 60t/km^2 by 2005. It is interesting that the minimum total forage occurred when pollock were at their peak; in the model, this is due to the fact that large pollock are also a predator on the other forage species. Another important note is that the model predicts a recovery of shrimp in recent years rather than the decline reported in nearshore small-mesh surveys by Piatt and Anderson (1999) as evidence for a "regime shift" of energy pathways in the Gulf. In fact, the continued importance and abundance of shrimp in recent years is confirmed by their continued importance in groundfish diets throughout the 1990s and up to 2005 (e.g. Yang et al. 2006).

On the other hand, if shrimp are not counted in the forage category, forage biomass can be seen to have decreased nearly 20%, from 37t/km^2 in the late 1960s to 30 t/km^2 between 2001 and 2005. According to the model, capelin drop as pollock biomass increases in the late 1970s, and fail to recover following the subsequent pollock declines between 1981 and 1985.

At the same time, predator biomass in the Gulf of Alaska has increased dramatically, primarily due to increases in arrowtooth flounder biomass (Figure 6A). The total predator density shown in Figure 6A is also considerably higher than that of the eastern Bering Sea (Figure 4A). When viewed by consumption rate rather than absolute biomass, it is worth noting that consumption of forage by whales remains high throughout the time series (Figure 6B), in spite of the substantial reduction of whale biomass in the late

1960s. The dominance of groundfish predators in the Gulf of Alaska suggests that a combination of top-down and bottom-up process oriented research will be important to fully understanding ecosystem dynamics in this system. This apparently high predation may also have important implications for fisheries management, especially for commercially important forage species such as pollock (see below).

Developing indices and thresholds of surplus production and predation

Even as fisheries policy has moved to more risk-averse strategies than fishing at maximum sustainable yield (MSY), the strategic assumption of "surplus" still exists in fisheries management policy. In contrast, an alternative viewpoint is that surplus does not truly exist because ecosystems are "strongly connected" predator/prey systems where all energy is used within the system (see Aydin 2004 for a discussion in relation to assumptions in ecosystem and age-structured population models). It is difficult to assess whether current fisheries practices "significantly take away" energy from other predators such as marine mammals. In particular, densities of fish required for successful foraging may be substantially higher than the amount actually consumed by predators, and thresholds of prey density may exist below which predator foraging or reproduction drops substantially (Furness, personal communication). Still, it is worth assessing, as a first step, whether the combination of current total fishing and predation on individual species is high compared to the species' production.

Figure 7A shows the mortality of walleye pollock, as estimated for 2005 for the Bering Sea and Gulf of Alaska from the existing food web models, using the maximum likelihood technique described above to estimate consumption and production rates of each species (119 species in the Gulf of Alaska, and 127 species in the eastern Bering Sea). For both models, M0 ("residual mortality") was estimated from fitting biomass trends to data as discussed above and in Appendix 1. Predation mortality (M2) was estimated from the best fit functional responses and predator biomass levels. Fishing exploitation rate (F) is simply the 2005 catch of each species divided by its biomass. The dotted line in the figure shows the estimated 2005 pollock production rate (production/biomass) for the two regions.

In both systems, the total mortality (total height of bars in Figure 7A) is higher than production in 2005, indicating a declining trajectory for both stocks. In the Gulf of Alaska, production is less than predation+fishing, indicating that this decline must come at the expense of other species in the ecosystem. In the eastern Bering Sea, however, production is greater than predation+fishing, but less than predation plus fishing plus residual mortality, indicating that this decline is not necessarily at the expense of other species in the system (although it may be); there is at least the potential that the Bering Sea decline could remove "surplus production" in the ecosystem sense. While there is no guarantee that increases in fishing would come at the expense of the population unexploited by predators (i.e. from M_0 rather than predation), the fact that fishing and predation generally occur on different components (ages) of the population means that fishing tends to avoid the proportion of the stock that forms the prey base.

Figure 5B shows a reconstructed time trend of biomass (top panel) and fishing mortality and fishing+predation mortality as a fraction of production (bottom panel) for walleye pollock in the Gulf of Alaska. The biomass time trend reproduces that estimated in the most recent GOA pollock assessment (Dorn et al 2005). The blue, horizontal line is a proxy for a single species reference point (F=65%M). This value is shown for reference only; the actual single-species recommended F as a proportion of M for GOA pollock can range from 53% to 83% of the single species M of 0.3, depending on the age structure of the population and the harvest control rule employed by the author (see Dorn et al. 2005 table 1.20). The blue changing line shows the actual exploitation rate estimated for pollock by dividing the catch by the biomass shown in the top panel of Figure 5B. It is clear that the actual exploitation rates for pollock have been below the proxy we have selected to represent the single species reference point, reflecting conservative single species management, although the stock may be fully exploited in terms of spawning stock biomass.

The red horizontal line in Figure 5B shows 100% of total production for each year in the reconstruction, with 100% being the height of the dotted line from Figure 5A. This estimate is year-specific to account for annual changes in population production. The red changing line shows fishing+predation mortality over time. It is clear from both this changing red line and from Figure 5a that pollock have a much higher proportion of predation mortality than fishing mortality in the GOA. However, the total fishing+predation mortality remained below total production for pollock from the 1960s through the mid 1980s. In 1987, fishing+predation mortality exceeded total production for pollock in the GOA ecosystem. Note that this threshold was not exceeded during the initial decline of pollock prior to 1987 (upper panel). This plot suggests that for species experiencing substantial predation mortality, even conservative single species fishing mortality rates may push total fishing+predation mortality above the productive capacity of the species if this predation is not taken into account. Previously, Dorn et al. (2005) noted that 1987-1990 was the time during which the adult biomass of two predators on adult pollock, Pacific cod and Pacific halibut, began to trend downwards, suggesting that the pollock "deficit production" may have affected dependent predator populations although the direct impacts of climate and recruitment for these species must also be considered. No similar downward trend is apparent for arrowtooth flounder, however arrowtooth do not depend on pollock for the majority of their food.

If this line representing 100% of production is used as a threshold for fishing+predation mortality, the likelihood of crossing this threshold will differ by a species' position in the food web. For example, for the predatory Pacific cod (Figure 8A), predation is very small in comparison to fishing, so the species would likely be at its single species limit before reaching the fishing+predation threshold. In contrast, in the current ecosystem model, forage species like capelin are assumed to be fully utilized within the food web (estimated biomass equal consumption +20%, Appendix 1), so the fishing+predation mortality threshold may be reached even with no fishing (Figure 8B). As with many forage fish in Alaska, the lack of a biomass time series for capelin precludes the rigorous comparisons possible for pollock and cod. However, by assuming a relatively high fixed proportion of capelin production is used to supply the consumption of capelin's predators, it is possible to employ this index to evaluate fluctuations in predation pressure on this and other protected forage fish. Given that predation mortality alone may absorb nearly all of a forage fish's production in a given year, it seems most precautionary to assume that forage fish have little "room" for fishing mortality within the fishing+predation mortality threshold; thus reinforcing the NPFMC ban on fishing for these species.

How does this index compare across all species in an ecosystem? Figure 9 (top) shows the ratio of fishing mortality relative to production on the X-axis, and predation mortality relative to production on the Y-axis. The area above the solid line in Figure 9 shows the region of the plot for which fishing+predation mortality is greater than 1, while the area between the solid and dotted lines show the region for which fishing+predation mortality is between 0.75 and 1.0. This lower limit was set as an indicator of when a species may have high predation+fishing (analogous to the single species Tier 5 specification that FABC should be 75% of FOFL). The diagonal line indicates the break between predation being greater than fishing (upper left) and fishing being greater than predation (lower right).

Out of 119 species in the Gulf of Alaska, 3 are above the solid line and 56 are between the two lines. Note that in an unexploited ("natural") ecosystem, many lower trophic levels would be fully consumed and therefore may be anywhere underneath the solid line indefinitely without declining; the dotted line is simply indicated as a "caution" about future production potential for the stock. Species above the solid line could not persist in that state without a decline that may affect of predators or fisheries. The 59 species above the dotted line are listed in Figure 9 (bottom). Species for which fishing is a substantial portion of fishing+predation mortality (>25%) are shown with double-boxed lines.

Of the three species above the solid line, sei whales are an "edge" species in the ecosystem which underwent substantial declines during whaling; there is no fishing mortality and predation mortality is due to transient killer whales which are assumed to have minor predation on all baleen whales. It is likely that errors in data coverage obscure any true trends for this species, especially as the portion of the sei whale stock in the Gulf of Alaska may be a fraction of its overall North Pacific biomass. The other species, walleye pollock and king crab, show substantial fishing and predation, although for both of them predation pressure is greater than fishing pressure. In cases where predation is greater than fishing, it is extremely unclear how management actions to reduce fishing would affect the dynamics of the stock.

Between the dotted and solid lines, 5 species have fishing greater than predation: Shortspine thornyheads, Sablefish, Grenadiers, Dusky rockfish, Dogfish, and Sharpchin rockfish. Biomass estimates for sharpchin rockfish are extremely uncertain in the GOA, which may exaggerate fishing exploitation rates and contribute to this result. However, biomass estimates for the other species are generally considered reliable. These are all species with lower production rates and predation (note that not all rockfish were above the dotted line); it is likely that "ecosystem concerns" for these species (e.g. predation and the effects on their predators) would be a greater concern in the management of these species**.**

Out of 127 species in the Bering Sea management region, 8 are in the above the solid line while 33 are between the two lines. None of the species above the solid line have high fishing pressure, and in fact all of these species are "forage" species that have dropped significantly since 1999 (Figure 3C). This highlights the deficit in forage production in the Bering Sea discussed earlier. Between the two lines are 6 species with substantial fishing: salmon, pollock, Greenland turbot, snow crab (*C. opilio*), rougheye rockfish, and Pacific ocean perch (POP). For these, predation and multispecies reference points should be assessed in greater detail, for example through multispecies modeling examining predation variation.

This method of assessing fishing and predation as a combined threshold for species production is an area for potential future development. The current report shows only point estimates of predation, it is important to realize that substantial error may exist around these estimates, and estimating the error bounds based on current data quality is a high priority for developing this index. Calculating these quantities requires reliable estimates of natural mortality M for a species and its predators, and therefore must be evaluated carefully before recommendation as a management measure. Also, it is extremely unclear, in cases such as Gulf of Alaska pollock where predation appears such a large proportion of total mortality, to what extent the reduction of fishing could mitigate population declines. Finally, it should be noted that this index does not indicate the prey densities that specific predator populations might require for foraging success; densities of prey aggregation may need to be considerably higher than the amount actually consumed for predators to forage on them successfully (Furness, personal communication).

Despite these caveats, measuring production against known predation (rather than merely considering natural mortality as "surplus") gives a first start at ranking species for future examination of potential competition with predators, and as such is recommended as a research tool or an indication of "caution" as synthesized from data on population trends and production throughout the managed ecosystems.

Summary of recent trends

The following is a summary of key ecosystem indicators in the baseline, obtained primarily from the Ecosystem Considerations Section (Tables 2-6).

1.) Climate indicators of PDO or El Nino status

North Pacific In the past three decades the North Pacific climate system experienced one major and at least one minor regime shift (Tables 2-5). A major transformation, or regime shift, occurred in atmospheric and oceanic conditions around 1977, part of the Pacific Decadal Oscillation (PDO), which represents the leading mode of North Pacific sea surface temperature (SST) variability and is related to the strength of the Aleutian low. A minor climate regime shift occurred in 1989, primarily in the winter PDO index and Arctic Oscillation index. A second potential shift occurred in 1998, and was associated with a change in the sign of the second principal mode of North Pacific SST variability, the Victoria pattern, in winter and the summer PDO index. The atmospheric expression of the Victoria pattern is a north-south pressure dipole, with the negative 500-hPa height anomaly center over the eastern Aleutian Islands and the positive center over the east-central North Pacific (positive mode of the pattern). During the period 1989-1997, atmospheric pressure tended to be above normal in the high latitudes and below normal in the mid-latitudes, which translated to a relative cooling in the Bering Sea. During the summer season, the 1998 shift exhibited itself in a transition from the north-south pressure dipole to a monopole characteristic of the negative PDO pattern. In 2003-2006, however, the summer and winter PDO indices were positive. The winter of 2006 was characterized by a weak La Niña event. During the winter and spring of 2006 the negative SST anomalies, that were associated with the final stages of the weak La Niña episode, disappeared in the central and eastern equatorial Pacific. Also a SST anomaly pattern developed in the North Pacific that had some elements of a negative Pacific Decadal Oscillation (PDO) phase, strengthening in the central North Pacific for example. It is somewhat surprising, therefore, that in spite of atmospheric pressure and wind patterns that were characteristic of the negative PDO phase, that the monthly PDO index remained positive through the first half of 2006. A contributing factor here is that the west Pacific was colder than normal, which projects on a positive phase of the PDO. The NP index jumped to a positive value in the winter of 2005-06, which is characteristic of the weak Aleutian low regime of 1947-1976

Bering Sea The major shift in the BS occurred after 1977, when conditions changed from a predominantly cold Arctic climate to a warmer subarctic maritime climate. The very warm winters of the late 1970s and 1980s were followed by cooler winters in the 1990s. This cooling was likely a result of a shift in the Arctic Oscillation and hence a tendency for higher sea-level pressure (SLP) over the Bering Sea. Since 1998, negative SLP anomalies have prevailed, which is indicative of greater Pacific influence and consistent with generally milder winters. The anomalously warm winter of 2005 follows similarly warm winters of 2003 and 2004. This warming becomes comparable in its scale with major warm episodes in the late 1930s and late 1970s – early 1980s. The spring transition is occurring earlier, and the number of days with ice cover after March 15 has a significant downward trend. In 2005, the ice cover index reached the record low value. The lack of ice cover over the southeastern shelf during recent winters resulted in significantly higher heat content in the water column. In 2006, however, although the average seasonal characteristics of thermal conditions in the Bering Sea were close to normal, the winter of 2006 was characterized by a significant degree of month-to-month variability. Month-to-month record temperature swings were associated with a restructuring of atmospheric circulation patterns over the North Pacific. Spring months were colder than normal, and ice extent was south of its normal position. The ice retreat index indicates that ice stayed in the vicinity of Mooring 2 (southeast Bering Sea) for almost 1.5 months after March 15, which is much longer than in the previous six years. Sea surface temperatures in May were the coldest since 1999, which suggests a more extensive cold pool than normal in the summer of 2006. A cold spring and late ice retreat were, probably, the most important features of the physical environmental conditions in 2006.

Aleutian Islands Climatic conditions vary between the east and west Aleutian Islands around 170 deg W: to the west there is a long term cooling trend in winter while to the east conditions change with the PDO. This is also near the first major pass between the Pacific and Bering Seas for currents coming from the east.

Gulf of Alaska Evidence suggests there were climate regime shifts in 1977 and 1989 in the North Pacific. Ecosystem responses to these shifts in the Gulf of Alaska (GOA) were strong after the 1977 shift, but weaker after the 1989 shift. Variation in the strength of responses to climate shifts may be due to the geographical location of the GOA in relation to the spatial pattern of climate variability in the North Pacific. Prior to 1989, climate forcing varied in an east-west pattern, and the GOA was exposed to extremes in this forcing. After 1989, climate forcing varied in a north-south pattern, with the GOA as a transition zone between the extremes in this forcing. The 1989 regime shift did not, therefore, result in strong signals in the GOA.

There were both physical and biological responses to both regime shifts in the GOA; however, the primary reorganization of the GOA ecosystem occurred after the 1977 shift. After 1977, the Aleutian Low intensified resulting in a stronger Alaska current, warmer water temperatures, increased coastal rain, and, therefore, increased water column stability. The optimal stability window hypothesis suggests that water column stability is the limiting factor for primary production in the GOA (Gargett 1997). After 1989 water temperatures were cooler and more variable in the coastal GOA, suggesting production may have been lower and more variable. Physical data collected on the NMFS Gulf of Alaska (GOA) bottom trawl survey indicate that summer temperatures in 2005 were the warmest on record. There has been a general warming of depths less than 50 m in the GOA (Martin, this report).

Predictions The NP index jumped to a positive value in the winter of 2005-06, which is characteristic of the weak Aleutian low regime of 1947-1976. Since this shift just occurred, it is uncertain whether it represents just a temporary change or actually heralds the beginning of a new regime. At the same time, the PDO index remained slightly positive, which is more consistent with the current regime established since the late 1970s than for the previous regime of a PDO phase. The Pacific/North American (PNA) teleconnection pattern is the leading mode of atmospheric circulation over the North Pacific and North America. The PNA index, obtained from the Climate Prediction Center (CPC), shows no sign of reversal from the high index regime established since 1977. The second empirical orthogonal function (EOF2) of SST in the North Pacific, also known as the Victoria pattern, accounted for much of the climate variability since 1990 (Bond et al. 2003). In the past several years, the principal component of this pattern declined to near zero values, and its role diminished.

The latest seasonal forecast produced by the NCEP coupled forecast system model suggests that the atmospheric processes described above will continue to operate throughout the rest of the year and in winter and spring of 2007. The model suggest anomalously frequent troughing in the lower to middle troposphere along the North American west coast, which tends to promote negative SST anomalies in the Northeast Pacific. Anomalously cold waters east of Japan are forecast to warm up, and the entire pattern will resemble the negative phase of the PDO. Due to a probable El Niño event, a narrow strip of warmer than normal waters off the west coast of North America is likely to develop.

Predicting regime shifts will be difficult until the mechanisms that cause the shifts are understood (Minobe 2000). It will require better understanding of the probability of certain climate states in the near-term and longer term and the effects of this variability on individual species production and distribution and food webs. Future ecosystem assessments may integrate various climate scenarios into the multispecies and ecosystem forecasting models by using assumptions about the effects of climate on average recruitment of target species.

2.) Population trends in pelagic forage biomass

GOA walleye pollock population status and trends

GOA walleye pollock are not considered overfished nor approaching an overfished condition. Estimated 2006 spawning biomass of GOA walleye pollock is 193, 092 t, or 35% of the unfished biomass and below $B_{40\%}$ (224,000 t) (Dorn et al. 2005). Estimates of the 2006 stock status are similar to those in 2005 (Dorn et al. 2005). The recent increase in spawning biomass has leveled off “due to the aging of the relatively strong 1999 and 2000 year classes and the lack of significant recruitment in subsequent years. Spawning biomass is projected to decline after 2006 at least until 2008. There is some evidence that the 2004 year class may be relatively strong, but uncertainty concerning its magnitude is high" (Dorn et al. 2005). Analyses indicate that probability of the stock dropping below B20% will be less than 1% in all years (Dorn et al. 2005).

AI Atka mackerel population status and trends

Total biomass of Atka mackerel was high in the early 1980's and again in the early 1990's (Lowe et al. 2002). Spawning biomass peaked in 1993, declined until 2002, then increased sharply (Lowe et al. 2005). Estimated spawning biomass is slightly lower than in last year's assessment due to the downward revision of the 1998 and 1999 yearclasses (Lowe et al. 2005). The 1999 yearclass is the third largest estimated yearclass in the time series, and the 2001 yearclass is also expected to be strong (Lowe et al. 2005). The total age 3+ biomass estimate for 2006 is 446,200 mt, a decrease of approximately 8% from the 2005 estimate of biomass (Lowe et al. 2005). Atka mackerel are not considered overfished nor approaching an overfished condition (Lowe et al. 2004). Lowe et al. (2005) state: "Under an $F_{40\%}$ harvest strategy, 2006 female spawning biomass is projected to be above $B_{40\%}$ but drop below in 2008 to 2010. However, it should be noted that in recent years the TAC has been set below ABC thus, actual *F*s have been below $F_{40\%}$."

BS walleye pollock population status and trends

BS walleye pollock are not considered overfished nor approaching an overfished condition. Ianelli et al. (2005a) state: "Historically, biomass levels have increased from 1979 to the mid-1980s due to the strong 1978 and relatively strong 1982 and 1984 year classes recruiting to the fishable population. Peak biomass occurred in 1985 and then the population declined to about 4 million t by 1991 as these above-average year classes decreased in abundance with age and were replaced by weaker year classes. In 1992 an upturn in abundance began with the recruitment of a strong 1989 year class. This was followed by the 1996 and 2000 year classes that have kept the stock at relatively high levels. Since 1992, the age 3 and older biomass has increased, and recently [has] been variable around 8 million tons. Assuming subsequent year classes are only average will mean that the stock will decline over the next few years…Projections based on the current age-composition estimates indicate that the spawning stock is likely to drop below the $B_{35\%}$ level by 2007 and may drop below B_{msy} by 2008."

Herring

Dressel et al. (this report) state: "Herring spawning biomass estimates in southeastern Alaska often change markedly from year to year, rarely exhibiting consistent, monotonic trends. Since 1980, three of the nine primary locations (Sitka Sound, Hoonah Sound, and Seymour Canal) have exhibited long term trends of increasing biomass and one area (Kah Shakes/Cat Island) has had a pronounced downward trend. Since 1997, the southeastern Alaska spawning herring biomass estimate has been above the long-term median of 81,120 tons (1980-2005). The 2004 and 2005 estimates of spawning biomass were the two highest in the 25-year time series…. Every stock except Seymour Canal exhibited low recruitment in 2004 and 2005 in relation to other years. Therefore, decreasing population biomass can be expected for most stocks unless recruitment increases substantially in upcoming years. "

Moffit (this report) states that, for Prince William Sound herring: "In the 1980s a strong recruitment occurred approximately every four years. The recruitment as age-3 fish from the 1984 and 1988 year classes were particularly large (~ 1 billion fish from 1984). The prefishery run biomass estimate peaked in 1988 and 1989 at >100,000 metric tons. The 1993 biomass projection was >100,000 mt; however, the 1993 observed biomass was < 30,000 mt (Marty et al. 2003). The stock collapsed and the biomass has remained (1993 – 2006) at levels less than half of the 1980-1992 average of 84,000 mt. The causes of the decline have been hypothesized to be related to effects of the 1989 *T/V Exxon Valdez* oil spill, commercial harvesting, or environmental effects (Carls et al. 2002, Pearson et al. 1999, Thomas and Thorne 2003)."

West (this report) states: "Abundance [of Togiak herring] peaked in the early 1980s with approximately 2.5 billion fish when … the 1977 and 1978 year classes recruited into the fishery as age-4 fish in 1981 and 1982. Beginning in 1983, total abundance steadily declined until modest recruitment events occurred in 1991 and 1992 from the 1987 and 1988 year classes. Temporal trends in Togiak herring abundance show that total abundance in much of the 1980s was above the 1978 - 2003 average but fell below in 1989 and has remained below average since, with the exception of slightly above average values in 1991 and 1992. The high abundance estimates in the early 1980s may be a result of projecting backwards from the ASA model which was used beginning in 1993. The aerial survey data for the same time period conflicts with those estimates yielding much lower biomass estimates. We continue to work on resolving this; the aerial survey data is currently being used to "ground truth" the ASA estimates. With the 1996 and 1997 recruitment entering the fishery in strength now, and the outlook that recent mild years should also provide substantial recruitment to the stock, the status of the Togiak herring stock has been changed from "nominal decline" to "stable"."

Herring bycatch in federally- managed FMP groundfish fisheries increased in 2003 and 2004 in the BSAI and in 2004 in the GOA (Haynie and Hiatt, this report). In 2004, herring bycatch was the third highest in the BSAI time series, and the highest on record in the GOA. The reason for this large increase in bycatch could be due to a shift in groundfish fisheries distribution, fishing techniques, and/or increased herring biomass. Both Kuskokwim and Norton Sound herring biomass estimates increased in 2003 and 2004 (http://www.cf.adfg.state.ak.us/region3/finfish/herring/forecast/05nsmp.pdf
April 20, 2005; http://www.cf.adfg.state.ak.us/region3/finfish/herring/forecast/05kuskmgtpl.pdf
April 20, 2005). Herring bycatch decreased in 2005 to the 4th lowest value since 1994 (Haynie and Hiatt, this report).

The 2003 and 2004 BSAI herring bycatch estimates represented 0.52% and 0.55% of the total estimated herring biomass in 4 managed areas of the Bering Sea: Togiak, Norton Sound, Cape Romanzof district, and the Kuskokwim area (West, this report; http://www.cf.adfg.state.ak.us/region3/finfish/herring/herrhom3.php). This was slightly above the 1994-2002 average of 0.44%. Bycatch of herring relative to assessed populations in the GOA range from 1% to 5.3% PWS and SEAK Alaska herring biomass estimates (Moffitt, this report; Dressel et al., this report). Overall, bycatch as a percent of assessed population biomass is small; however, spatial overlap of groundfish fisheries with these populations has not been examined here.

Squid

Most squid catch is incidental to the pollock fisheries, and there are no directed squid fisheries in Alaska at this time (Gaichas 2005). In the BSAI, after reaching 9,000 mt in 1978, total squid catches declined to only a few hundred tons in 1987-95 (Gaichas 2005). Gaichas (2005) states: "The 2001 estimated catch of squid, 1,810 t was the highest in the past five years and is much closer to the ABC of 1,970 t than any estimated catch since the 1980s. The estimated catch for 2002 was similar. Catches in 2003-2005 are more comparable to pre-1999 levels."

Squid bycatch in groundfish fisheries of the GOA decreased from 1997 to 2000 (97.5 to 18.6 t) and then increased in 2001 (90.8 t) due to very high catches in area 620 and increased catches in areas 610 and 630 (Gaichas 2002; Gaichas and Boldt 2003). Bycatch increased in 2004 and peaked in 2005 at 582.4 t (Gaichas and Boldt, this report).

Forage species

The bycatch of forage species in the GOA increased considerably in 2001 (540.8 t) compared to 1997-2000 (27.2-124.9 t), primarily due to a large increase in the catches of smelts in area 620 (128.8 t) (Gaichas and Boldt 2003; Nelson 2003). The bycatch decreased to 158.3 t in 2002 (Nelson 2003), then increased to a record high of 1052.8 t in 2005 (Connors and Guttormsen 2005). This high catch of forage species in 2005 was primarily due to a large increase in the catch of eulachon and unidentified osmerids. Conners and Guttormsen (2005) state that most of these catches "…came from the pollock fishery in the Kodiak and Chirikof regions, primarily from midwater trawls but to some extent from bottom trawls…The reason for the large increase in eulachon catch in 2005 is unknown, but bottom trawl survey data…suggest increased abundance of these fishes in 2001- 2005."

Rough approximations of the exploitation rate of GOA capelin and eulachon are uniformly low at 2.2% or less (Connors and Guttormsen 2005). Connors and Guttormsen (2005) state that "Very high biomass estimates for both eulachon and capelin in 2003 resulted in low estimated exploitation rates. There is an increasing trend in both the catch and estimated exploitation rates for eulachon from 1999 to 2005. Considering that these rates are calculated from what is thought to be a sizeable underestimate of biomass, the actual exploitation rates for these two species are likely lower."

Conners and Guttormsen (2005) also state that "The catch of other families within the forage fish assemblage in the GOA from 1997 to 2005 was small. Stichaeidae (pricklebacks) and Pacific sandfish each had catches of two to five tons per year, but no other family in the assemblage had a recorded catch of greater than one ton since 1997. This lack of catch is probably due to small size and habitat preferences that make these species unavailable to commercial gear. Pacific sand lance, for example, is known to be a major prey item for seabirds and sea lions (Aydin et al in review, Sinclair and Zeppelin 2002) but is very difficult to catch with any gear other than beach seines."

Bycatch of forage species has been variable in the BSAI, ranging from 15.5 to 82.8 mt, with the lowest bycatch occurring in 2005. High catches of sandfish were observed in 2000 in area 513. Bycatch of sand lance and lanternfish also increased in 2001 (Gaichas and Boldt 2003). There is no assessment of BS forage fish; therefore, bycatch can not be compared to population abundances.

3.) Degree of or change in spatial/temporal concentration of fishery on

GOA Walleye pollock
Winter fishing effort is usually concentrated in Shelikof Strait and near the Shumagin Islands, and targets pre-spawning pollock (Dorn et al. 2005). Summer fishing areas typically occur on the east side of Kodiak Island and in nearshore waters along the Alaska Peninsula (Dorn et al. 2005). Since 1992, the GOA pollock TAC has been spatially and temporally apportioned to reduce potential impacts on Steller sea lions (Dorn et al. 2005). Spatial distribution of TACs is based on the distribution of biomass in groundfish surveys, with the purpose of potentially reducing overall intensity of adverse effects on other pollock consumers, and ensuring that no smaller component of the stock experiences higher mortality than other components. Temporal distribution of TAC is divided equally among the 4 seasons, thus, temporal and spatial exploitation rates have been fairly constant over time. Dorn et al. (2005) also state: "The Steller Sea Lion Protection Measures implemented in 2001 established four seasons in the Central and Western GOA beginning January 20, March 10, August 25, and October 1, with 25% of the total TAC allocated to each season. Allocations to management areas 610, 620 and 630 are based on the seasonal biomass distribution as estimated by groundfish surveys. In addition, a new harvest control rule was implemented that requires a cessation of fishing when spawning biomass declines below 20% of unfished levels."

Atka mackerel
The distribution of biomass in the Western, Central, and Eastern Aleutians, and the southern Bering Sea shifted between each of the 1991, 1994, 1997, 2000, 2002, and 2004 surveys, and most dramatically in area 541 in the 2000 survey (Lowe et al. 2004). In 1994 for the first time since the initiation of the Aleutian triennial surveys, a significant concentration of biomass was detected in the southern Bering Sea area (66,600 t) (Lowe et al. 2004). This occurred again in 1997 (95,680 t), 2002 (59,883 t), and in 2004

(267,556 mt). These biomass estimates are a result of large catches from a single haul encountered north of Akun Island in all four surveys. In both 1991 and 1994, the Western area contributed approximately half of the total estimated Aleutian biomass, but dropped to 37% in 1997 (Lowe et al. 2004). The proportion of biomass in the Western area increased to 42% in 2004. In 1994, 14% of the Aleutian biomass was found in the Central area compared to 51% in 1997 and up to 65% 2000 survey. The 2004 survey showed the Central area contributing 42% of the Aleutian biomass (Lowe et al. 2004).

Lowe et al. (2005) state: "The patterns of the Atka mackerel fishery generally reflect the behavior of the species: (1) the fishery is highly localized and usually occurs in the same few locations each year; (2) the schooling semi-pelagic nature of the species makes it particularly susceptible to trawl gear fished on the bottom; and (3) trawling occurs almost exclusively at depths less than 200 m. In the early 1970s, most Atka mackerel catches were made in the western Aleutian Islands (west of 180° W longitude). In the late 1970s and through the 1980s, fishing effort moved eastward with the majority of landings occurring near Seguam and Amlia Islands. In 1984 and 1985 the majority of landings came from a single 1/2° latitude by 1° longitude block bounded by 52° 30'N, 53°N, 172°W, and 173°W in Seguam Pass (73% in 1984, 52% in 1985)."

A four-year schedule from 1999-2002 was proposed to disperse fishing both temporally and spatially within Steller sea lion critical habitat in the BSAI (Lowe et al. 2003). The TAC was divided equally between two seasons, January 1 to April 15 and September 1 to November 1 (Lowe et al. 2002). Spatial dispersion of fishing was accomplished by dividing catch between areas within and outside of critical habitat. This four-year plan was in addition to bans on trawling within 10 nm of all sea lion rookeries in the Aleutian district and within 20 nm of the rookeries on Seguam and Agligadak Islands (in area 541), which were instituted in 1992 (Lowe et al. 2003). The goal of spatial dispersion was to reduce the proportion of each seasonal allowance caught within CH to no more than 40% by the year 2002. No CH allowance was established in the Eastern subarea because of the year-round 20 nm trawl exclusion zone around the sea lion rookeries on Seguam and Agligadak Islands that minimized effort within CH (Lowe et al. 2003). The regulations implementing this four-year phased-in change to Atka mackerel fishery management became effective on 22 January 1999 and lasted only 3 years (through 2001). In 2002, new regulations affecting management of the Atka mackerel, pollock, and Pacific cod fisheries went into effect. Season dates and allocations remained the same; however the maximum seasonal catch percentage from CH was raised from the goals of 40% to 60% (Lowe et al. 2004). To compensate, effort within CH in the Central and Western Aleutian fisheries was limited by allowing access to each sub-area to half the fleet at a time (Lowe et al. 2004). In 2002, trawling for Atka mackerel was prohibited within 10 nm of all rookeries in areas 542 and 543; this was extended to 15 nm around Buldir Island and 3 nm around all major sea lion haulouts (Lowe et al. 2004). Steller sea lion CH east of 178˚- W in the Aleutian district, including all CH in subarea 541 and 1˚ longitude-wide portion of subarea 542 is closed to directed Atka mackerel fishing (Lowe et al. 2004).

BS walleye pollock

The fishery that focuses on winter-spawning aggregations begins in January (A season), typically lasts 4 to 6 weeks, and is primarily concentrated north and west of Unimak Island and along the 100m isobath of the Bering Sea shelf (Ianelli et al. 2002). The B-season fishery usually begins in September and has shifted to areas west of 170° W after 1992, when the Catcher Vessel Operational Area was implemented. Since 1998, the length of both seasons has increased, with the winter fishery extending into March and the summer season beginning in mid-late June. In the past few years, there have been consistent concentrations of catch around Unimak Island and along the 100m isobath northwest of the Pribilof Islands (Ianelli et al. 2005a). The spatial distribution of the winter fishery varied in 2002-2005 (Ianelli et al. 2005a). For example, in 2003, the winter fishery was distributed further north than in previous years, possibly due to warmer temperatures and earlier roe development (Ianelli and Barbeaux 2004). The 2004 winter fishery was further south than in 2003, and the 2004 summer/fall fishery was more to the southeast of the Pribilof Islands than in 2003. Also, in the fall of 2004, there was a salmon bycatch-related area closure.

Herring
Prince William Sound: In 2006 and 2007, the herring food/bait fishery in PWS continues to be closed and no commercial sac roe or spawn-on-kelp fisheries will occur because the biomass estimate is below the minimum spawning biomass threshold (22,000 t) (Moffit, this report).

Bristol Bay: In 2006 there was no spawn-on-kelp harvest so half of the unharvested 1,500-ton spawn-on-kelp allocation was reallocated to the Togiak sac roe fishery. In 2004, as in 2003, long-duration seine openings in the Togiak herring fishery were planned over a large area, so processors could limit harvests for their individual fleets, based upon processing capacity. The duration of seine and gillnet openings have increased substantially since 1999; however total harvest has remained similar (http://www.cf.adfg.state.ak.us/region2/finfish/herring/togiak/toghhist.php).
In 1995, the allowable depth of purse seine gear was reduced to limit individual set catches and catch holding times (Weiland et al. 2004). Limiting catches therefore resulted in a larger number of openings for a longer duration (Weiland et al. 2004).

Since the late 1980s, Togiak gillnet harvest areas were reduced due to insufficient test fishing coverage or quality (Weiland et al. 2004). Mesh sizes used in the gillnet fishery were changed from 3 inch to 3 1/8 inch (stretched) in about 1993, which resulted in increased catch of female herring and, therefore, a higher percentage of mature roe (Weiland et al. 2004).

Southeast Alaska: In southeast Alaska, the gillnet sac roe fishery in Revilla Channel was not opened during 2000-2004 because the biomass was below the minimum threshold (Davidson et al. 2005). The fishery was also closed in 2005 because no herring spawn was observed in 2004 (Davidson et al. 2005). The fishery in West Behm Canal was closed in 2004 and was closed in 2005 due low biomass numbers (for both gillnets and purse seines; Davidson et al. 2005). No harvest of Hobart/Houghton herring occurred in 2001-2005 (Davidson et al. 2005). Also, in southeast Alaska, purse seine herring fisheries have occurred in two areas: Lynn Canal and Sitka Sound. The fishery in Lynn Canal has been closed since 1982 and was closed in 2005, due to the low biomass observed in that area in 2004 (Davidson et al. 2005).

Indirect effects of groundfish fisheries on pinnipeds may include competition, such as overlap in pinniped prey and fishery target species or size classes, or overlap in pinniped foraging areas and commercial fishing zones. Since it is difficult to measure these indirect effects, Steller sea lion rookery and haul-out trend sites are monitored in seven areas of Alaska during June and July aerial surveys. Although not all 1990s trend sites in Alaska were surveyed in 2006, all 1990s trend sites were surveyed in two of the six Alaskan sub-areas. These complete or nearly complete sub-area surveys in 2006 convey some information about local trends. Counts of non-pup sea lions on 1990s trend sites in the eastern and western Gulf of Alaska, and eastern Aleutian Islands were essentially unchanged between 2004 and 2006. For each of these 3 sub-areas, counts had increased considerably (20-43%) between 2000 and 2004. Thus, the 2006 count indicates that the population of adult and juvenile Steller sea lions in these areas may have stabilized. In the western Aleutian Islands, non-pup counts on the 9 trend sites surveyed in 2006 declined 19% from 2004, suggesting that the decline observed in the western Aleutian Islands sub-area may be continuing. The number of Northern fur seal pups born on the Pribilof Islands provides an index of the population status there. The number of pups born on St. Paul and St. George Islands has continued to decrease in 2004. NMFS, along with its research partners in the North Pacific, is exploring several hypotheses to explain these trends, including climate or fisheries related changes in prey quality or quantity, and changes in the rate of predation by killer whales.

Squid

Gaichas (2005) states that, in the BSAI, “Most squid have been caught as bycatch in the midwater trawl pollock fishery primarily over the shelf break and slope or in deep waters of the Aleutian Basin (subareas 515, 517, 519, 521 and 522). The spatial distribution of the observed portion of the squid catch has changed over time; while the Aleutian Islands management areas contributed a measurable portion of observed squid catch between 1990 and 1997, observed squid catch has been almost exclusively from areas [517] and 519 since 2001. Some of this redistribution could be due to changes in observer coverage over time, but because the primary fisheries in these areas have high levels of observer coverage, this redistribution could also reflect changing fishing patterns and/or changes in squid distributions.”

4.) Trophic level of the catch and total catch biomass

Total catch levels and composition for the three regions show the dominance of walleye pollock in the catch from around the 1970s to at least the early 1990s. Other dominant species groups in the catch were rockfish prior to the 1970s in the Aleutian Islands and the Gulf of Alaska, and Atka mackerel in the 1990s in the Aleutian Islands. All these species are primarily zooplankton consumers and thus show alternation of similar trophic level species in the catch rather than a removal of a top-level predator and subsequent targeting of a lower trophic level prey.

Stability in the trophic level of the total fish and invertebrate catches in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska is an indication that the "fishing-down the food web" effect is not occurring in these regions. Although there has been a general increase in the amount of catch since the late 1960s in all areas, the trophic level of the catch has been high and stable over the last 25 years. The single metrics of TL or FIB indices, however, may hide details about fishing events. We, therefore, plotted the trophic level of catches in the BS, AI, and GOA in a similar style to that recently published by Essington et al. (2006). This again supports the idea that fishing-down the food web is not occurring in Alaska, and there does not appear to be a serial addition of lower-trophic-level fisheries in the BS or GOA. In general, it appears that fishing events are episodic in the AI and GOA, and pollock dominate catches in the BS.

5.) Removal of top predators

Groundfish fishery bycatch of:

Sharks

Catch of spiny dogfish in groundfish fisheries has been variable and concentrated primarily in the Central and Western GOA (areas 630 and 640), although low catch in the eastern GOA may be an artifact of a trawl exclusion in that area (Courtney et al. 2004; Boldt et al. 2003). Catches of spiny dogfish were highest in 1998 and 2001 in many areas of the GOA and Prince William Sound and in all three data sources of shark bycatch, NMFS observer data, IPHC survey data, and the ADFG sablefish survey (Courtney et al. 2004; Boldt et al. 2003). Spiny dogfish catch in the BS is low, but also peaked in 2001. Bycatch in the BS is primarily from along the Alaska Peninsula and along the BS shelf (Courtney et al. 2004; Boldt et al. 2003).

In the GOA, sleeper shark bycatch in NMFS observer data is concentrated in the central and western GOA; whereas, the IPHC survey caught sleeper sharks along the entire coastal GOA (Courtney et al. 2004; Boldt et al. 2003). There was no apparent temporal pattern in sleeper shark bycatch in the GOA or PWS. Bycatch in the BS was lower and concentrated along the BS shelf. BS sleeper shark bycatch in 2001 was the highest since 1997 (Courtney et al. 2005; Boldt et al. 2003). Courtney et al. (2005) state that the: “Total BSAI [sleeper shark] catch (405.4 mt) / total BSAI survey biomass (17,647 mt) was 0.02. A reliable point estimate of M does not exist for Pacific sleeper sharks. However, a 2% reduction in biomass per year due to fishing is likely less than natural mortality for Pacific sleeper sharks, unless they are extremely long lived. Based upon this risk criterion, Pacific sleeper sharks do not appear to be at risk of overfishing at current levels of incidental catch. There was a relatively large proportion of unidentified sharks captured in the BSAI fishery (21%). Identification of sharks to species in the BSAI is necessary in order to accurately determine whether any individual species within the complex are at risk of overfishing."

Most salmon sharks are caught with pollock trawls and bycatch is concentrated in the central and western GOA (Courtney et al. 2004; Boldt et al. 2003). No temporal pattern of bycatch in the GOA was apparent. Very few are caught in the IPHC or ADFG longline surveys or in the BS (Boldt et al. 2003).

Birds

Most seabird bycatch is taken with longline gear (65-94%), although some bycatch is taken with trawls (6-35%) or pots (1%). The average annual longline bycatch of seabirds is comprised of primarily fulmars, gulls, and some unidentified birds, albatross, and shearwaters. Of the total longline seabird bycatch in 2004, 94.3% was caught in the BS, 2.5% in the AI, and 3.2% in the GOA. Pots catch primarily Northern fulmars, whereas trawl and longline fisheries catch a wider variety of seabirds. In 2002, total catch of seabirds was 4,694 in the BS, 124 in the AI, and 161 in the GOA (Fitzgerald et al. this report). Between 1993 and 2004 the average annual bycatch in the combined Alaskan longline fisheries was 13,144 birds (Fitzgerald et al. this report). Over this period the average annual bycatch rates (birds per 1,000 hooks) were 0.065 in the AI and BS areas and 0.021 in the GOA (Fitzgerald et al. this report). Those rates have dropped in the last few years, with the running 5-year average now (2000-2004) at 0.035, 0.036, and 0.010 for the AI, BS, and GOA Regions respectively.

Pinnipeds

Incidental mortality of pinnipeds in groundfish fisheries was low from 1998-2005, and did not exceed PBRs, and are not expected to have a direct effect on the population status of pinnipeds (Sinclair and Testa, this report). Between 1998 and 2005, an average of 24 harbor seals was taken annually in fisheries in both SEAK and the GOA, and an average of 1 was taken in the BS (Sinclair and Testa, this report). An annual average of 2.6 and 24.6 Steller sea lions were taken in the Eastern and Western Pacific (Sinclair and Testa, this report). Sixteen Northern fur seals on average were taken in the East North Pacific annually (Sinclair and Testa, this report).

Recent population trends of top predator species that are managed groundfish:

BS Greenland Turbot

Ianelli et al. (2005b) state that "Recruitment of young juvenile Greenland turbot has been poor since the early 1980s based on EBS shelf trawl surveys. There were several strong year-classes through the 1970s, which were followed by moderate recruitment of Greenland turbot during the 1980s and poor levels through the 1990s. The declining trend seems to have slowed since 2000 but these estimates must be viewed with caution." Spawning biomass is estimated to be at its lowest level in the time series (Ianelli et al. 2005b).

BS and GOA ATF

Arrowtooth flounder (ATF) are the most abundant groundfish in the GOA; however, they are not a major target of commercial fisheries (Turnock et al. 2002). The biomass of age3+ ATF in the GOA "increased dramatically between the 1960 and 1970s, declined slightly from the 1980s to the mid-1990s, and increased through 2002" (Turnock et al. 2005). The 2005 model results indicate that the estimated biomass increased from 330,994 t in 1961 to a high of 2,109,700 t in 2005 (Turnock et al. 2005).

In the BSAI, ATF are not the most abundant groundfish. They represented 3% to 8% of the total groundfish biomass in the 1980's and between 8% and 12% of total groundfish biomass from 1990 to

2002 (Wilderbuer and Sample 2002a). Wilderbuer and Nichol (2005c) state: "Model estimates indicate that arrowtooth flounder total biomass increased more than 3.5 times from 1976 to the 2005 value of 946,700 t" due to five strong year classes (1980, 1983, 1986, 1987, 1988; Wilderbuer and Nichol 2005c). Also, Wilderbuer and Nichol (2005c) state: "After a rapid increase from 1985-95, the population leveled-off from 1996-2003 before increasing again the past few years to its highest level yet observed, largely from the influence of the record high 2005 shelf survey biomass estimate. Female spawning biomass is also estimated to be at high level, 646,600 t in 2005, also the highest level estimated from 1976 to the present….Recent increases in arrowtooth flounder biomass can be attributed to the strong 1995 and 1998 year classes. Small fish present in the past two shelf surveys indicate strong 2001 and 2002 year classes which should keep stock size at a high level in the near future."

Sablefish

Sablefish abundance increased in the mid-1960s, declined in the 1970s due to heavy fishing, increased in the late 1970s and 1980s, and has since decreased (Hanselman et al. 2005). The relative abundance of sablefish decreased faster in the Eastern BS, AI, and Western GOA than in Central and Eastern GOA, the center of sablefish abundance (Sigler et al. 2003). This has been attributed to size-dependent migration, since small sablefish migrate westward and large sablefish migrate eastward (Heifetz and Fujioka 1991). The 1997 year class appears to be an important part of the total biomass and is projected to account for 23% of 2005 spawning biomass (Sigler et al. 2004). Currently, sablefish abundance appears to be moderate, and spawning biomass is projected to be stable from 2005 to 2006 (Hanselman et al. 2005).

Halibut

Halibut biomass in the GOA varied from 164,253 t to 271,142 t between 1935 and 1980 (S. Hare, International Pacific Halibut Commission, personal communication). After 1980, halibut biomass increased substantially to a high of 638,450 t in 1996. Biomass decreased slightly in the late 1990's but has been relatively stable in 2002-2005 (572,703 – 583,219 t) (S. Hare, International Pacific Halibut Commission, personal communication).

6.) Introduction of non-native species

Invasive species are those that are not native to Alaska and that could harm the environment, economics, and/or human health of the region (Fay 2002). Currently, Alaska has relatively few aquatic (including marine) invasive species. The Alaska Department of Fish and Game is developing an aquatic nuisance species management plan to minimize negative effects in Alaska. The introduction of aquatic invasive species in Alaska can occur in a number of ways, such as those that Fay (2002) lists, including: "fish farms, the intentional movement of game or bait fish from one aquatic system to another, the movement of large ships and their ballast water from the United States West Coast and Asia, fishing vessels docking at Alaska's busy commercial fishing ports, construction equipment, trade of live seafood, aquaculture, and contaminated sport angler gear brought to Alaska's world-renowned fishing sites." The main marine invasive species that are in Alaska or that could potentially be introduced to Alaska include the following:

a. Atlantic salmon (*Salmo salar*) that escape from British Columbian and Washington fish farms have been found in streams near Cordova, Ketchikan, and Yakutat and in the Bering Sea (Fay 2002). Natural spawning of escaped Atlantic salmon has been observed in British Columbian streams, indicating that this could also occur in Alaska. Fay (2002) states: "It is thought Atlantic salmon would most likely compete with native steelhead (*Oncorhynchus mykiss*), cutthroat trout (*Oncorhynchus clarkia*), Dolly Varden (*Salvelinus malma*), and coho salmon (*Oncorhynchus kisutch*), and may also adversely impact other species of Pacific salmon."
b. Green crab (*Carcinus maenas*), native to northern Europe, has become established in California north to Vancouver Island. Fay (2002) states: "It is thought to be capable of surviving environmental conditions at least as far north as the Aleutian Islands." This crab occupies areas

close to shore and out-competes other crab species. This could pose a threat to Alaskan tanner and Dungeness crab populations, since they use nearshore areas as nurseries.

c. Chinese mitten crab (*Eriocheir sinensis*), native to China, is now established in California and may have spread to the Columbia River (Fay 2002). Fay (2002) states: "With a catadromous life history…it can move up rivers hundreds of miles where it may displace native fauna, and it is known to feed on salmonid eggs, which could affect salmon recruitment."

d. Oyster spat and associated fauna: Uncertified oyster spat that is imported to Alaska for farming purposes can introduce not only oyster spat (although it is thought that Alaskan waters are too cold for oysters to reproduce), but also other invertebrate larvae, bacteria and viruses (Fay 2002).

e. Bacteria, viruses, and parasites: Fay (2002) states: "Little is known about the threat of the movement of bacteria, viruses, and parasites within or to Alaska. Devastations from the Pacific herring virus in PWS is well known and documented….movement of ballast water from one place to another within Alaska coastal waters could result in injury to other fisheries. Atlantic Ocean herring disease could also be introduced into Alaska through the import of frozen herring that are used as bait by Alaskan commercial fishers."

Total catch provides an index of how many vessels are potentially exchanging ballast water resulting in the possible introduction of non-native species. Total catch in the eastern BS was relatively stable from 1984 to the mid-1990s at approximately 1.7 million t. In 1999 there was a decrease in catch primarily due to decreased catches of pollock and flatfish, but catches have since increased to approximately 1.9 million t annually in 2002-2004.

Total catch in the AI is much lower than in the BS and has been more variable (from 61,092 to 190,750 t between 1977 and 2004). Total catch peaked in 1989, comprised mainly of pollock, and in 1996, comprised of pollock, Pacific cod, Atka mackerel, and rockfish. Pollock were a large proportion of catches from the late 1970s to the early 1990s. In 2004, most species catches decreased slightly (the largest decrease was in POP), except the catch of Atka mackerel and other species which increased. Total catch in 2004 was about 99,879 t.

In the GOA, total catch has ranged from less than 50,000 t in the 1950s to highs of 384,242 t in 1965, which was associated with high rockfish catches, and 377,809 t in 1984, which was associated with high pollock catches. Since the 1985, total catch has varied between 180,301 t (1987) and 307,525 t (1992). Catches in 2004 were 196,296 t. Catches of pollock and Pacific cod determine the major patterns in catch variability.

7.) Trend in discard levels relative to recent population trends in scavenger species

Discards of Target Species

Discards of target groundfish decreased after 1997 in both the GOA and BSAI, after which it has been relatively stable (Hiatt, this report). From 1998 to 2005, the biomass of groundfish discarded was higher in the BSAI (average 119,493 t) than in the GOA (average 23,082 t); however, the discard rate was higher in the GOA (approximately 12%) than in the BSAI (approximately 7%) (Hiatt, this report). In 2005, the discards and discard rates were the lowest in the time series (1994-2004) at 15,481 t (8.3%) in the GOA and 98,156 t (4.96%) in the BSAI; Hiatt, this report).

Discards of Non-Target Species

Catch and discards of non-target species (forage, HAPC biota, and non-specified groups) have been roughly stable in the BSAI and GOA since 1997, with the lowest values recorded in 2005 for both the BSAI and GOA (Gaichas and Boldt, this report). Non-target catch in both areas is primarily comprised of non-specified groups. In the BSAI, jellyfish, sea stars, grenadiers, and other fish dominated the non-specified group. In the GOA, grenadiers were the dominant fish caught in the non-specified category in all years (Gaichas and Boldt, this report).

Scavenger Species in the GOA and BSAI:

Birds

Overall, seabird breeding chronology in 2003 early or average, with early nesters predominate in the NB/C, SEBS, and SEAK. The highest number of late nesters was in SWBS, where no birds were early. Seabird productivity in 2003 varied throughout regions and among species, but there was a trend of above average or average productivity in most regions. An exception was SWBS, where 42% of samples (n = 26) had below average productivity. The year 2003 appeared to be an average or above average year for productivity for most planktivores and surface piscivores, but a larger proportion of diving piscivores (38 %, n= 32) had below average productivity. Of the 96 species x sites samples, declining seabird populations comprised 22%, while 20% showed increasing trends. The majority of samples showed no discernable change (58% of samples). Planktivores were stable or increasing at all monitored sites, with the exception of least auklets at Kasatochi Island (Dragoo et al. 2006). Among surface piscivores, most populations were stable or increasing, although there were species with decreasing trends in SEBS, SWBS, and GOA. The majority (59%, n = 54) of diving piscivore population trends were stable, although there were more negative trends in the GOA and SEBS.

Gulls

Glaucous-winged gull numbers at Buldir (southwest Bering Sea) decreased significantly between 1992 and 2002 (Dragoo et al. 2004). Gull numbers at Kasatochi (southwest Bering Sea) were also low in 2002. The population of gulls at Middleton Island (GOA), however, increased significantly between 1983 and 1993 (Dragoo et al. 2004), with a slight decrease in 1997 and 1998 (the most recent survey years). Productivity of glaucous-winged gulls was average or above average at all colonies in 2002 (Dragoo et al. 2004).

Kittiwakes

Scavenging is not the primary feeding mode of kittiwakes but they are opportunistic feeders that often follow fishing vessels and consume offal or discards (S. Fitzgerald, personal communication). In the GOA, black-legged kittiwake populations increased significantly in PWS, but decreased at Chowiet and Middleton Islands (Dragoo et al. 2004). SEBS populations have generally decreased from the mid-1970s until 1999; these decreases were significant at St. Paul Island and at C. Peirce (Dragoo et al. 2004). At St. Paul Island population numbers declined from 1976 to 1999, with a slight upturn in 2002. Population numbers at C. Peirce in the SEBS declined from 1992-99, but were relatively stable during 1999-2002. The SWBS colony at Buldir was the only other colony that showed a significant increase in population numbers from estimates in the 1970s (Dragoo et al. 2004). Productivity of black-legged kittiwakes in 2002 was above average at all colonies except three, Cape Lisburne and St. Lawrence in northern BS, and Buldir in the southwest BS (Dragoo et al. 2004). Productivity was below average in SEBS and GOA in 2005 (Fitzgerald et al., this report).

Red-legged kittiwakes declined significantly at St. Paul Island in the southeast BS, but significantly increased at Buldir in the southwest BS through 2002 (Dragoo et al. 2004). Estimates from 2002 showed increased numbers at both St. Paul and St. George Islands; however numbers continued to decline at Koniuji Island in 2002 (Dragoo et al. 2004). Productivity was average or above average at all colonies in 2002, but below average in the SEBS in 2005 (Dragoo et al. 2004).

Fulmars

Approximately 440,000 fulmars nest at the Semidi Islands in the GOA, 500,000 on Chagulak Island in the AI, 80,000 on the Pribilofs in Central BS, and 450,000 on St. Matthew/Hall Islands in northern BS (Hatch and Nettleship 1998). Population estimates for the three monitored colonies in 2002, St. Paul and St. George Islands in the southeast BS and Chowiet Island in the GOA, were highly variable with no significant trends (Dragoo et al. 2004).

Skates

Skates are caught incidentally in many groundfish fisheries, especially the hook and line fishery for Pacific cod and in trawl fisheries for pollock, rock sole, and yellowfin sole. The catch of skates in groundfish fisheries in the GOA has varied from 1828 t (in 2001) to 6484 t (in 2002) (Gaichas et al. 2005). Estimates of skate catch for the entire GOA across all fisheries was 8,882 t in 1997 and increased to 12,324 t in 2004. Gaichas et al. (2005) note: "that of all GOA skate species, big skate biomass was the only one not to remain stable or increase in the 2005 survey results. However, it is difficult to determine if the observed decline in big skate survey biomass is directly attributable to increased fishery catch of large adult females since 2003."

In the BSAI, Gaichas et al. (2005) note: "The biomass of all skate species combined has shown an increasing trend from 1975-2004." Estimated skate biomass in the EBS increased after 1985, peaked in 1990 (at 534,556 t), and has varied between 325,292 t (in 2000) and 534,569 t (in 2005) since (Gaichas et al. 2005). Skate biomass in the AI increased from 34,421 t in 2002 to 53,068 in 2005 (Gaichas et al. 2005).

Sablefish

See #5.)

Cod

Estimated age 3+ biomass of cod in the GOA declined from about 1990 through the present and spawning biomass also declined from about 1995 through to the present (Thompson and Dorn 2005). The 2001, 2002, and 2003 year classes are estimated to be weak, therefore, as they "work their way through the age structure in the coming years, continued decreases in stock biomass are likely" (Thompson and Dorn 2005).

The biomass and spawning biomass of Pacific cod in the BSAI "shows a near-continual decline from 1987 through 1998, although the trend has been fairly flat since then" (Thompson and Dorn 2005). Thompson and Dorn (2005) state: "Of the 15 year classes that have followed the strong 1989 year class, only four (1992, 1996, 1999, and 2000) have point estimates higher than the 1977-2004 average, and only three (1992, 1996, and 1999) have confidence intervals that fall entirely above the 1977-2004 average. Five other year classes (1990, 1991, 1995, 1998, and 2004) have point estimates that fall below the 1977-2004 average but confidence intervals that overlap the 1977-2004 average."

8.) Unobserved mortality on benthic organisms: Bottom gear effort

Bottom trawl effort in the GOA and AI decreased after 1990 due to reduced pollock and Pacific cod TACs (Coon, this report). Since 1998, effort has been relatively stable in the GOA and AI, with a slight increase in 2003. The bottom trawl effort in the GOA has been at the lowest in the time series in 2004 and 2005 (Coon, this report). In the BS, bottom trawl effort peaked in 1997 and then declined. Currently, the bottom trawl effort in the BS is relatively stable, and is approximately six times higher than that in the AI or GOA (Coon, this report). Both bottom trawl and longline effort in the BS is also more concentrated than in the AI or GOA (Coon, this report). Most fishing effort in the BS is north of False Pass and along the shelf edge. Fishing effort is concentrated along the shelf edge in the AI and along the shelf edge of the GOA with small areas of effort near Chirikov, Cape Barnabus, Cape Chiniak, and Marmot Flats (Coon, this report).

9.) Diversity measures – Species diversity

Target Species Status
No BSAI or GOA groundfish stock or stock complex is overfished and no BSAI or GOA groundfish stock or stock complex is being subjected to overfishing. Halibut is a major stock (jointly managed with the West Coast) that is not considered subject to overfishing. Two stocks are considered overfished: Pribilof Island blue king crab and St. Matthew Island blue king crab. Four stocks of crabs are under continuing rebuilding plans: BS snow crab, EBS tanner crab, Pribilof Island blue king crab, and St. Matthew Island blue king crab.

In the Alaska Region, there are 35 Fish Stock Sustainability Index (FSSI) stocks and an FSSI score of 140 would be achieved if every stock scored the maximum value, 4 (see Fish Stock Sustainability Index and status of groundfish, crab, salmon and scallop stocks, this report). The current overall Alaska FSSI is 112, based on updates through August 18, 2006. The overall Bering Sea score is 65 of a possible maximum score of 88. The BSAI groundfish score is 47 of a maximum possible 52 and BSAI king and tanner crabs score 18 of a possible score of 36. The Gulf of Alaska groundfish score is 43 of a maximum possible 48. The sablefish, which are managed as a BSAI/GOA complex, score is 4.

Marine Mammal and Bird Status
Short-tailed albatross are considered endangered; their population is increasing, and is currently estimated at 1,900 (Fitzgerald et al. 2004). Three short-tailed albatross were recorded in observer bycatch data from 1993 to 2003 in the BSAI longline fishery and none were recorded in the GOA longline fishery (Fizgerald et al. 2004).

Spectacled eiders and Steller's eiders are endangered in the action area. USFWS considers marbled murrelets, red-legged kittiwakes, and Kittlitz's murrelets "species of concern". It was estimated between 1 and 14 red-legged kittiwakes were caught in the BS longline fishery in 2002; none were reported in the GOA longline fishery (Fitzgerald et al. 2003). In the BS trawl fishery 1 to 37 and 9 to 124 red-legged kittiwakes were caught in the BS trawl fishery in each of 2001 and 2002, respectively.

The western stock of Steller sea lions (Cape Suckling to Russia and Japan) are considered endangered (Sinclair 2004). The Eastern stock of Steller sea lions (from southeast Alaska to California) are classified as threatened (Sinclair 2004). See #5.) for population status.

There are two stocks of Northern fur seals in U.S. waters: Eastern Pacific and San Miguel Island (Sinclair 2004). Northern fur seals are considered depleted. See #5.) for population status.

Between 1980's and 2002, arctic terns declined 60% in PWS and Eastern Kodiak Island, but increased in Glacier Bay (Kuletz and Rivera 2002). Pigeon guillemots declined 55% in PWS and 20% in Glacier Bay, and remained relatively stable on Kodiak Island and in Icy Bay (Kuletz and Rivera 2002). Marbled and Kittlitz's murrelets declined by 55% in PWS and 60% in Glacier Bay (Kuletz and Rivera 2002).

Recent trends in bycatch of sensitive life-history species (sharks, HAPC biota).

Sharks

In the GOA, since 1997, most spiny dogfish were caught with Pacific cod longline and trawl (42%), sablefish longline (20%), flatfish trawl (18%, and rockfish longline (17%) in areas 630, 640 and 650 (Courtney et al. 2004). Pacific sleeper sharks were caught primarily with pacific cod longline (61%) and pollock trawl (25%) in areas 630, 620, and 610 (Courtney et al. 2004). Most salmon sharks were caught with pollock trawl (66% in areas 630, 620, and 610 (Courtney et al. 2004).

In the BSAI, since 1997, most sleeper sharks were caught with Pacific cod longline (30%), pollock trawl (26%), Greenland turbot longline (17%), flatfish trawl (12%), and sablefish longline (10%) in areas 521 and 517 (Courtney et al. 2005). Courtney et al. (2005) state: "From 1997 – 2002 in the BSAI, Pacific sleeper sharks were caught primarily in areas 521 (57%) and 517 (20%). There appears to be an increasing trend in bycatch of Pacific sleeper sharks from BSAI areas 521 and 517 during the years 1997 – 2002". Catches of spiny dogfish and salmon sharks were rare in the BSAI (Courtney et al. 2004).

See #5.) for catch trends.

HAPC biota

HAPC biota caught in groundfish fisheries includes seapens/whips, sponges, anemones, tunicates, and corals. Bycatch of HAPC biota in the BSAI has ranged from 922.8 t (in 1999) to 2,548.3 t (in 1997), comprising up to 5.3% of all non-target species caught (Gaichas and Boldt, this report). Bycatch of HAPC biota is substantially lower in the GOA (15.0-46.1 t), and represents up to 0.21% of total non-target catch (Gaichas and Boldt, this report). Sponges, anemones, and some corals represented the majority of the HAPC biota caught in the GOA; whereas, tunicates and sponges, with some anemones, were the dominant HAPC biota caught in the BSAI. There was no apparent temporal trend in catches of any HAPC biota in the GOA. The catch of seapens/whips increased in the BSAI from 1997 to 2001. The lowest bycatch in the BSAI occurred in 1999 due to decreased catches of tunicates.

HAPC biota are also caught in the NMFS trawl surveys; however, these surveys are not designed to sample these organisms and may not represent true population trends (Martin, this report). Martin (this report) states that for GOA HAPC biota: "Despite these problems, a few trends are clearly discernible. The frequency of occurrence of sponge in survey tows has been quite high and remarkably stable over the entire survey area with the exception of the 1983 and 1986 surveys where the use of different gear likely had a large influence on the sponge catches. Likewise, the relative abundance of sponges has been quite stable with the exception of the large estimated mean CPUE in the central AI in 1994. There does seem to have been a general increase in sea anemone abundance in the southern Bering Sea in recent years. In the GOA, sponge and sea anemone abundances seem to generally decrease from west to east across the GOA. The frequency of occurrence for both of these groups seems to have increased over time in all areas.

Recent trends in amount of area closed to fishing (measure of buffer against extinction)

In 2001, over 90,000 nmi of the EEZ were closed to trawling all year, and 40,000 nmi were closed seasonally (Coon, this report). Additionally 40,000 nmi were closed on a seasonal basis. Most state waters (0-3 nmi) are closed to bottom trawling (Coon, this report). Closures in 2006 were similar to 2005 except for new closures implemented in 2006 as part of protection for Essential Fish Habitat encompasses a large portion of the Aleutian Islands. The largest of these closures is called the Aleutian Islands Habitat Conservation area and closes 279,000 to bottom trawling year round. By implementing this closure Alaska's EEZ has 41% closed to bottom trawling.

Community diversity measures

Average species richness and diversity of the groundfish community in the Gulf of Alaska increased from 1990 to 1999 with both indices peaking in 1999 and sharply decreasing thereafter (Mueter, this report). Species richness and diversity on the Eastern Bering Sea shelf have undergone significant variations from 1982 to 2003 (Mueter, this report). Species diversity increased from 1983 through the early 1990s, was relatively high and variable throughout the 1990s, and decreased significantly after 2000 (Mueter, this report). Spatial shifts in distribution from year to year appear to be the primary drivers of changes in species richness.

Decadal-scale trends are observed in combined standardized indices of recruitment and survival of major demersal and pelagic stocks in the BS and GOA (Mueter, this report). Recruitment indices suggests that recruitment of demersal species in the Gulf of Alaska and Bering Sea followed a similar pattern with mostly "above-average recruitments from the mid- or late 1970s to the late 1980s, followed by below-average recruitments during the early 1990s (GOA) or most of the 1990s (BSAI)" (Mueter, this report). Mueter notes there is a "strong indication for above-average recruitment in the GOA from 1994-2000 (with the exception of 1996, which had a very low recruitment index). A similar trend was evident in the Bering Sea, but was much less pronounced. The [survival] indices showed very similar patterns. As in previous years, indices from both regions were unusually high in 1984, when 19 out of 23 stocks had above-average log-recruitment and [survival] indices relative to the 1970-2001 period…The observed patterns in recruitment and survival suggest decadal-scale variations in overall groundfish productivity in the Gulf of Alaska and Bering Sea that are moderately to strongly correlated between the two regions…These variations in productivity are correlated with and may in part be driven by variations in large-scale climate patterns such as the PDO or more regional measures such as ocean temperatures" (Mueter, this report).

Genetic diversity – qualitative summary of degree of fishing on spawning aggregations and older age group abundances of target groundfish stocks

In the GOA, female arrowtooth flounder represent ~70% of catches in survey and fishery data due to lower availability or higher natural mortality of males (Turnock et al. 2002). Arrowtooth flounder recruitment to the BS slope increases with fish age, reaches a maximum at age 9, after which, 50% of age 9+ fish remain on the shelf (Wilderbuer and Sample 2002b). Females comprise the majority of the catches.

Spawning walleye pollock populations have been the focus of the winter fishery in the GOA since the 1980's (Dorn et al. 2002). Since the early 1990's the winter pollock fishery in the BSAI has focused on spawning aggregations (Ianelli et al. 2002).

In the BSAI, female rock sole in spawning condition are desirable; therefore, fishing has focused on winter spawning concentrations north of the Alaska Peninsula (Wilderbuer and Walters 2002).

The majority of herring fisheries are sac-roe harvests that focus on pre-spawning herring (Funk, http://www.cf.adfg.state.ak.us/geninfo/finfish/herring/overview/overview.htm, October 6, 2003).

Community size spectrum analysis of the eastern Bering Sea fish community (Bartkiw et al., this report) indicates there has not been a systematic decline in the amount of large fish from 1979 to 2002.

Table 2. Bering Sea/Aleutian Islands time series descriptions and sources presented in Table 3. Anomalies of these time series were calculated by subtracting the mean and dividing by the standard deviation, based on the time series reported below. Most data was taken from the Ecosystem Indicators section, and the author is noted with the year of the Ecosystem Considerations section.

BERING SEA, ALEUTIAN ISLANDS						
Issue	**Effect**	**Index**	**Period**	**Description**	**Relevance**	**Source**
Physical Environment	Climate	Ice index	1954-2006	A combination of 6 highly correlated ice variables	Indicator of a dominant and driving factor of the BS ecosystem	http://www.beringclimate.noaa.gov/index.html, October 18, 2006
Physical Environment	Climate	SAT	1916-2006	Surface winter air temperature (degrees Celsius)	Indicator of water column stratification, hence production	http://www.beringclimate.noaa.gov/index.html, October 18, 2006
Physical Environment	Climate	PDO	1901-2006	Pacific Decadal Oscillation (leading PC of monthly SST anomalies in the North Pacific Ocean, poleward of 20 deg. N)	Indicator of state of the N. Pacific	http://jisao.washington.edu/pdo/PDO.latest, June 22, 2006
Physical Environment	Climate	May SST	1970-2006	May sea surface temperature (degrees Celsius)	Indicator of water column stratification, hence production	http://www.beringclimate.noaa.gov/index.html, October 18, 2006
Physical Environment	Climate	AOI	1951-2006	Arctic Oscillation Index (dominant pattern of non-seasonal sea-level pressure (SLP) variations north of 20 deg. N)	Indicator of state of BS; negative values associated with warm winters	http://www.beringclimate.noaa.gov/index.html, October 18, 2006
Physical Environment	Climate	Summer BT	1982-2006	Summer bottom temperature (degrees Celsius)	May affect distribution of some species	Lauth 2006
Predator-prey	Pelagic forage	Herring	1974-1998	Togiak herring age-4 recruits (numbers)	Indicator of population of a commonly utilized forage species	West 2006
Predator-prey	Pelagic forage	A.Mackerel	1977-2002	Atka mackerel log-transformed recruit per spawning biomass	Indicator of population of a commonly utilized forage species	NPFMC; Boldt et al. 2006
Predator-prey	Pelagic forage	Pollock	1964-2005	Walleye pollock log-transformed recruit per spawning biomass	Indicator of population of a commonly utilized forage species	NPFMC; Boldt et al. 2006
Predator-prey	Pelagic forage	Forage fish	1997-2005	Forage fish non-target catch (mt)	Indicator of population of a commonly utilized forage group	Gaichas 2006
Predator-prey	Pelagic forage	Squid	1997-2005	Estimated total (retained and discarded) catches of squid (mt) in the eastern Bering Sea and Aleutian Islands by groundfish fisheries.	Indicator of population of a commonly utilized forage group	Gaichas 2006

Predator-prey	Removal of top predators	BS TL	1954-2004	Bering Sea trophic level of the catch	Indicator of removal of top predators	Livingston and Boldt 2006
Predator-prey	Removal of top predators	AI TL	1962-2004	Aleutian Island trophic level of the catch	Indicator of removal of top predators	Livingston and Boldt 2006
Predator-prey	Removal of top predators	Sharks	1997-2005	Shark non-target catch (mt)	Indicator of removal of top predators	Gaichas 2006
Predator-prey	Removal of top predators	SSL	1989-2004	Non-pup Steller sea lion counts observed at rookery and haulout trend sites in the eastern, central, and western AI during June and July aerial surveys	Indicator of status of top predators	Sinclair and Testa 2005
Predator-prey	Removal of top predators	GT	1974-2004	Greenland turbot log-transformed recruit per spawning biomass	Indicator of status of top predators	NPFMC; Boldt et al. 2006
Predator-prey	Removal of top predators	ATF	1976-2001	Arrowtooth flounder log-transformed recruit per spawning biomass	Indicator of status of top predators	NPFMC; Boldt et al. 2006
Predator-prey	Removal of top predators	Jellyfish	1982-2006	Jellyfish relative CPUE in survey catches	Indicator of status of top predators	Lauth 2006
Predator-prey, Diversity	Removal of top predators, Species diversity	Seabird Mort.	1993-2004	Seabird incidental catch rate in BS hook and line fisheries (birds per 1,000 hooks)	Indicator of removal of top predators	Fitzgerald et al. 2006
Predator-prey	Top predators	COMU	1976-2005	Common murre productivity (fledglings per nest site) at St. Paul Island	Indicator of status of top predators	D.E. Dragoo, USFWS, personal communication, 2006
Predator-prey	Top predators	TBMU	1976-2005	Thick-billed murre productivity (fledglings per nest site) at St. Paul Island	Indicator of status of top predators	D.E. Dragoo, USFWS, personal communication, 2006
Predator-prey, Energy flow	Energy redirection, Removal of top predators	BLKI	1975-2005	Black-legged kittiwake productivity (fledglings per nest site) at St. Paul Island	Indicator of status of top predators; indicator of scavenger species population trends and the influence of discards	D.E. Dragoo, USFWS, personal communication, 2006
Predator-prey, Energy flow	Energy redirection, Removal of top predators	RLKI	1975-2005	Red-legged kittiwake productivity (fledglings per nest site) at St. Paul Island	Indicator of status of top predators; indicator of scavenger species population trends and the influence of discards	D.E. Dragoo, USFWS, personal communication, 2006

Energy flow	Energy redirection, Removal of top predators	GWGU	1992-2005	Glaucous-winged gulls productivity (total chicks/total eggs) at Buldir Island	Indicator of status of top predators; indicator of scavenger species population trends and the influence of discards	D.E. Dragoo, USFWS, personal communication, 2006
Energy flow, Predator-prey	Energy removal, Introduction of non-native species	BS catch	1954-2004	Total catch Bering Sea (mt)	Indicator of total energy removal; indicator of ballast water exchange with the potential for introducing non-native species	NPFMC 2005a, Boldt et al., 2006
Energy flow, Predator-prey	Energy removal, Introduction of non-native species	AI catch	1962-2004	Total catch Aleutian Islands (mt)	Indicator of total energy removal; indicator of ballast water exchange with the potential for introducing non-native species	NPFMC 2005a, Boldt et al., 2006
Energy flow	Energy removal	BS H+L	1990-2005	Hook and line (longline) effort (hours of gear set)	Indicator of catch removals	Coon 2006
Energy flow	Energy removal	AI H+L	1990-2005	Hook and line (longline) effort (hours of gear set)	Indicator of catch removals	Coon 2006
Energy flow	Energy removal	BS Pel. Trawl	1995-2005	Bering Sea pelagic trawl duration (24 hour days)	Indicator of catch removals	Coon 2006
Energy flow, Diversity	Energy removal, Functional (habitat) diversity	BS B. Trawl	1990-2005	Bering Sea bottom trawl duration (24 hour days)	Indicator of catch removals; indicator of benthic guild disturbance	Coon 2006
Energy flow, Diversity	Energy removal, Functional (habitat) diversity	AI B.Trawl	1990-2005	Aleutian Island bottom trawl duration (24 hour days)	Indicator of catch removals; indicator of benthic guild disturbance	Coon 2006
Energy flow	Energy redirection	Discard rate	1994-2005	Proportion of total catch biomass of managed groundfish discarded	Indicator of redirection of energy	Hiatt 2006
Energy flow	Energy redirection	Cod	1964-2004	Pacific cod log-transformed recruit per spawning biomass	Indicator of scavenger species population trends and the influence of discards	NPFMC; Boldt et al. 2006
Diversity	Functional diversity	HAPC	1997-2005	HAPC non-target catch (mt)	Indicator of structural habitat diversity	Gaichas 2006
Diversity	Species diversity	BS Diversity	1982-2004	Bering Sea groundfish diversity (Shannon-Wiener index) in bottom trawl survey	Indicator of number of species and their relative abundance	Mueter 2005

Diversity	Species diversity	BS Richness	1982-2004	Bering Sea groundfish richness (average number of species per survey haul in bottom trawl survey)	Indicator of spatial shifts in distribution or number of species	Mueter 2005
Other	Other	BB Salmon	1900-2003	Total catch of Bristol Bay salmon (numbers)	Indicator of pelagic fish productivity	Eggers 2004
Other	Other	Crab B	1980-2005	Total crab biomass (mt)	Indicator of benthic invertebrate productivity	Otto and Stevens 2005
Other	Other	AK plaice	1975-2002	Alaska plaice log-transformed recruit per spawning biomass	Indicator of groundfish productivity	NPFMC; Boldt et al. 2006
Other	Other	YFS	1964-2000	Yellowfin sole log-transformed recruit per spawning biomass	Indicator of groundfish productivity	NPFMC; Boldt et al. 2006
Other	Other	POP	1960-1994	Pacific ocean perch log-transformed recruit per spawning biomass	Indicator of groundfish productivity	NPFMC; Boldt et al. 2006
Other	Other	Northerns	1977-1994	Northern rockfish log-transformed recruit per spawning biomass	Indicator of groundfish productivity	NPFMC; Boldt et al. 2006
Other	Other	Rock sole	1975-1999	Rock sole log-transformed recruit per spawning biomass	Indicator of groundfish productivity	NPFMC; Boldt et al. 2006
Other	Other	FHS	1977-2002	Flathead sole log-transformed recruit per spawning biomass	Indicator of groundfish productivity	NPFMC; Boldt et al. 2006
Other	Other	Log(CPUE)	1982-2004	Logarithm of total catch per unit effort of fish and invertebrates in bottom trawl surveys	Indicator of overall abundance of demersal and benthic species	Mueter 2005

Table 3. Standardized anomalies of time series in the Bering Sea/Aleutian Islands from 1970 to the present, using a similar method as Link et al. (2002) and DFO (2003) used for ecosystems on the east coast of the U.S. and Canada. Symbols and shading represent seven divisions of anomalies; blank cells indicate no data. Time series were arranged on the y-axis so that variables with similar responses were grouped together. The time series presented were chosen because of their importance to ecosystem processes in the Bering Sea/Aleutian Islands; however, there are some variables that will be added when those time-series become available. See Table 2 for a description of the time series included in this table.

	70		72		74		76		78		80		82		84		86		88		90		92		94		96		98		00		02		04		06
SAT	o	-	-	o	-	--	--	o	+	++	+	+	+	o	o	+	o	+	-	+	o	-	o	o	o	-	++	o	o	o	-	++	-	+	+	+	o
PDO	+	-	--	o	-	-	-	+	o	-	o	+	o	+	+	+	+	++	+	-	o	--	o	o	+	-	o	o	+	o	-	o	o	++	o	o	+
MaySST	+	-	-	o	+	-	-	+	++	++	+	++	-	+	-	-	-	o	o	o	o	o	-	+	o	-	+	-	-	-	-	o	o	+	+	+	-
AI catch	o	-	o	-	-	-	-	-	-	-	o	o	o	o	+	o	o	o	o	++	+	+	+	++	++	++	++	+	+	o	o	o	o	o	o		
BB Salmon	+	-	-	-	-	-	-	-	o	+	+	+	o	++	++	+	o	o	o	+	++	+	++	+++	++	+++	++	o	-	+	+	o	o	o			
Herring					o	-	-	+++	+++	o	-	o	-	o	o	-	-	+	o	o	o	o	o	o	-	-	o	+	o								
Ice index	o	+	+	o	+	+	+	o	-	--	o	-	--	o	o	o	o	-	o	-	o	+	+	-	o	+	--	o	+	o	+	--	+	-	-	--	o
AOI	-	o	o	+	o	+	+	--	-	-	o	o	o	o	o	-	-	-	o	++	+	+	+	++	o	+	-	o	o	+	+	-	+	o	-	o	-
RLKI						+	++	++	-	+					-	o	o	-	+	-	o		o	+	o	-	-	o	+	o	+	-	+	-	o	-	
Summer BT													-	+	o	o	-	+	o	+	o	o	-	+	-	-	+	o	+	--	-	o	+	++	+	+	-
A.Mackerel								++	o	o	o	-	-	-	o	o	+	o	++	o	-	o	o	-	-	o	--	-	+	++	+	-	o				
GT					+	+	o	++	+	o	o	-	-	o	+	+	o	-	-	o	+	-	-	-	-	-	-	-	-	-	o	+	+	+	++		
Pollock	-	-	o	o	+	o	+	+	++	+	+	o	+	-	o	-	--	--	--	o	o	o	+	-	-	-	o	-	-	o	o	-	-	-	-		
Jellyfish													-	-	-	-	-	-	-	-	-	o	o	o	+	o	+	+	+	+	+++	o	o	o	o	o	-
AK plaice						+++	++	+	+	+	+	-	-	o	-	-	o	-	o	-	o	-	o	-	o	o	-	o	o	+	+	o	+				
YFS	+	+	++	++	++	+	+	o	o	o	o	o	-	o	-	-	-	-	-	-	-	o	-	-	-	o	-	-	-	-	-						
Northerns								+	o	o	o	-	-	-	++	o	-	-	+	+	-	-	-	o	+												
BS Diversity													-	-	-	-	-	-	-	-	o	+	+	o	+	+	+	+	++	o	o	+	-	-	o		
log(CPUE)													-	o	-	--	-	o	o	o	o	o	o	+	++	+	o	+	-	+	o	o	o	+	+		
Cod	o	o	o	o	++	o	+++	+++	+	++	o	o	+	-	o	-	-	-	o	o	o	o	o	-	-	o	o	o	o	+	o	o	o	-	o		
TBMU							++	o	+						--	+	o	o	o	o	o		o				o	-	--	o	o	o	+	o	-	-	
Crab B											++	+	+	o	-	-	-	o	o	+	++	++	+	o	o	o	o	o	o	-	-	-	-	-	-	o	
BLKI						+	+	+	o	+					-	o	o	o	+	-	o		o	o	-	-	-	o	+	-	+	-	++	+	+	-	
BS Richness													+	o	o	--	-	--	-	-	o	+	o	+	o	-	o	-	+	o	o	+	-	+	++		
Squid								++	+++	++	++	+	+	+	o	o	-	-	-	-	-	-	-	-	-	-	o	o	-	-	-	o	o	o	o	o	
ATF							+	o	o	+	++	o	o	++	+	+	++	+	o	-	-	-	-	-	-	-	-	-	o	-	-	o					
FHS								+	++	+	++	++	+	+	+	+	o	o	o	-	o	o	-	-	-	-	-	-	-	-	-	-	-				
POP	o	o	o	o	o	o	+	+	+	+	+	++	+	+	++	+	+	o	o	o	-	-	-	-	-												
BS H+L																					-	-	o	-	o	o	o	o	o	o	+	+	+	+	+	--	
AI H+L																					-	o	+	+	o	-	o	-	o	o	+	++	-	-	-	-	
Rock sole						+	o	o	o	+	+	+	+	+	+	+	+	+	o	o	o	o	-	-	-	-	-	--	--	-							
GWGU																							o	-	-	o	o	++	-	o	-		+	+	o	o	
AI B.Trawl																					+++	+	o	o	o	o	+	-	o	-	-	-	o	o	-	-	
COMU							o		+							+	-	+	+	o	o		o				o	-	---	o	o	+	+	o	o	--	
Sharks																												-	o	o	o	+	++	-	-	-	
HAPC																												+	-	--	o	+	+	+	+	-	
SSL																				o	+	+	+		o		o		-		-		-		-		
BS Pel.Trawl																										o	+++	o	+	-	-	o	o	o	-	o	
BS B.Trawl																					--	+	+	+	+	+	+	+	o	-	o	-	-	-	-	-	
Discard rate																									+	+	+	+	o	o	o	-	-	-	-	-	
Seabird Mort.																								o	o	+	o	+	++	o	+	-	-	-	-		
Forage fish																												o	o	o	+	++	-	-	o	-	
BS catch	+	+	+	+	+	+	o	o	o	o	o	o	o	o	o	+	+	+	+	+	+	+	+	+	+	+	+	+	o	o	o	+	+	+	+		
BS TL	o	o	+	+	+	+	+	+	o	o	+	+	+	+	o	o	o	o	o	o	+	o	o	o	o	+	+	o	o	+	+	+	+	+	+		
AI TL	-	-	o	+	o	o	o	o	o	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	o	o	o	o	o	o	o	o	o	o	o		

Legend	
X>2.6	+++
2.6>X>1.6	++
1.6>X>0.5	+
0.5>X>-0.5	o
-0.5>X>-1.6	-
-1.6>X>-2.6	--
X<-2.6	---

Table 4. Gulf of Alaska time series descriptions and sources presented in Table 5. Anomalies of these time series were calculated by subtracting the mean and dividing by the standard deviation, based on the time series reported below. Most data was taken from the Ecosystem Indicators section, and the author is noted with the year of the Ecosystem Considerations section.

GULF OF ALASKA						
Issue	**Effect**	**Index**	**Period**	**Description**	**Relevance**	**Source**
Physical Environment	Climate	MLD	1974-2006	Winter mixed layer depth at GAK1 (north GOA) (m)	Indicator of water column conditioning; physical forcing	Sarkar et al. 2006
Physical Environment	Climate	AOI	1951-2006	Arctic Oscillation Index	Indicator of sea level pressure; physical forcing	http://www.beringclimate.noaa.gov/index.html; October 18, 2006
Physical Environment	Climate	PDO	1901-2006	Pacific Decadal Oscillation	Winter sea surface temperature; physical forcing	http://jisao.washington.edu/pdo/PDO.latest; October 18, 2006
Predator-prey	Pelagic forage	Pollock	1969-2004	Walleye pollock log-transformed recruit per spawning biomass	Indicator of population of a commonly utilized forage species	NPFMC; Boldt et al. 2006
Predator-prey	Pelagic forage	Herring	1977-2002	Southeast Alaska age-3 herring recruits	Indicator of population of a commonly utilized forage species	Dressel et al. 2006
Predator-prey	Pelagic forage	Pandalids	1972-2005	Pandalid shrimp catch per unit effort in ADFG small mesh survey	Indicator of population of a commonly utilized forage group	Litzow 2006
Predator-prey	Pelagic forage	Eulachon	1972-2005	Eulachon catch per unit effort in ADFG small mesh survey	Indicator of population of a commonly utilized forage species	Litzow 2006
Predator-prey	Pelagic forage	Forage fish	1997-2005	Forage fish non-target catch (mt)	Indicator of population of a commonly utilized forage group	Gaichas 2006
Predator-prey	Pelagic forage	Squid	1997-2005	Squid catches non-target catch (mt)	Indicator of population of a commonly utilized forage group	Gaichas 2006
Predator-prey	Removal of top predators	TL	1956-2004	Gulf of Alaska trophic level of the catch	Indicator of removal of top predators	Livingston and Boldt 2006
Predator-prey	Removal of top predators	Sharks	1997-2005	Shark non-target catch (mt)	Indicator of removal of top predators	Gaichas 2006
Predator-prey	Removal of top predators	SSL	1989-2004	Non-pup Steller sea lion counts observed at rookery and haulout trend sites in the eastern, central, and western GOA during June and July aerial surveys	Indicator of status of top predators	Sinclair and Testa 2005
Predator-prey	Top predators	Sablefish	1960-2004	Sablefish log-transformed recruit per spawning biomass	Indicator of status of top predators	NPFMC; Boldt et al. 2006
Predator-prey	Top predators	ATF	1961-2002	Arrowtooth flounder log-transformed recruit per spawning biomass	Indicator of status of top predators	NPFMC; Boldt et al. 2006

Predator-prey, Diversity	Removal of top predators, Species diversity	Seabird Mort.	1993-2004	Seabird incidental catch rate in GOA hook and line fisheries (birds per 1,000 hooks)	Indicator of removal of top predators	Fitzgerald et al. 2006
Predator-prey	Top predators	COMU	1976-2005	Common murre productivity (fledglings per nest site at Chowiet	Indicator of status of top predators	D.E. Dragoo, USFWS, personal communication, 2006
Predator-prey	Top predators	TBMU	1976-2005	Thick-billed murre productivity (fledglings per nest site at Chowiet	Indicator of status of top predators	D.E. Dragoo, USFWS, personal communication, 2006
Predator-prey, Energy flow	Energy redirection, Removal of top predators	BLKI	1983-2002	Black-legged kittiwake productivity (fledglings per nest in Prince William Sound	Indicator of status of top predators	D.E. Dragoo, USFWS, personal communication, 2005
Energy flow, Predator-prey	Energy removal, Introduction of non-native species	Total catch	1970-2004	Total catch Gulf of Alaska (mt)	Indicator of total energy removal; indicator of ballast water exchange with the potential for introducing non-native species	NPFMC 2005b; Boldt et al. 2006
Energy flow	Energy removal	H+L	1990-2005	Hook and line (longline) effort (hours of gear set)	Indicator of catch removals	Coon 2006
Energy flow, Diversity	Energy removal, Functional (habitat) diversity	Bottom trawl	1990-2005	Gulf of Alaska bottom trawl duration (24 hour days)	Indicator of catch removals; indicator of benthic guild disturbance	Coon 2006
Energy flow	Energy redirection	Discard rate	1994-2005	Proportion of total catch biomass of managed groundfish discarded	Indicator of redirection of energy	Hiatt 2006
Energy flow	Energy redirection	Cod	1977-2004	Pacific cod log-transformed recruit per spawning biomass	Indicator of scavenger species population trends and the influence of discards	NPFMC; Boldt et al. 2006
Diversity	Functional diversity	HAPC	1997-2005	HAPC non-target catch Gulf of Alaska (mt)	Indicator of structural habitat diversity	Gaichas 2006
Diversity	Species diversity	Diversity	1990-2003	Gulf of Alaska groundfish diversity (Shannon-Wiener index)	Indicator of number of species and their relative abundance	Mueter 2005
Diversity	Species diversity	Richness	1990-2003	Gulf of Alaska groundfish richness (average number of species per survey haul)	Indicator of spatial shifts in distribution or number of species	Mueter 2005
Other	Other	Salmon	1900-2003	Total GOA salmon catch (numbers)	Indicator of pelagic fish productivity	Eggers 2004
Other	Other	FHS	1984-2002	Flathead sole log-transformed recruit per spawning biomass	Indicator of groundfish productivity	NPFMC; Boldt et al. 2006
Other	Other	POP	1977-1994	Pacific Ocean perch log-transformed recruit per spawning biomass	Indicator of groundfish productivity	NPFMC; Boldt et al. 2006
Other	Other	Northerns	1977-1994	Northern rockfish log-transformed recruit per spawning biomass	Indicator of groundfish productivity	NPFMC; Boldt et al. 2006
Other	Other	log(CPUE)	1990-2003	Total catch per unit effort of fish and invertebrates in bottom trawl surveys	Indicator of overall abundance of demersal and benthic species	Mueter 2005

Table 5. Standardized anomalies of abiotic and biotic time series in the Gulf of Alaska from 1970 to the present, using a similar method as Link et al. (2002) and DFO (2003) used for ecosystems on the east coast of the U.S. and Canada. Symbols and shading represent seven divisions of anomalies; blank cells indicate no data. Time series were arranged on the y-axis so that variables with similar responses were grouped together. The time series presented were chosen because of their importance to ecosystem processes in the Gulf of Alaska; however, there are some variables that will be added when those time-series become available. See Table 4 for a description of time series.

	70		72		74		76		78		80		82		84		86		88		90		92		94		96		98		00		02		04		06
Total catch	-	-	o	o	o	o	o	o	o	o	o	+	+	+	++	++	o	o	o	o	+	+	+	+	+	o	o	+	+	+	o	o	o	o	o		
PDO	+	-	--	o	-	-	-	+	o	-	o	+	o	+	+	+	+	++	+	-	o	--	o	o	+	-	o	o	+	o	-	o	o	++	o	o	+
Pollock	-	-	o	o	+	o	+	+	++	+	+	o	+	-	o	-	--	--	--	o	o	o	+	-	-	-	o	-	-	o	o	-	-	-	-		
	-	-	-	--	o	o	-	++	+	o	++	+	-	-	+	-	o	-	o	-	o	o	o	o	o	+	o	+	o	o	+	-	o	o	+		
Sablefish	o	-	-	-	-	-	-	o	o	o	o	o	o	+	+	+	+	o	o	+	+	++	+	++	++	++	++	+	++	+++	+	+++	+	+++			
Salmon	o	-	-	-	-	-	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	+	+	+	+	+	+		
catch			-	o	o	o	o	o	o	o	o	o	-	o	o	o	o	o	-	o	-	-	o	-	-	o	-	-	o	-	-	+	+	++	+++	o	
TL					+	+	-	-	-	o	-		++	-	-	+	-	+	+		+	+	+	+	o	+	o	-	+	-	o	o	-	--	o	+	+
Eulachon	-	o	o	+	o	+	+	--	-	-	o	o	o	o	o	-	-	-	o	++	+	+	+	++	o	+	-	o	o	+	+	-	+	o	-	o	-
																					-			+			+			-		-		+			
MLD										o	+	+								+	o	o		o		o			---				+		-	o	
AOI								+	o	o	o	-	-	-	++	o	-	-	+	+	-	-	-	o	+												
Herring														o	o	+	+	+	+	-	o	--	-	o	-	+	o	o	--	o	+	+	+				
COMU	o	o	o	o	++	o	+++	+++	+	++	o	o	+	-	o	-	-	-	o	o	o	o	o	-	-	o	o	o	o	+	o	o	o	-	o		
Northerns			++	+	++	+	+++	+	+	o	o	o	o	o	o	-	-	o	-	-	-	-	o	-	-	-	-	-	-	-	-	o	o	-	o	-	
	+	++	++	+	++	+	+	+	++	+	o	o	+	+	+	o	o	o	-	-	-	-	-	-	-	-	o	o	o	+	o	-	-				
BLKI								+	++	+	++	++	+	+	+	+	o	o	o	-	o	o	-	-	-	-	-	-	-	-	-	-	-				
COD	o	o	o	o	o	o	+	+	+	+	+	++	+	+	++	+	+	o	o	o	-	-	-	-	-												
Pandalid																					o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	+++	
ATF																				++	+	+	o		o		-		-		-		-		-		
FHS																												-	-	-	-	+	o	o	o	++	
																									+	+	+	+	-	-	o	o	o	+	-	-	
POP																												o	o	-	-	o	o	o	o	+++	
log(CPUE)																					++	+	+	+	o	o	o	o	o	-	-	o	-	o	-	-	
SSL																								o	-	+	++	o	++	o	o	-	-	-	-		
Forage fish																												o	++	o	o	o	-	-	-	-	
Discard rate										+	o	++								o	o	+		o		o			--				-		-	o	
								o	-	o	+	o	-	o	+++	o	-	-	+++	-	-	-	o	o	o	o	-	o	o	o	o	-	-				
Squid																					-			o			o			++		-		o			
Bottom trawl																					--			o			o			+		o		+			
Seabird																												o	o	o	+	o	++	-	--	o	

Legend	
X>2.6	+++
2.6>X>1.6	++
1.6>X>0.5	+
0.5>X>-0.5	o
-0.5>X>-1.6	-
-1.6>X>-2.6	--
X<-2.6	---

Conclusions – trend summary

The Bering Sea was subject to a change in the physical environment and an ecosystem response after 1977, a minor influence from shifts in Arctic atmospheric circulation in the early 1990s, and persistent warm conditions over the previous 4 years (Table 3). A major transformation, or regime shift, of the Bering Sea occurred in atmospheric conditions around 1977, changing from a predominantly cold Arctic climate to a warmer subarctic maritime climate as part of the Pacific Decadal Oscillation (PDO). This shift in physical forcing was accompanied by a major reorganization of the marine ecosystem on the Bering Sea shelf over the following decade. Surveys show an increase in the importance of pollock to the ecosystem. Weather data beginning in the 1910s and proxy data (e.g. tree rings) back to 1800 suggest that, except for a period in the 1930s, the Bering Sea was generally cool before 1977, with sufficient time for slow growing, long-lived, cold-adapted species to adjust. Thus the last few decades appear to be a transition period for the Bering Sea ecosystem.

A comprehensive report (National Research Council 1996) attributes the ecosystem reorganization toward pollock to the combination of fishing and the 1976 regime shift. They hypothesize that fishing of large whales increased the availability of planktonic prey, fishing on herring reduced competition, and fishing on flatfish reduced predation. The modeling study of Trites et al. (1999) noted that the increase in pollock biomass could not be explained solely by trophic interaction from these removals, and favored environmental shifts as an explanation. While the physical shift after 1976 was abrupt and pollock biomass increased rapidly, the ecosystem adjustment probably took a prolonged period as relative biomass shifted within the ecosystem. Biodiversity measures (richness and evenness) of roundfish, excluding pollock, decreased throughout the 1980s and were stable in the 1990s (Hoff 2003). Jellyfish, which share a common trophic level with juvenile pollock and herring, may have played a role in the ecosystem adjustment as their biomass increased exponentially beginning in the early 1980s, but recently have crashed in 2001-2003.

A specific Arctic influence on the Bering Sea began in the early 1990s, as a shift in polar vortex winds (the Arctic Oscillation – AO) reinforced the warm Bering conditions, especially promoting an earlier timing of spring meltback of sea ice. Flatfish increased in the mid-1980s due to changes in larval advection (Wilderbuer et al. 2002), but the AO shift to weaker winds have since reduced these favorable conditions (Overland et al. 1999).

Warm conditions tend to favor pelagic over benthic components of the ecosystem (Hunt et al. 2002, Palmer 2003). Cold water species, i.e. Greenland turbot, Arctic cod, snow crab and a cold water amphipod, are no longer found in abundance in the SE Bering Sea, and the range of Pacific walrus is moving northward. While it is difficult to show direct causality, the timing of the reduction in some marine mammals suggests it is due to some loss of their traditional Arctic habitat. Although physical conditions appear mostly stable over the last decade, the warmest water column temperatures have occurred in 2001—2005 on the southeast Bering Sea shelf, despite considerable year-to-year variability in the AO and PDO.

The overall climate change occurring in the Arctic, as indicated by warmer atmospheric and oceanic temperatures and loss of 15 % of sea ice and tundra area over the previous two decades, is hypothesized to make the Bering Sea less sensitive to the intrinsic climate variability of the North Pacific. Indeed, when the waters off of west coast of the continental U.S. shifted to cooler conditions after 1998, the subarctic did not change (Victoria pattern), in contrast to three earlier PDO shifts in the 20th century. Neither the PDO nor the Victoria indices can fully explain an abrupt shift to warmer conditions in the Bering Sea since 2000. In the current warm regime, the magnitude of SAT fluctuations has been steadily increasing since the mid-1980s, and the Bering

Sea may become even warmer before it will switch to a new cold regime. If the regime concept is true, this switch may happen anytime soon, especially given the uncertain state of the North Pacific climate, suggesting that it may be in a transition phase.

Climatic conditions vary between the east and west Aleutian Islands around 170 deg W: to the west there is a long term cooling trend in winter while to the east conditions change with the PDO. This is also near the first major pass between the Pacific and Bering Seas for currents coming from the east. Pollock and Atka mackerel do not appear to vary on a decadal-scale; however, the biomass of pollock appears to be higher than it was in the 1980s. Pacific ocean perch population dynamics vary on a decadal-scale. For example, Pacific ocean perch survival changed at approximate times of regime shifts, 1975 and 1989. There is not enough information on the early life history of Pacific ocean perch to define a mechanism for the observed variations.

Evidence suggests there were climate regime shifts in 1977, 1989, and possibly 1998 in the North Pacific; although, current positive PDO values suggest the 1998 shift may not be considered a significant shift. Ecosystem responses to these shifts in the Gulf of Alaska (GOA) were strong after the 1977 shift, but weaker after the 1989 and 1998 shifts. Variation in the strength of responses to climate shifts may be due to the geographical location of the GOA in relation to the spatial pattern of climate variability in the North Pacific. Prior to 1989, climate forcing varied in an east-west pattern, and the GOA was exposed to extremes in this forcing. After 1989, climate forcing varied in a north-south pattern, with the GOA as a transition zone between the extremes in this forcing. The 1989 and 1998 regime shifts did not, therefore, result in strong signals in the GOA.

There were both physical and biological responses to all regime shifts in the GOA; however, the primary reorganization of the GOA ecosystem occurred after the 1977 shift. After 1977, the Aleutian Low intensified resulting in a stronger Alaska current, warmer water temperatures, increased coastal rain, and, therefore, increased water column stability. The optimal stability window hypothesis suggests that water column stability is the limiting factor for primary production in the GOA (Gargett 1997). A doubling of zooplankton biomass between the 1950s-1960s and the 1980s indicates production was positively affected after the 1977 regime shift (Brodeur and Ware 1992). Recruitment and survival of salmon and demersal fish species also improved after 1977 (Table 5). Catches of Pacific salmon in Alaska increased, recruitment of rockfish (Pacific ocean perch) increased, and flatfish (arrowtooth flounder, halibut, and flathead sole) recruitment and biomass increased. There are indications that shrimp and forage fish, such as capelin, were negatively affected by the 1977 shift, as survey catches declined dramatically in the early 1980s (Anderson 2004, Table 5). The decline in marine mammal and seabird populations, observed after the 1977, shift may have been related to the change in forage fish availability (Piatt and Anderson 1996).

After 1989 water temperatures were cooler and more variable in the coastal GOA, suggesting production may have been lower and more variable. After 1989, British Columbia (BC) salmon catches and survival were low and Queen Charlotte Island (northern BC) herring declined. Salmon catches in Alaska, however, remained high. Groundfish biomass trends that began in the early 1980s continued, with increases in flatfish biomass. By the late 1980s arrowtooth flounder, rather than walleye pollock, were dominant. Large groundfish biomass estimates resulted in negative recruit per spawning biomass anomalies of demersal fish.

There is some indication that the GOA ecosystem may have weakly responded to the 1998 regime shift. Increased storm intensity from 1999 to 2001 resulted in a deeper mixed layer depth in the central GOA, and coastal temperatures were average or slightly below average. After 1998, coho survival increased in southern BC, shrimp catches increased in the northern GOA (*but have since declined again in 2003)*, and the 1999 year class of both walleye pollock and Pacific cod was strong in the northern GOA. It is unknown if changes observed after the 1998 shift will persist in the GOA and how long the current conditions in the GOA will last.

It is apparent that many components of the Alaskan ecosystems respond to decadal-scale variability in climate and ocean dynamics. Predicting regime shifts will be difficult until the mechanisms that cause the shifts are understood (Minobe 2000). Monitoring indicator species is one method to improve our knowledge of the mechanisms that cause the shifts. Potential indicator species of regime shifts would include those that have a short life-span, are sensitive to changes, are key trophic groups, and/or are targeted by fisheries which produce data that is readily available. Examples of potential indicator species in the GOA that fit some of these criteria include sockeye and pink salmon, juvenile fish abundance, ichthyoplankton, as well as zooplankton biomass and composition.

No significant adverse impacts of fishing on the ecosystem relating to predator/prey interactions, energy flow/removal, or diversity are noted in any of the alternatives. However, there are several cases where those impacts are unknown because of incomplete information on population abundance of certain species such as forage fish or benthic organisms not well-sampled by surveys. Similarly, bycatch rates of some nontarget species are not well-known at the species level so population-level impacts of bycatch on those species cannot be determined.

There are gaps in understanding the system-level impacts of fishing and spatial/temporal effects of fishing on community structure and prey availability. Validation and improvements in system-level predator/prey models and indicators are needed along with research and models focused on understanding spatial processes. Improvements in the monitoring system should include better mapping of corals and other benthic organisms, development of a system for prioritizing non-target species bycatch information in groundfish fisheries, and identification of genetic subcomponents of stocks. In the face of this uncertainty, additional protection of sensitive or rare ecosystem components such as corals or local spawning aggregations should be considered. Improvements in understanding both the nature and direction of future climate variability and effects on biota are critical. Until more accurate predictions of climate status and effects can be made, a range of possible climate scenarios and plausible effects on recruitment should be entertained.

As noted by Carpenter (2002), a limitation of ecological forecasts includes the uncertainty of predictions because the future probability distributions of drivers such as climate may be unknown or unknowable. Development of possible future scenarios, expansion of our forecasting capabilities within the space/time constraints that are relevant to human action, and identification of management choices that are robust to a wide range of future states are possible ways this assessment can be broadened in the future.

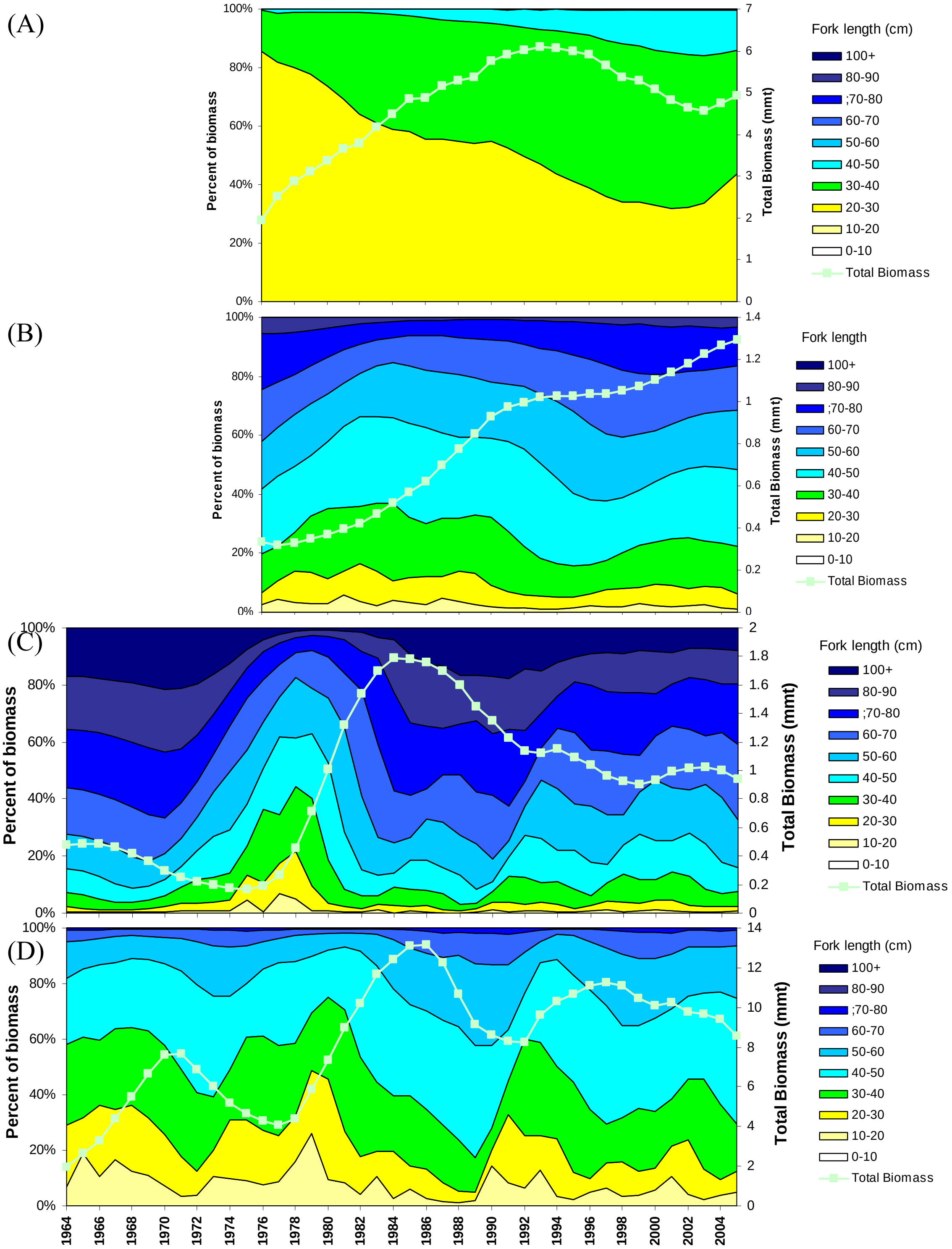


Figure 1. Relationships of population biomass trends and population age structure for major EBS stocks. White line in each figure shows assessed EBS biomass (mmt) of (A) combined rock sole (Wilderbuer and Nichol 2005a), yellowfin sole (Wilderbuer and Nichol 2005b), and flathead sole (Stockhausen et al. 2005) populations; (B) arrowtooth flounder (Wilderbuer and Nichol 2005c); (C) Pacific cod (Thompson and Dorn 2005), and (D) walleye pollock (Ianelli et al. 2005a). Colors show percent by weight of 10cm fork length size classes in the population according to each stock assessment.

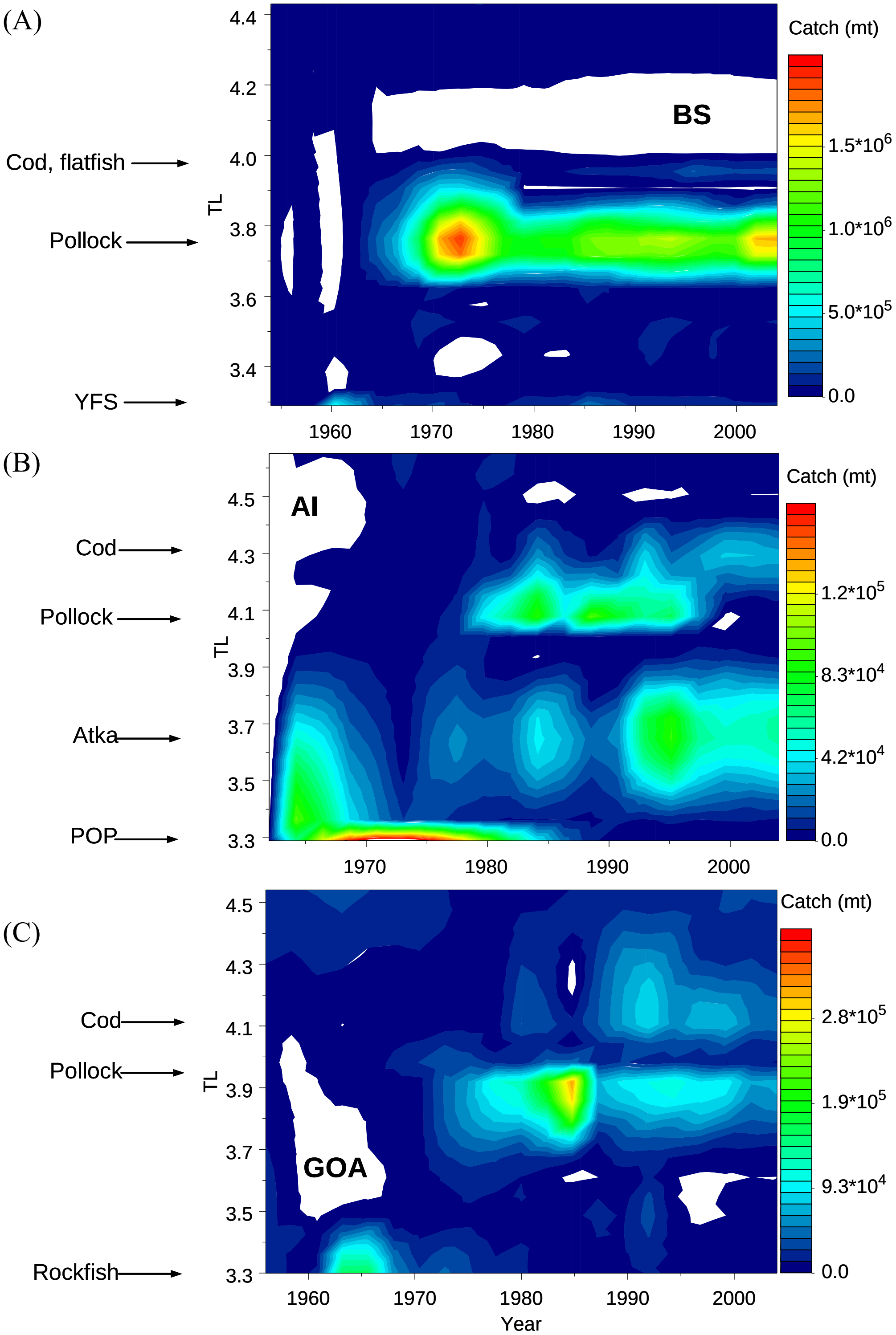


Figure 2. Trophic level of the catch in Alaska: Total catch of all species plotted as colour contours by trophic level and year for the Bering Sea (A) , Aleutian Islands (B), and Gulf of Alaska (C). The species comprising the main catches and their approximate trophic levels are labeled on the left side of the graphs. Note: all scales are different for each ecosystem.

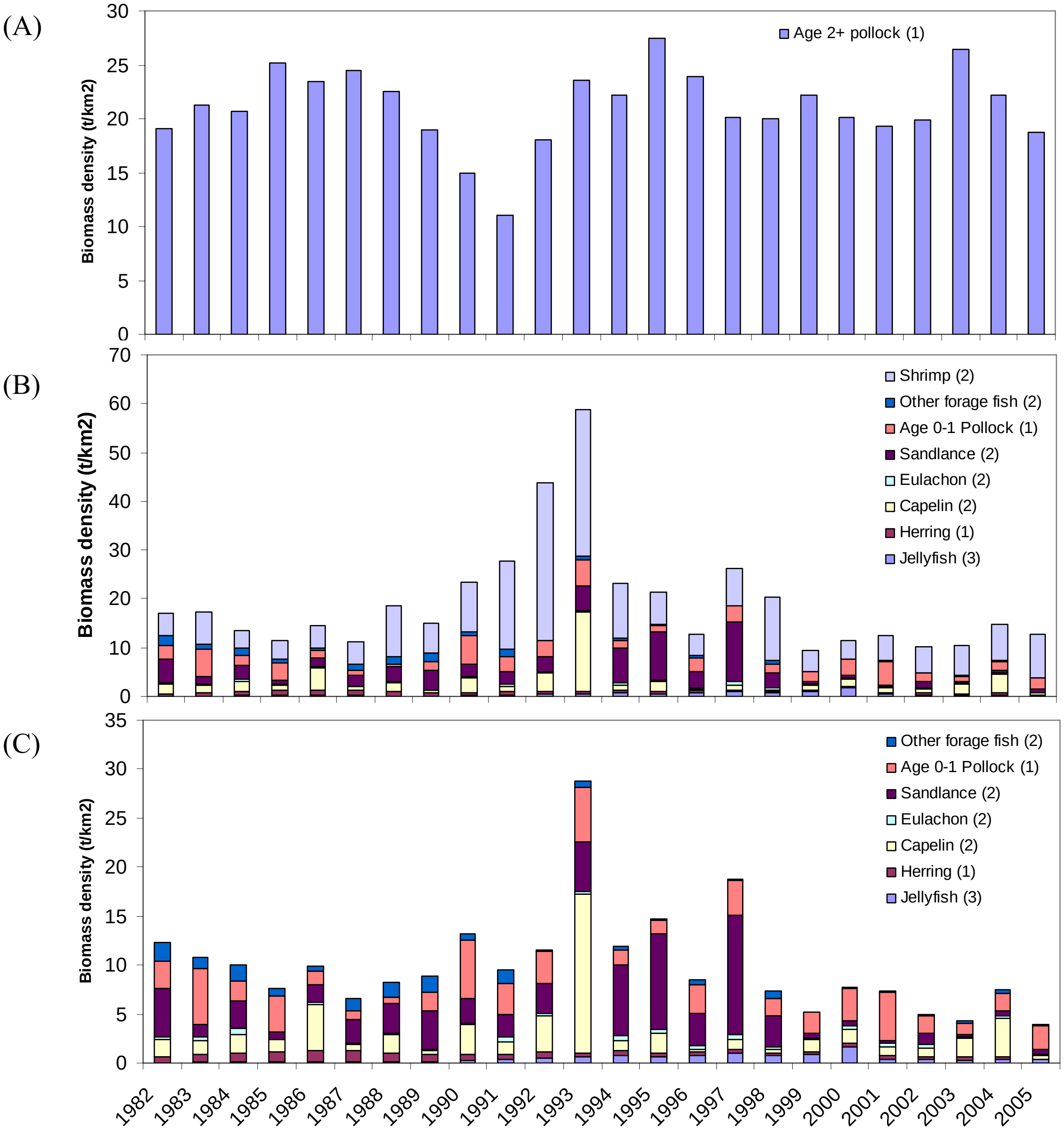


Figure 3. Trends in Eastern Bering Sea biomass density (t/km^2) of selected forage species, 1982-2005. Age 2+ pollock densities (A) are taken from the stock assessment (Ianelli et al. 2005a), as are densities of juvenile pollock in B and C). Densities for other species are trawl survey estimates corrected by total consumption as described in the text. (B) shows forage species including shrimp, (C) shows the same set of forage species without shrimp.

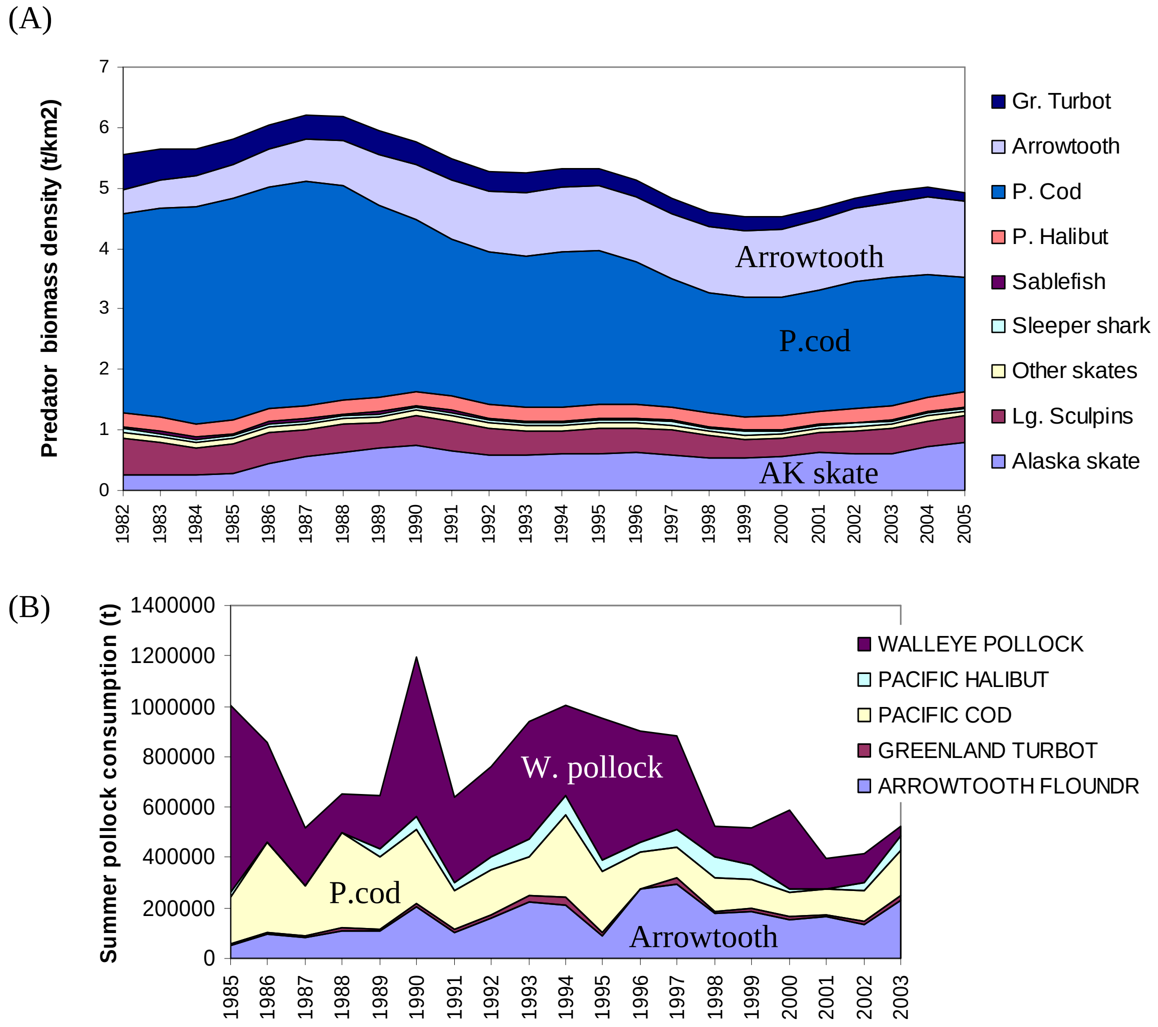


Figure 4. Trends in EBS predator biomass and consumption of pollock by predators. (A) Biomass density estimates (t/km^2) of selected eastern Bering Sea groundfish predators from stock assessments or trawl surveys, 1982-2005. (B) Estimates of summer consumption of Bering Sea walleye pollock (t/summer season) by predator species, 1985-2003, as calculated from trawl survey and stomach contents data as described in Lang et al. (2005) and Appendix B.

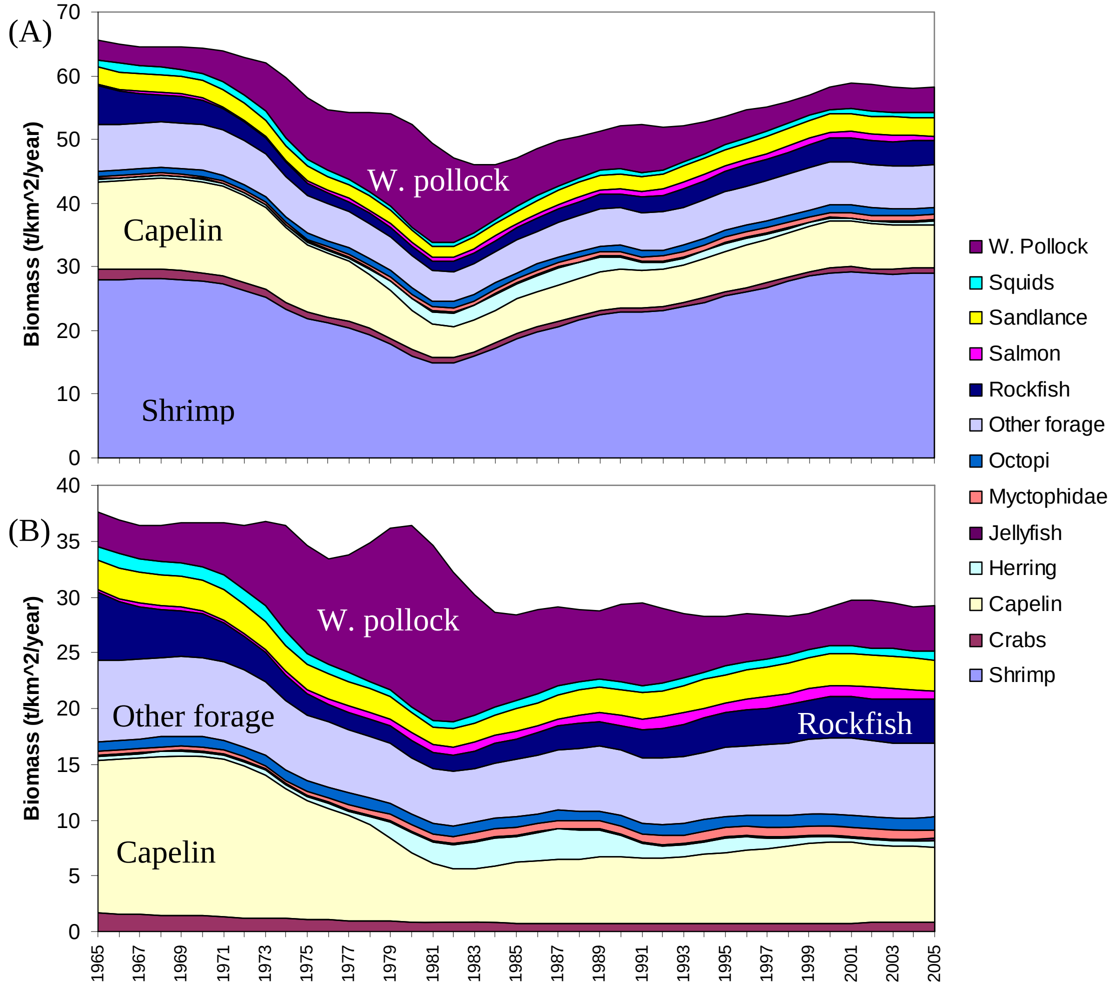


Figure 5. Trends in GOA forage species. Reconstructed Gulf of Alaska forage densities (t/km^2), as calculated from stock assessments (walleye pollock, Pacific herring, and rockfish) and from a maximum likelihood estimation from biomass dynamics models as described in the text (other species). (A) Forage species including shrimp; (B) Forage species excluding shrimp.

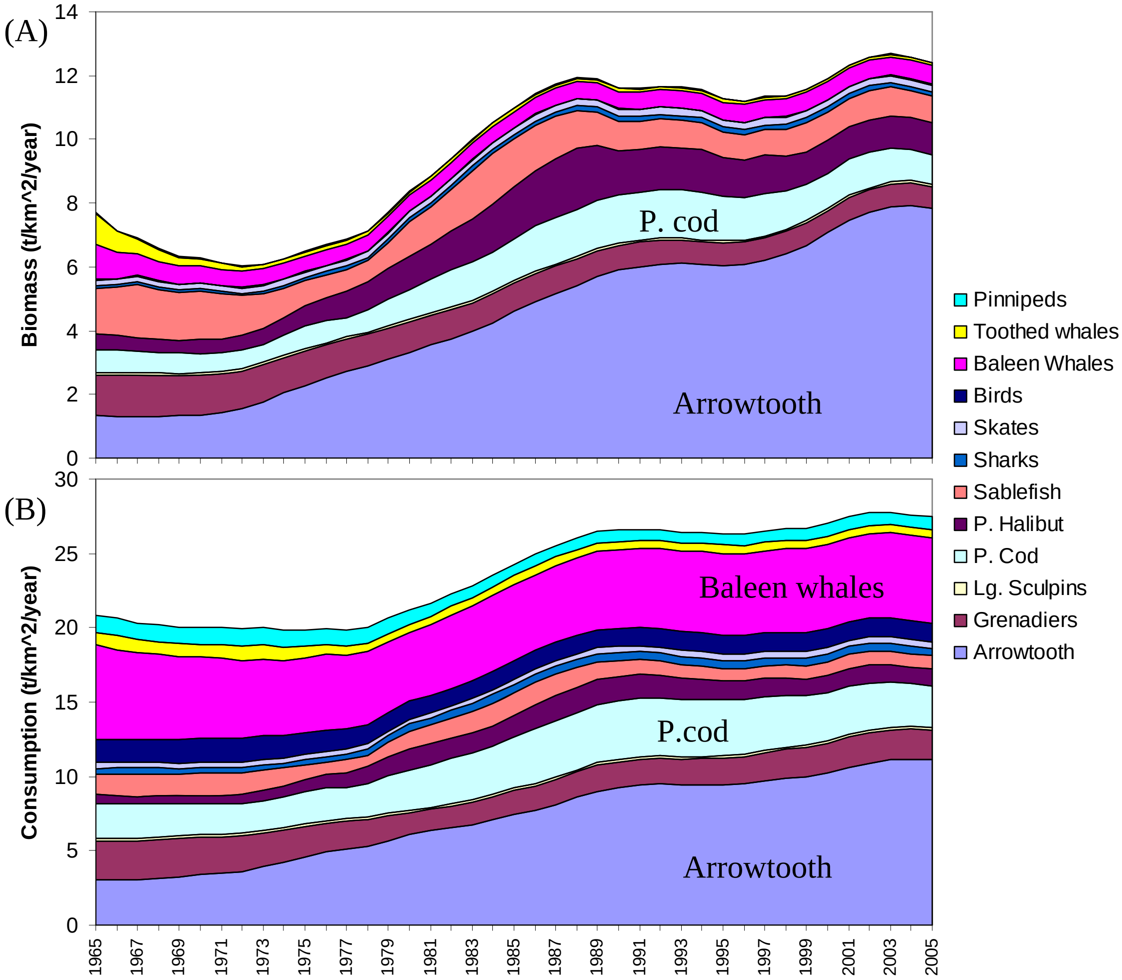


Figure 6. Trends in GOA predator biomass and total consumption. (A) Reconstructed Gulf of Alaska forage biomass densities (t/km^2), as calculated from stock assessments (arrowtooth flounder, Pacific cod, Pacific halibut, and pinnipeds) and from a maximum likelihood estimation from biomass dynamics models as described in the text (other species). (B) Consumption estimates of all prey (t/km^2/year) by these predators from best fit of biomass dynamics model.

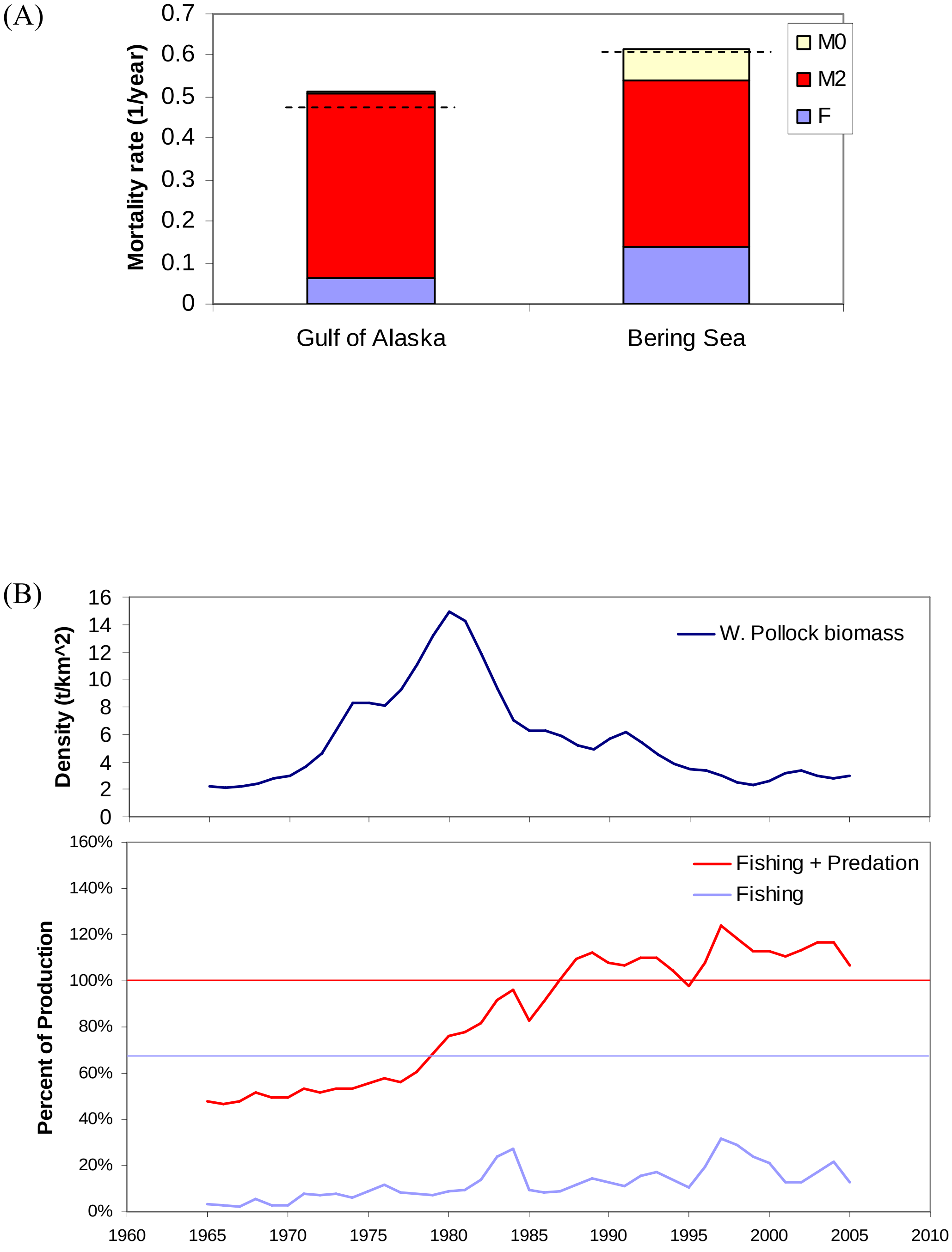


Figure 7. Estimates of fishing and predation mortality for pollock. (A) Mortality components of walleye pollock of the Bering Sea and the Gulf of Alaska in 2005, showing fishing mortality (F, exploitation rate on age 2+ pollock) as estimated from the stock assessment, predation mortality (M2) estimated as described in the appendix, and "other" mortality (M0) estimated as the difference between single species total mortality and the sum of F and M2. Dotted line indicates production rate. (B) Upper panel: Biomass density (t/km^2) of GOA walleye pollock from stock assessment. Lower panel: time series of F and M2 as a fraction of total production rate, resulting from biomass dynamics model run (maximum likelihood parameter set).

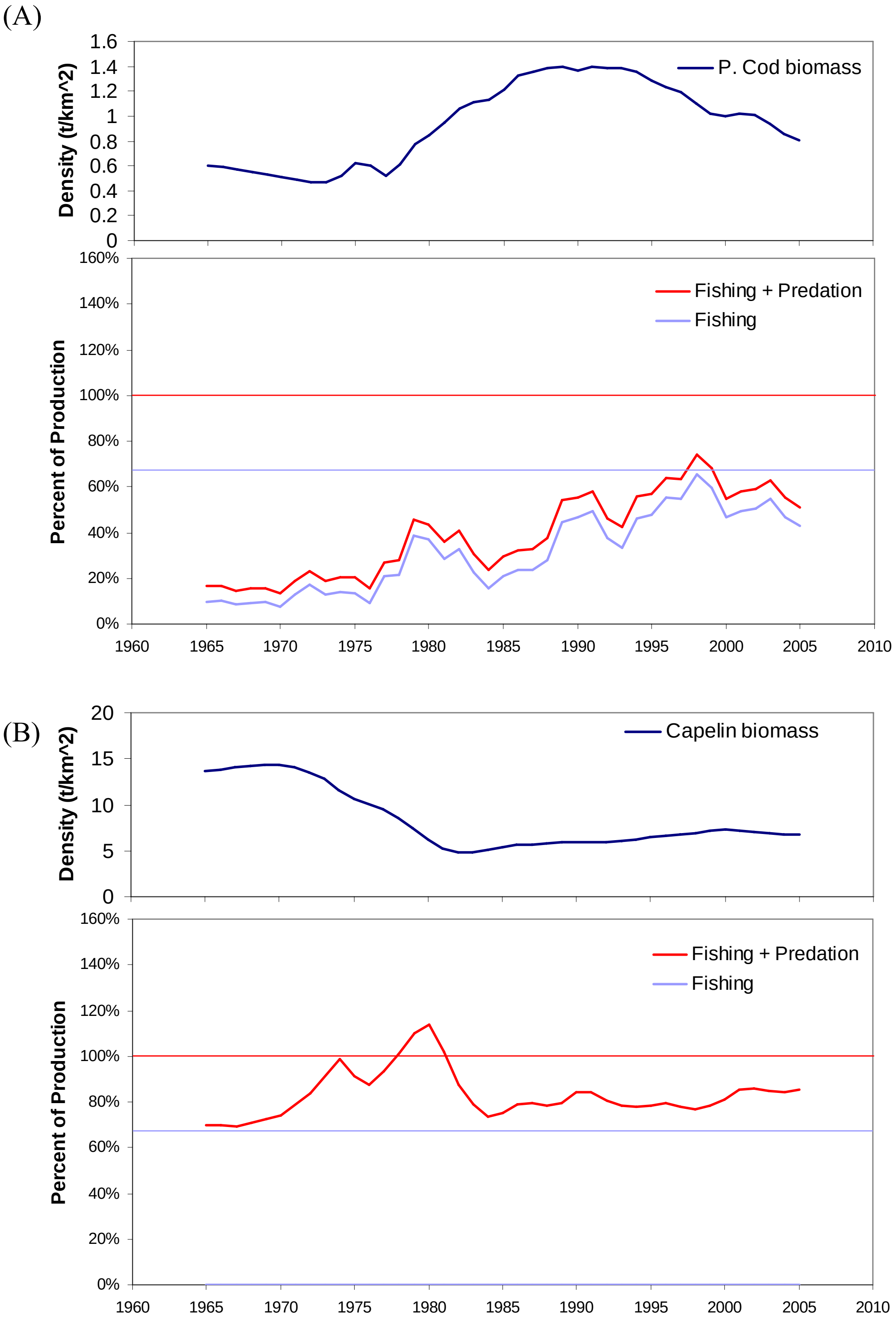
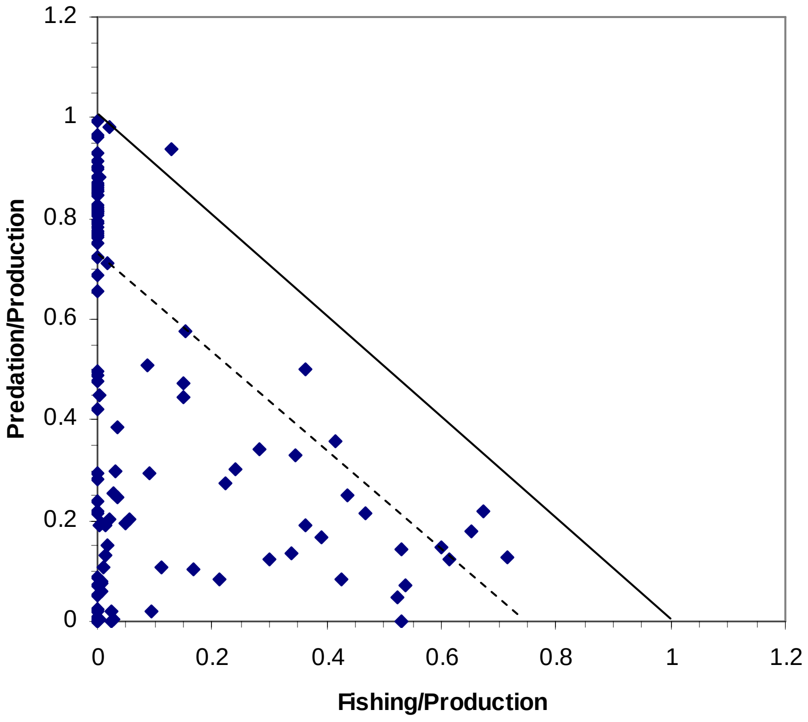


Figure 8. (A) Upper panel: Biomass density (t/km^2) of GOA Pacific cod from stock assessment. Lower panel: time series of fishing and predation as a fraction of total production rate, resulting from biomass dynamics model run (maximum likelihood parameter set). (B) Upper panel: Biomass density (t/km^2) of GOA capelin reconstructed from biomass dynamics model. Lower panel: time series of fishing and predation as a fraction of total production rate, resulting from biomass dynamics model run (maximum likelihood parameter set).



Species above solid line

Sei whales
W. Pollock
King Crab

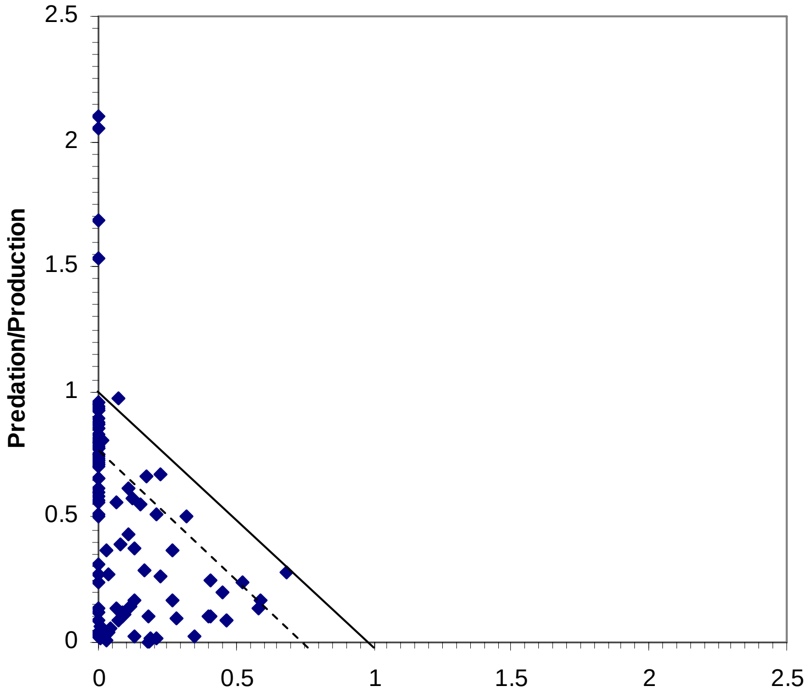
Species between dotted and solid lines

Euphausiids
Gelatinous filter feeders
Pelagic Amphipods
Herring_Juv
Misc. Crustacean
Pandalidae
Benthic Amphipods
Shortspine Thorns
Misc. fish shallow
Eulachon
Oth. pelagic smelt
W. Pollock_Juv
Squids
Sablefish

Pteropods
Myctophidae
Capelin
Lg Phytoplankton
Oth. managed forage
Bivalves
Chaetognaths
Grenadiers
Dusky Rock
NP shrimp
Misc. worms
Copepods
Hydroids
Sandlance

P. Halibut_Juv
Pelagic microbes
Macroalgae
Misc. crabs
P. Cod_Juv
Eelpouts
Bathylagidae
Snails
Dogfish
Fish Larvae
Hermit crabs
Mysids
Octopi
Sharpchin Rock

Figure 9. Sources of mortality relative to production for GOA species. Fishing/Production ratio versus Predation/Production ratio for the Gulf of Alaska for 2005 (based on stock assessment biomass and catch levels and biomass dynamics reconstructions for unassessed species). Solid line indicates level above which (Fishing+Predation=1.0 Dotted line indicates level above which (Fishing+Predation)/Production ≥ 0.75. List shows all species which are in red or yellow on graph. Boxed species on list indicate species for which fishing is greater than 25% of fishing plus predation.



Species above solid line

Herring_Juv
Sandlance
Oth. pelagic smelt
Capelin
Euphausiids
Oth. managed forage
Eulachon
Scyphozoid Jellies

Species between dotted and solid lines

Salmon returning
King Crab_Juv
FH. Sole_Juv
Lg Phytoplankton
Eelpouts
Myctophidae
Misc. fish deep
Sm Phytoplankton
W. Pollock
NP shrimp
Macroalgae
Arrowtooth_Juv
Pteropods
Hydroids
Gr. Turbot
W. Pollock_Juv
Wintering seals
Opilio
Benthic Amphipods
Salmon outgoing
Chaetognaths
Misc. worms
Squids
Pandalidae
YF. Sole_Juv
Benthic microbes
Gelatinous filter feeders
Misc. Crustacean
Bairdi_Juv
P. Cod_Juv
Rougheye Rock
POP
Snails

Figure 10. Sources of mortality relative to production for EBS species. Fishing/Production versus Predation/Production for the Bering Sea for 2005 (based on stock assessment biomass and catch levels and biomass dynamics reconstructions for unassessed species). Solid line indicates level above which (Fishing+Predation=1.0 Dotted line indicates level above which (Fishing+Predation)/Production ≥ 0.75. List shows all species which are in red or yellow on graph. Boxed species on list indicate species for which fishing is greater than 25% of fishing plus predation.

Table 6. Indicator summary of most indicators in the Ecosystem Considerations chapter.

INDICATOR	**OBSERVATION**	**INTERPRETATION**
Physical Oceanography		
Arctic Oscillation Index	Currently near neutral; AOI implicated in the 1988/89 climate shift	Negative values are associated with warm winters
Pacific Decadal Oscillation	Currently slightly positive but near the long-term mean.	When the PDO is positive SST anomalies tend to be positive along the North American coast, extending to the south-eastern Bering Sea
SST Anomalies	Winter 2005/2006 warm water pool in the east-central North Pacific. 2006 was cold in the BS.	BS cold due to more sea ice and later ice retreat than previous 5 years
EBS summer bottom temperature	The 2006 average summer bottom temperature was well below the 1982-2005 average	Bottom temperatures are affected by sea ice and may in turn affect pollock distribution
EBS ice cover index	Sea ice extent anomalies in January 2006 were positive and ice extent was south of its median position for the period 1979-2000	Colder waters on shelf, may result in southward shift of shelf ecosystems. With more ice in 2006, May SST were cooler
Ice retreat index	Ice retreated early 1996-2005 (except in 1999). In 2006, the ice retreated late (May)	The EBS may be shifting to an earlier spring transition. Unclear what conditions in 2006 will bring.
EBS sea ice (AK Native traditional knowledge)	1989-98 ice formation was delayed until early to mid-December vs. mid-October in years prior to 1989.	May be implicated in poor walrus and spotted seal health
AI summer bottom temperature	2004 temperatures were average	Average year
GOA summer temperature	2005 temperatures were the warmest yet recorded in depths less than 50 m. Initial survey data indicates high SST	General warming trend in depths less than 50 m since 1984.
PAPA Trajectory Index	Surface water circulation in the eastern Gulf of Alaska winter 2006 shows southward values (below the mean) yet still near normal conditions compared to some of the earlier extremes	Surface water circulation in the GOA has been near average in the last five years but has become slightly negative (southward) in 2006.
Seasonal rainfall at Kodiak	Winter 2006 had below avg., spring normal, and June above avg. rainfall	Survival potential of age-0 walleye pollock is “weak to average”, because less rainfall does not promote eddies in the ACC, which are beneficial to pollock
Wind mixing south of Shelikof Strait	January-June of 1998-2006 have been below average except March 2003 and March 2005 and June 2006	Weaker than average mixing after spawning (Feb-Mar) favors pollock survival
Ocean transport in WGOA	ACC was more organized and stronger in 2003 than in 2001 or 2002	Complex flow as seen in 2003, creates eddies which are favorable to pollock survival

INDICATOR	OBSERVATION	INTERPRETATION
Eddies in the GOA	Eddy kinetic energy (EKE) high since 1999. EKE in 2005 returned to low values.	Eddies may be areas of high productivity. No eddies in first half of 2005. May decrease cross-shelf transport of heat, salinity, nutrients, phytoplankton.
Habitat		
Area closed to trawling BSAI and GOA	2006 had same closures as 2005 plus new closures to protect EFH. Largest closure: AI Habitat Conservation area	Less trawling than prior to 1999 on bottom in certain areas though may concentrate trawling in other areas
Groundfish bottom trawling effort in GOA	Bottom trawl time in 2004 decreased but was generally similar to 1998-03.	Less trawling on bottom
Scallop tows in GOA	Number of tows decreased in 2001/02 in EGOA but increased in Kodiak relative to 2000/01	Generally decreasing number of scallop tows by area since 1997/98
Longline effort in GOA	Effort levels were about the same in 2003 and 2004.	Generally stable levels of longline effort in 1990's to 2004
Total exploitation rate in GOA	Rates have remained relatively constant since the mid-1980's	Generally stable exploitation rates
HAPC biota bycatch in GOA groundfish fisheries	Estimated at 32t for GOA in 2005, ranged from 27 to 46 t since 1997.	About constant in GOA 1997-2005, with an peak in 2002.
HAPC biota biomass indices from GOA bottom trawl survey	Slight decrease or stable anemones observed in central and western GOA in 2005.	Survey may provide biomass index for anemones and sponges; more research is needed to understand and interpret trends
Groundfish bottom trawling effort in EBS	Bottom trawl time in 2005 decreased slightly but was similar to 2004. 2005 had lowest effort in time series (1990-2005)	Less trawling on bottom relative to 1991-97
Groundfish bottom trawling effort in AI	About the same in 2005 compared to 2004 generally stable trend since 1998	Less trawling on bottom relative to 1990-97
Scallop tows in EBS/AI	Number of tows decreased in 2001/02 in western AK	Generally decreasing number of scallop tows since 1997/98
Longline effort in BSAI	Higher in 2005 relative to 2004 in the BS; slight increase in 2004 relative to 2003 in AI	Generally increasing levels of longline effort in 1990's to present in the BS
Total exploitation rate in BS	Rates have remained relatively constant since the mid-1980's	Generally stable exploitation rates
HAPC biota bycatch in EBS/AI groundfish fisheries	Estimated at 1345 t for BSAI in 2005; ranged from 923 to 2548 t since 1997.	Second lowest catch since 1997.
HAPC biota biomass indices in EBS bottom trawl survey	These groups have been better identified in the survey in the 1990s to present	Survey may provide biomass index for seapens, anemones, and sponges. More research needed to understand trends

INDICATOR	**OBSERVATION**	**INTERPRETATION**
HAPC biota biomass indices in the AI bottom trawl survey	Survey may provide biomass index for seapens, anemones, and sponges.	More research needed to understand trends
Target Groundfish		
Groundfish fleet	Total number of vessels actually fishing in 2005 was lowest since 1994. During 2001 to 2005, trawl vessel counts decreased.	Slight decrease in number of vessels since 2000.
Groundfish discards	increased somewhat between 1998 and 2003, but have declined again in recent years	Fairly stable rates of discarding since 1998, with recent decline since 2004
Total groundfish catch EBS	Total catch in 2004 as in 1990s, pollock dominant; pollock similar to 2003	Catch biomass about the same from 1984-2004
Total groundfish catch AI	Total catch in 2004 similar to 2003, Atka mackerel dominant	Total catch returning to lower levels
Total biomass EBS/AI	Total about the same in 2005 as in 1997, increase in pollock biomass, pollock dominant	Relatively high total biomass since about 1981
EBS recruit per spawner	Some above average recruitment in the early 1990s; since 2000, most below average, except Greenland turbot and AK plaice	Groundfish survival was low in mid- to late-1990s
BSAI groundfish stock status	In 2005, 0 overfished, none subjected to overfishing	All major stocks are not overfished and none are being subjected to overfishing
Total groundfish catch GOA	Total catch lower in 2004 is similar to 2003; slight increase in pollock catch.	Total catch similar from 1985 through present
Total biomass GOA	Biomass declined 1982-01, slight increase in 2002 to 2005 to about same level as 1996, arrowtooth dominant and increasing; slight increase in pollock biomass in 2005.	Relatively low pollock biomass compared to peak in 1982
GOA recruit per spawner	Recruit per spawner below average in the 1990s for some age-structured stocks	Some groundfish recruitment is low in the 1990s , but it is variable depending on the species
GOA groundfish stock status	In 2005, 0 overfished, and none subjected to overfishing	All major stocks are not overfished and none are being subjected to overfishing
Nutrients and Productivity		
Nutrients and chlorophyll N.GOA shelf	Nutrient concentrations and chlorophyll biomass generally higher in 2000 relative to 1998 and 1999	Higher productivity in 2000 relative to 1998 and 1999
Nutrients and productivity EBS	Ice conditions favored spring ice-edge phytoplankton bloom in 1997, but not in 1998 or 1999. Conditions in 1998 and 1999 may have favored dinoflagellate growth	

INDICATOR	OBSERVATION	INTERPRETATION
Zooplankton		
BS zooplankton	No apparent trend 1954-1998; low biomass 1999-2004 in all domains	
GOA zooplanton	Zooplankton biomass peaked in 2002 during 1998-2003	Trends depend on shelf or slope habitat as well as month.
Forage		
Forage bycatch EBS	16 t in 2005 lowest in time series, 19-83 t in 1997-2004, mostly smelts	Lower smelt bycatch in 2005
Larval fish in GOA	Decadal trend in abundance of many species; elevated abundance in late 1980s to mid-1990s relative to early and mid-1980s for some species	Larval abundance in late spring is linked to species-specific combinations of environmental variables, with seasonal variation in linkages
Forage biomass indices from EBS bottom trawl survey	Survey may provide biomass index for some species	More research needed to interpret trends
Forage biomass indices from AI bottom trawl survey	Survey may not sample these well enough to provide biomass indices	
Forage bycatch GOA	1053 t in 2005 highest in time series, 27-540 t in 1997-2004; mostly smelts	Higher smelt catches in 2005 compared to other years.
Forage biomass indices from GOA bottom trawl survey	Eulachon index increased in 2001 in central and western GOA and was at a record high in 2003 in central GOA. 2005 values were similar to those in 2001 in central GOA	Survey may provide biomass index eulachon. More research needed to interpret trends
Forage biomass indices from ADFG inshore small mesh survey in GOA	Capelin CPUE remained low in 2005; eulachon CPUE continued the trend of recent high values	Catches through 2005 do not show any significant deviation from the groundfish-dominated community state
Miscellaneous and other managed species		
GOA Jellyfish from ADFG small mesh survey	CPUE high since 1985; CPUE in 2005 remained high.	
EBS Jellyfish	2001-2006 were low relative to 1992-2000.	Continuation of low levels of jellyfish biomass; similar to levels in the 1980s
NMFS bottom trawl survey - EBS	Survey may provide biomass index for some species	More research on life history characteristics of species needed to interpret trends
NMFS bottom trawl survey - AI	The 2006 survey had the highest jellyfish CPUE for all survey years, with a large increase in the eastern AI	More research needed to interpret trends
Crab stock status - BSAI	2 stocks overfished (Pribilof Is. and St. Mathew Is. blue king)	Mixed crab stock status

INDICATOR	**OBSERVATION**	**INTERPRETATION**
EBS snow crab recruiment	Higher during 1979-87, after which recruitment has been low	Low recruitment could be due to fishing, climate, and/or change in distribution
Bristol Bay red king crab	Strong year classes prior to 1977 (in late 1960s and early 1970s); weak year classes in 1980s and 1990s.	Recruitment may partly relate to regime shifts (1977 and 1989)
Scallop stock status	1 stock- not overfished	
PWS Herring stock status	Pre-fishery run biomass estimate peaked in 1989; stock collapsed afterwards and remains low	Fishery remains closed for fall 2006 and spring 2007.
SEAK Herring stock status	The 2004 and 2005 estimates of spawning biomass were the two highest in 25-year time series. Every stock except Seymour Canal exhibited low recruitment in 2004 and 2005.	Decreasing population biomass can be expected for most stocks unless recruitment increases substantially in upcoming years
Togiak Herring stock status	2005 abundance and age 4 recruits decreased slightly from 2004	Abundance is still below 1978-02 average; but population is considered stable because high abundance in 1980s may be a result of the model used.
Salmon stock status	0 stocks overfished, 5 stocks not overfished, 0 stocks unknown	Generally, Alaskan salmon stocks have been at high levels of abundance in the last 20 years; except some stocks, such as Yukon River chum, and some sockeye runs
Salmon Populations (AK Native Traditional Knowledge)	Decrease in Yukon River salmon populations 1989-1998	
ADF&G large mesh inshore-GOA	Arrowtooth flounder are main component of offshore catches, while Tanner crab have replaced flathead sole as the largest catch in the bays	Increasing dominance of arrowtooth flounder offshore, changing community in bays.
ADF&G small mesh inshore survey-GOA	Pandalid shrimp CPUE in 2005 continues to be low; in 2005 smooth pink shrimp (*Pandalus jordani*) were caught in two bays	Appearance of smooth pink shrimp may possibly indicate a northward distribution shift in response to recent warming of the Gulf of Alaska
NMFS bottom trawl survey-GOA	Survey may provide biomass index for some species	More research needed to interpret trends
Prohibited species bycatch	There was a large increase in bycatch of other salmon and herring in 2003-2005. Decreased bycatch of other king crab and herring; increased bycatch of bairdi, tanner and red king crabs, and chinook salmon, and bycatch mortality of halibut was similar to 2004.	In 2005, there was a decrease in the bycatch of 2 prohibited species an increase in 5 species.
BSAI Non-specified species bycatch	Non-specified species bycatch was lowest in 2005 (14,442 t) compared to other years (14,983 to 25,122 t).	Decreased bycatch of non-specified species. Dominant species in non-specified bycatch were jellyfish, sea stars, and grenadiers
GOA Non-specified species bycatch	Non-specified species bycatch was lowest in 2005 (8,555 t) compared to other years (11,123 -24,634 t).	Decreased bycatch of non-specified species. Dominant species were grenadiers and sea stars.

INDICATOR	OBSERVATION	INTERPRETATION
Marine Mammals		
Alaskan sea lion western stock non-pup counts	Non-pup counts at some trend sites eastern AI were essentially unchanged between 2004 and 2006.	Population in eastern AI may be stable. Not all sites were surveyed in 2006.
Alaskan eastern stock sea lion counts	In the western AI, non-pup counts on 9 trend sites in 2006 declined 19% from 2004.	Population in western AI may be continuing to decline. Not all sites were surveyed in 2006.
Northern fur seal pup counts	Annual rate of decline on both islands combined during 1998-2004 was 6.2% per year	Pup production at low levels not seen since 1918 (St. Paul) and 1916 (St. George)
Seabirds		
Seabird breeding chronology	Overall seabird breeding chronology was early or average, with early nesters predominate in the NB/C, SEBS, and SEAK. The highest number of late nesters was in SWBS, where no birds were early.	Earlier hatching times are associated with higher breeding success
Seabird productivity	Varied by region and species, but there was a trend of above average or average productivity in most regions, except SWBS	Variable chick production
Population trends	Mixed: majority showed no discernable trend through to 2003.	Variable depending on species and site
Seabird bycatch	2004 longline bycatch is decreasing or stable in the BS, AI, and GOA.	Unclear relationship between bycatch and colony population trends
Aggregate Indicators		
Trophic level catch EBS and AI	Constant, relatively high trophic level of catch since 1960s	Not fishing down the food web
Trophic level catch GOA	Constant, relatively high trophic level of catch since 1970s	Not fishing down the food web
Groundfish biodiversity EBS	Significant change in flatfish and roundfish species richness and evenness in late 1980s; stable to the present	An event in the 1970s sparked ecosystem changes that were perpetuated into the late 1980s and early 1990s; an event in the late 1980s countered the 1970s event
EBS groundfish community size spectrum	The bottom trawl fish community appears to have fewer small individuals and more large individuals through time.	This may be a reflection of climate driven declines in recruitment in the 1990's
EBS groundfish community composition	There were no differences in k-dominance curves between year groups.	There appear to be no major changes in community composition over time.

INDICATOR	OBSERVATION	INTERPRETATION
Groundfish species richness and diversity - BS	Diversity increased 1983-1990's; decreased after 2001; average in 2004. Richness has been variable	
Groundfish species richness and diversity - GOA	Species richness and diversity increased from 1990-99, decreased after 1999.	
Combined standardized indices of groundfish recruitment	Above-average recruitment from the mid- or late 1970s to the late 1980s, followed by below-average recruitment during the early 1990s (GOA) or most of the 1990s (BSAI); above-average recruitment in the GOA from 1994-2000 (except 1996). A similar trend was evident in the Bering Sea, but was much less pronounced	Recruitment are a function of both spawner biomass and environmental variability
Combined standardized indices of groundfish survival	Similar patterns as recruitment. Indices for GOA and BSAI were unusually high in 1984, when 19 out of 23 stocks were above-average.	Trends in survival rate indices, which are adjusted for differences in spawner biomass, are presumably driven by environmental variability but are even more uncertain than recruitment trends
Groundfish productivity BS	Decreased from 1978-2004; this is a significant decrease in the BSAI when pollock are removed from analysis.	May be a decrease in overall production or could be due to density-dependent response to observed increases in biomass
Groundfish productivity GOA	Lower than in BS and less variable; decreased slightly from 1978-2004.	
Total trawl survey fish and invertebrate CPUE BS	Peaked in 1994, was near 20-year average in 2000, increased in 2003 and 2004; long-term increase from 1982-2003	Increased overall abundance of demersal and benthic species
Total trawl survey fish and invertebrate CPUE GOA	Peaked in 1993-96, decreased until 1999, increased slightly in 2001, at record high in 2003	Increased overall abundance of demersal and benthic species

APPENDIX 1: Model Details

While the ECOPATH modeling method allows for flexibility and “manual adjustments” to model balancing, these methods were not used for developing the eastern Bering Sea, Gulf of Alaska, and Aleutian Islands food web models, as substantial data was available. For most species, estimates of biomass, ration, diet composition, catch, and production rates were available or could be calculated directly from existing data as described in sections 4-6, below. Therefore, the only calculated quantity for each species (“solved” by ECOPATH linear equations) was M_0, or residual natural mortality (the difference between total mortality and predation + fishing mortality), using the equation in section 2, below. Furthermore, during fitting to time series, the ECOPATH estimate of M_0 was treated as a starting rather than ending point for maximum likelihood estimation.

For species for which biomass estimates were unreliable due to low catchability of the surveys (primarily forage, benthos, and lower trophic levels), biomass was estimated by fixing M_0 to be 20% of production, and calculating the biomass required to sustain consumption (section 1, below). The only situations in which manual “tuning” was necessary were for a few isolated cases of prey identification issues in diets (primarily for gelatinous species of zooplankton) and to account for the mismatch between survey and fishery areas in the Aleutian Islands. This latter issue was a particular difficulty as the shelf survey extended only to 500m depth, however a substantial portion of area, ecosystem processes, and fisheries occur at greater depths, and this mismatch had a great impact due to the extremely narrow shelf around the islands. Therefore, high production shown in the Aleutians is a reflection of oceanic and deep processes “concentrating” on the narrow continental shelf.

All cases in which biomass was estimated through fixing M_0 or where manual tuning was performed were considered to be “lower” data quality and are indicated as such on results graphs, except in cases where likelihood estimation was applied to these initial calculations.

It is important to note that the critical parameter for all of these processes is mortality; mortality not only affects production rates, but affects the relative contribution of different age classes to ration and diet compositions. Here, we do not fit or calculate total mortality but rather use single-species assessment estimates or literature values; therefore uncertainty in the single-species estimates of M are propagated into the ECOPATH food web model. Since our estimation process explicitly fits mortality components, cases where the data is sufficient to provide estimates of predation mortality and M_0 may be improvements over single-species assumptions.

A full documentation of this process and all data used as inputs to these models is available in Aydin et al. (in review).

1. Estimates of biomass and catchability from minimum consumption estimates.

Forage species are not sampled well by current gear in the Bering Sea and Gulf of Alaska. However, relative biomass (CPUE) from surveys is reported with annual CVs less than interannual variation, implying that CPUE may be useful as an index. To sum these indices, converting to a standard assumption on catchability is necessary. In order to do this, calculating the minimum biomass required to support measured groundfish consumption is one possibility, as follows:

The biomass (B), ration (Ration), and diet composition (DC, % wet weight) are calculated for groundfish predators within a reference (base) year. Equations for DC and ration calculations are described in Appendix sections 4 and 5, respectively. For the Bering Sea, the base year is 1991, while for the Gulf of Alaska the default years are 1990 and 1993 combined. Minimum required biomass of prey is then calculated as the sum of consumption by its predators as a fraction of its mortality as follows:

$$\hat{B}_{cons,f}^{1991} = \frac{\sum_{pred}\left(B_{pred}^{1991} \cdot Ration_{pred}^{1991} \cdot DC_{pred,f}^{1991}\right)}{0.8 \cdot Z_f^{1991}} \qquad (1.1)$$

Here, Z is the mortality (equilibrium production rate) of the forage species, generally taken from single-species estimates from literature review (Appendix section 6). 0.8 is a "default minimal" assumption that 20% of the forage fish production is "unexplained" (attributed to M_0). When fit to time trends, this assumption of M_0 is a fit parameter; however for summing relative forage biomass it is a default assumption to this method.

After biomass for the reference year is calculated, the catchability q of the survey for the forage species is calculated as:

$$\hat{q}_{cons,f}^{survey} = \frac{CPUE_{survey,f}^{1991}}{\hat{B}_{cons,f}^{1991}} \qquad (1.2)$$

Then, for years other than the reference year, survey CPUE may be converted to biomass using the conversion:

$$\hat{B}_{cons,f}^{year} = \frac{CPUE_{survey,f}^{year}}{\hat{q}_{cons,f}^{survey}} \qquad (1.3)$$

A future improvement will be to specifically estimate q over multiple years of diet and mortality data to evaluate the stability of this calculation of q.

2. Estimates of unaccounted mortality (M_0).

Residual ("unexplained" or "unaccounted") natural mortality (M_0) for a population is calculated from species biomass B_f, predator biomass (B_{pred}), ration (Ration), and diet composition (DC, % wet weight) of the prey in the predators' diets in a reference (base) year. Equations for DC and ration calculations are described in Appendix sections 4 and 5, respectively. For the Bering Sea, the base year is 1991, while for the Gulf of Alaska the default years are 1990 and 1993 combined. M_0 is then calculated using the following formula:

$$M_{0f} = Z_f^{1991} - \frac{\sum_{pred}\left(B_{pred}^{1991} \cdot Ration_{pred}^{1991} \cdot DC_{pred,f}^{1991}\right)}{B_f^{1991}} \qquad (2.1)$$

Here, Z is the mortality (equilibrium production rate) of the forage species, generally taken from single-species estimates from literature review (Appendix section 6). It is possible for M_0 to be negative, indicating that consumption is greater than a declining population. In this case, the rate of decline during the reference year is estimated from time series data and added to prey biomass and the value is recalculated.

If one or more predator biomass levels are unknown, M_0 must be estimated simultaneously with predator biomass as described in Equation 1.1. In this case, the vector of unknowns M_0 or B (one for each species) is solved simultaneously: this solution is the “ECOPATH balance” solution for the food web.

3. Maximum likelihood estimation for a biomass dynamics model

The food web model estimated from rates as described in sections 1 and 2 is turned into a biomass dynamics model as follows:

$$\frac{dB_i}{dt} = \sum_{prey} GE \cdot c(B_i, B_{prey}) - M_0 B - FB - \sum_{pred} c(B_{pred}, B_i) + \varepsilon \qquad (3.1)$$

GE and M_0 are fit parameters for growth efficiency and unaccounted mortality, F is year-specific fishing rate, ε is process error and c() is the following consumption equation:

$$c(B_{pred}, B_{prey}) = Q^*_{link}\left(\frac{X_{link} \cdot Y_{pred}}{X_{link} - 1 + Y_{pred}}\right)\left(\frac{D_{link} \cdot Y_{prey}^{\theta_{link}}}{D_{link} - 1 + Y_{prey}^{\theta_{link}}}\right) \qquad (3.2)$$

where $Yi = B_i^t \big/ B_i^*$. B* and Q* are biomass and consumption rates in a base year; this base year does not need to be an equilibrium state of the model. X_{link} is a predator/prey pair specific value greater than 1 which determines predator density dependence on foraging (the numerical response) while D_{link} is a predator/prey specific value greater than 1 which determines the satiation of handling time/predation mortality for that link. θ_{link} is a shape parameters which determines if predation is constant with prey density (θ_{link}=0), saturating (Type II functional response; θ_{link}=1) or prey switching (Type III functional response; θ_{link}=2). θ_{link} can take on intermediate values. Since these parameters are link-specific, the dimensionality is reduced by assuming predator and prey specific foraging behavior for each species that is additive for each predator/prey pair, so that:

$$X_{link} = 1 + \exp(x_{prey} + x_{pred}),$$

$$D_{link} = 1 + \exp(d_{prey} + d_{pred}) \text{ , and}$$

$$\theta_{link} = (\theta_{prey} + \theta_{pred}).$$

Overall, this gives 8 parameters per species to fit: GE, M_0, x_{prey}, x_{pred}, d_{prey}, d_{pred}, θ_{prey}, and θ_{pred}.

To run simulations, equation 3.1 is integrated using Adams-Basforth integration with monthly timesteps (finer timesteps did not appreciably affect results). To obtain parameter point estimates, three weighted error functions are used assuming lognormal error (log sum-of-squares minimization criteria):

1. For 1965-2005, stock assessment biomass for species with age-structured assessments and catches are assumed to be “perfectly known” and the annual process error (change in biomass) required to follow these biomass trends is calculated and applied. Functional response parameters are fit to minimize this process error: a future extension of this method may be to apply a nonlinear Kalman filter to allow for error specification within each time trend.
2. For species with no age-structured stock assessments the difference between the dynamic

model-predicted 1990-93 average biomass and the initial food web model biomass (e.g. coming from trawl survey data or consumption estimates) was considered as observation error.

3. Finally, there is a persistence criteria: any parameter set which causes one or more species to go extinct (be reduced to below 1/1000 of its initial biomass) following 50 years of equilibrium fishing pressure is rejected; as all species in the model have persisted over the modeled time period this criterion simply establishes a thermodynamic (trophically bounded) parameter set.

In addition, two broad groups of species, whales and commercial crabs, were subjected to substantial depletion through fishing during the modeled time period. For these species, historical catch time series were applied, and the criteria that the 1990-3 biomass of these species be near their food web biomass levels resulted in estimating ecosystem parameters that could support substantially higher “pre-modern exploitation” levels of biomass.

Two methodological concerns are raised by the fitting method. The first is the matter of degrees of freedom; a total of 8 parameters per species for each of the 119 species in the model results in 952 parameters while the biomass time trends currently used give a total of 672 “data” points for fitting. However, the constraints applied by the persistence criterion (#3, above) greatly influence the parameter covariance, e.g. the predation of upper trophic levels combined is not permitted to greatly exceed lower trophic level production. If parameters are chosen randomly and independently from uniform distributions, over 90% of parameter sets are rejected, indicating that the degrees of freedom for the model are lower than 952 independent parameters. Still, many of the resulting maximum likelihood estimates are not strongly discriminating of whether prey switching may be taking place; the future addition of direct fitting to historical diet data will improve these results.

Second, using single-species stock assessment model outputs as “known” biomass trends requires the multi-species model to try to match the single-species blanket assumption of constant natural mortality, which has the potential for introducing the single-species metaphor of fixed species interaction into a more dynamic simulation. This is partially mitigated by the fact that the adult biomass time trends come from assessments of large groundfish predators, for which predation morality is generally low. For several of these groundfish species, the ecosystem model tracks separate juvenile and adult components; in these cases, juvenile biomass levels from the stock assessment are not used. The one place this remains an issue is for walleye pollock, which initial results indicate show an increase in adult natural mortality in recent years. One possibility for removing this circularity is to iterate between the ecosystem and single-species models; using the M reconstructed from the ecosystem model to derive a new single-species estimate for biomass, then using that new biomass in the ecosystem model, iterating until an agreement between the models is reached; this work is planned for the near future.

4. Diet composition calculations

Notation:
DC = diet composition
W = weight in stomach
n = prey
p = predator
s = predator size class
h = survey haul
r = survey stratum

B = biomass estimate
v = survey
a = assessment
R = ration estimate

The diet composition for a species is calculated from stomach sampling beginning at the level of the individual survey haul (1), combining across hauls within a survey stratum (2), weighting stratum diet compositions by stratum biomass (3), and finally combining across predator size classes by weighting according to size-specific ration estimates and biomass from stock assessment estimated age structure (4). Ration calculations are described in detail below.

Diet composition (DC) of prey n in predator p of size s in haul h is the total weight of prey n in all of the stomachs of predator p of size s in the haul divided by the sum over all prey in all of the stomachs for that predator size class in that haul:

$$DC_{n,p,s,h} = W_{n,p,s,h} \Big/ \sum_{n} W_{n,p,s,h} \qquad (4.1)$$

Diet composition of prey n in predator p of size s in survey stratum r is the average of the diet compositions across hauls within that stratum:

$$DC_{n,p,s,r} = \sum_{h} DC_{n,p,s,h} \Big/ h \qquad (4.2)$$

Diet composition of prey n in predator p of size s for the entire area t is the sum over all strata of the diet composition in stratum r weighted by the survey biomass proportion of predator p of size s in stratum r:

$$DC_{n,p,s,t} = \sum_{r} DC_{n,p,s,r} * B^{v}_{p,s,r} \Big/ \sum_{r} B^{v}_{p,s,r} \qquad (4.3)$$

Diet composition of prey n in predator p for the entire area t is the sum over all predator sizes of the diet composition for predator p of size s as weighted by the relative stock assessment biomass of predator size s times the ration of predator p of size s:

$$DC_{n,p,t} = \sum_{s} DC_{n,p,s,t} * B^{a}_{p,s} * R_{p,s} \Big/ \sum_{s} B^{a}_{p,s} * R_{p,s} \qquad (4.4)$$

5. Ration Calculations

Size specific ration (consumption rate) for each predator was determined by the method of fitting the generalized Von Bertalanffy growth equations (Essington et al. 2001) to weight-at-age data collected aboard NMFS bottom trawl surveys.

The generalized Von Bertalanffy growth equation assumes that both consumption and respiration scale allometrically with body weight, and change in body weight over time (dW/dT) is calculated as follows (Paloheimo and Dickie 1965):

$$\frac{dW_t}{dt} = H \cdot W_t^d - k \cdot W_t^n \qquad (5.1)$$

Here, W_t is body mass, t is the age of the fish (in years), and H, d, k, and n are allometric parameters. The term $H \cdot W_t^d$ is an allometric term for "useable" consumption over a year, in other words, the consumption (in wet weight) by the predator after indigestible portions of the prey have been removed and assuming constant caloric density between predator and prey. Total consumption (Q) is calculated as $(1/A) \cdot H \cdot W_t^d$, where A is for a fractional conversion between prey and predator wet weights that accounts for indigestible portions of the prey and differences in caloric density. The term $k \cdot W_t^n$ is an allometric term for the amount of biomass lost yearly as respiration.

Based on an analysis performed across a range of fish species, Essington et al. (2001) suggested that it is reasonable to assume that the respiration exponent n is equal to 1 (respiration linearly proportional to body weight). In this case, the differential equation above can be integrated to give the following solution for weight-at-age:

$$W_t = W_\infty \cdot \left(1 - e^{-k(1-d)(t-t_0)}\right)^{\frac{1}{1-d}} \qquad (5.2)$$

Where W_∞ (asymptotic body mass) is equal to $(H/k)^{\frac{1}{1-d}}$, and t_0 is the weight of the organism at time=0. If the consumption exponent d is set equal to 2/3, this equation simplifies into the "specialized" von Bertalanffy length-at-age equation most used in fisheries management, with the "traditional" von Bertalanffy K parameter being equal to the k parameter from the above equations divided by 3.

From measurements of body weight and age, equation 2 can be used to fit four parameters (W_∞, d, k, and t_0) and the relationship between W_∞ and the H, k, and d parameters can then be used to determine the consumption rate $H \cdot W_t^d$ for any given age class of fish. For these calculations, weight-at-age data available and specific to the modeled regions were fit by minimizing the difference between log(observed) and log(predicted) body weights as calculated by minimizing negative log likelihood: observation error was assumed to be in weight but not aging. A process-error model was also examined but did not give significantly different results.

Initial fitting of 4-parameter models showed, in many cases, poor convergence to unique minima and shallow sum-of-squares surfaces: the fits suffered especially from lack of data at the younger age classes that would allow fitting to body weights near t=0 or during juvenile, rapidly growing life stages. To counter this, the following multiple models were tested for goodness-of-fit:

1. All four parameters estimated by minimization;
2. *d* fixed at 2/3 (specialized von Bertalanffy assumption)
3. *d* fixed at 0.8 (median value based on metaanalysis by Essington et al. 2001).
4. t_0 fixed at 0.
5. *d* fixed at 2/3 with t_0 fixed at 0, and *d* fixed at 0.8 with t_0 fixed at 0.

The multiple models were evaluated using Aikeike's Information Criterion, AIC. In general, the different methods resulted in a twofold range of consumption rate estimates; consistently, model #3, *d* fixed at 0.8 while the other three parameters were free, gave the most consistently good results using the AIC. In some cases model #1 was marginally better, but in some cases, model #1 failed to converge. The poorest fits were almost always obtained by assuming that d was fixed at 2/3.

To obtain absolute consumption (*Q*) for a given age class, the additional parameter *A* is required to account for indigestible and otherwise unassimilated portions of prey. We noted that the range of indigestible percentage for a wide range of North Pacific zooplankton and fish summarized in Davis (2003) was between 5-30%, with major zooplankton (copepods and euphausiids), as well as many forage fish, having a narrower range of indigestible percentages, generally between 10-20%. Further, bioenergetics models, for example for walleye pollock (Buckley and Livingston 1994), indicate that nitrogenous waste (excretion) and egestion resulted in an additional 20-30% loss of consumed biomass. As specific bioenergetics models were not available for most species, we made a uniform assumption of a total non-respirative loss of 40% (from a range of 25-60%) for all fish species, with a corresponding *A* value of 0.6.

Finally, consumption for a given age class was scaled to population-level consumption using the available numbers-at-age data from stock assessments, or using mortality rates from stock assessments and the assumption of an equilibrium age structure in cases where numbers-at-age reconstructions were not available.

6. Production rates

Production per unit biomass (P/B) and consumption per unit biomass (Q/B = R, ration above) for a given population depend heavily on the age structure, and thus mortality rate of that population. For a population with an equilibrium age structure, assuming exponential mortality and Von Bertalanffy growth, P/B is in fact equal to total mortality Z (Allen 1971) and Q/B is equal to (Z+3K)/A, where K is Von Bertalanffy's K, and A is a scaling factor for indigestible proportions of prey (Aydin 2004). If a population is not in equilibrium, P/B may differ substantially from Z although it will still be a function of mortality.

For the Bering Sea, Aleutian Islands, and Gulf of Alaska ECOPATH models, P/B and Q/B values depend on available mortality rates, which were taken from estimates or literature values used in single-species models of the region. It is noted that the single-species model assumptions of constant natural mortality are violated by definition in multispecies modeling; therefore, these estimates should be seen as "priors" to be input into the ECOPATH balancing procedures or other parameter-fitting (e.g. Bayesian) techniques.

Several methods were used to calculate P/B, depending on the level of data available. Proceeding from most data to least data, the following methods were used:

1. If a population is not in equilibrium, total production P for a given age class over the course of a year can be approximated as ($N_{at} \cdot \Delta W_{at}$), where N_{at} is the number of fish of a given age class in a given year, exponentially averaged to account for mortality throughout the year, and ΔW_{at} is the change in body weight of that age class over that year. For a particular stock, if weight-at-age data existed for multiple years, and stock-assessment reconstructed numbers-at-age were also available, production was calculated by summing this equation over all assessed age classes. Walleye pollock P/B for both the EBS and GOA were calculated using this method: examining the components of this sum over the years showed that numbers-at-age variation was responsible for considerably more variability in overall P/B than was weight-at-age variation.
2. If stock assessment numbers-at-age were available, but a time series of weight-at-age was not available and some weight-at-age data was available, the equation in (1), above, was used, however, the change in body weight over time was estimated using fits to the generalized Von Bertalanffy equations described in the consumption section, above.
3. If no stock assessment of numbers-at-age was available, the population was assumed to be in equilibrium, so that P/B was taken to equal Z. In cases for many nontarget species, estimates of Z were not available so estimates of M were taken from conspecifics with little assumed fishing mortality for this particular calculation.

ECOSYSTEM STATUS INDICATORS

The purpose of this section is to provide new information and updates on the status and trends of ecosystem components to stock assessment scientists, fishery managers, and the public. The goals are to provide stronger links between ecosystem research and fishery management and to spur new understanding of the connections between ecosystem componenets 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 ecosystems, we will be able to derive ecosystem indicators that reflect this new understanding.

Physical Environment

Ecosystem Indicators and Trends Used by FOCI

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Last updated: November 2006

FOCI's scientists employ a number of climate, weather, and ocean indices and trends to help describe and ascribe the status of the ecosystem to various patterns or regimes. This document presents some of these with respect to current (2004) conditions. This section begins with an overview of North Pacific climate for 2004, including an examination of trends and tendencies in multidecadal and decadal climate regimes. Following this section are sections dealing explicitly with the western Gulf of Alaska and eastern Bering Sea. Within these are continuations of discussions begun in 2003 on eddy kinetic energy in the Gulf of Alaska and modeled drift trajectories for the Bering Sea.

Pacific Climate Overview

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Last updated: November 2006

Summary*. Atmospheric circulation over the North Pacific during 2006 was characterized by a high degree of variability. A strong Aleutian low, which dominated in December 2005, substantially weakened and split into two centers in January 2006. The anomalous high pressure center that formed over the central North Pacific is consistent with the weak La Niña that was present in the tropical Pacific. The anomalous atmospheric circulation was accompanied by a southward expansion of negative sea surface temperature anomalies in the Gulf of Alaska and a relatively warm water pool in the North Pacific near the dateline that persisted through spring and summer of 2006. There are conflicting signals regarding the evolution of North Pacific SST anomalies into 2007. Coupled GCM forecasts from the Climate Prediction Center suggest persistence of the current SST anomaly pattern into early 2007. On the other hand, a weak to moderate El Nino is forming in the fall of 2006, which often is associated with a stronger than normal Aleutian low, which itself usually acts to cool the central North Pacific and bring about a narrow strip of warmer than normal water along the North American coast. A great deal of ambiguity still exists regarding a possible climate regime shift in the late 1990s. Some indices, such as the winter PDO index from N. Mantua and Pacific/North American (PNA) index, lack substantial and systematic changes in their states. An alternative version of the winter PDO index from National Climate Data Center and summer PDO index, however, feature statistically significant shifts to negative values in 1998/99. That time also corresponds to a statistically significant shift in the El Niño/ Southern Oscillation.*

1. El Niño – Southern Oscillation (ENSO)

During September 2005- January 2006, below-average SSTs developed throughout most of the central and eastern equatorial Pacific. In February 2006 positive SST anomalies developed in the extreme eastern equatorial Pacific, similar to what occurred in 1999, 2000 and 2001 (La Niña years). Based on the Oceanic Niño Index (ONI), which has become the de-facto standard used by NOAA to identify ENSO events, these conditions in the equatorial Pacific qualified as a weak La Niña episode (Figure 11).

Recently, SST anomalies have increased in the west-central and extreme eastern equatorial Pacific to qualify for a weak El Niño event. Statistical and coupled model forecasts produced by the Climate Prediction Center suggest that there is a potential for this event to strengthen into a moderate event by winter. However, the spread of these forecasts indicates considerable uncertainty in the outlook for late 2006 and early 2007.

2. Arctic Sea-Ice

The warming trend in the Arctic is illustrated in Figure 12, which shows the Northern Hemisphere sea ice extent in March, as measured from passive microwave instruments onboard NOAA satellites. March is the month when Arctic sea ice reaches its maximum extent. The overall downward trend in the sea ice extent has accelerated in the past four years. In 2006 it was 14.5 million square kilometers, the lowest value for any March on record (Figure 12). This is 1.2 million square kilometers below the long-term (1979-2000) mean. The implications of this trend for the North Pacific are likely to include a tendency for a shorter season during which intense cold-air outbreaks of arctic origin can occur.

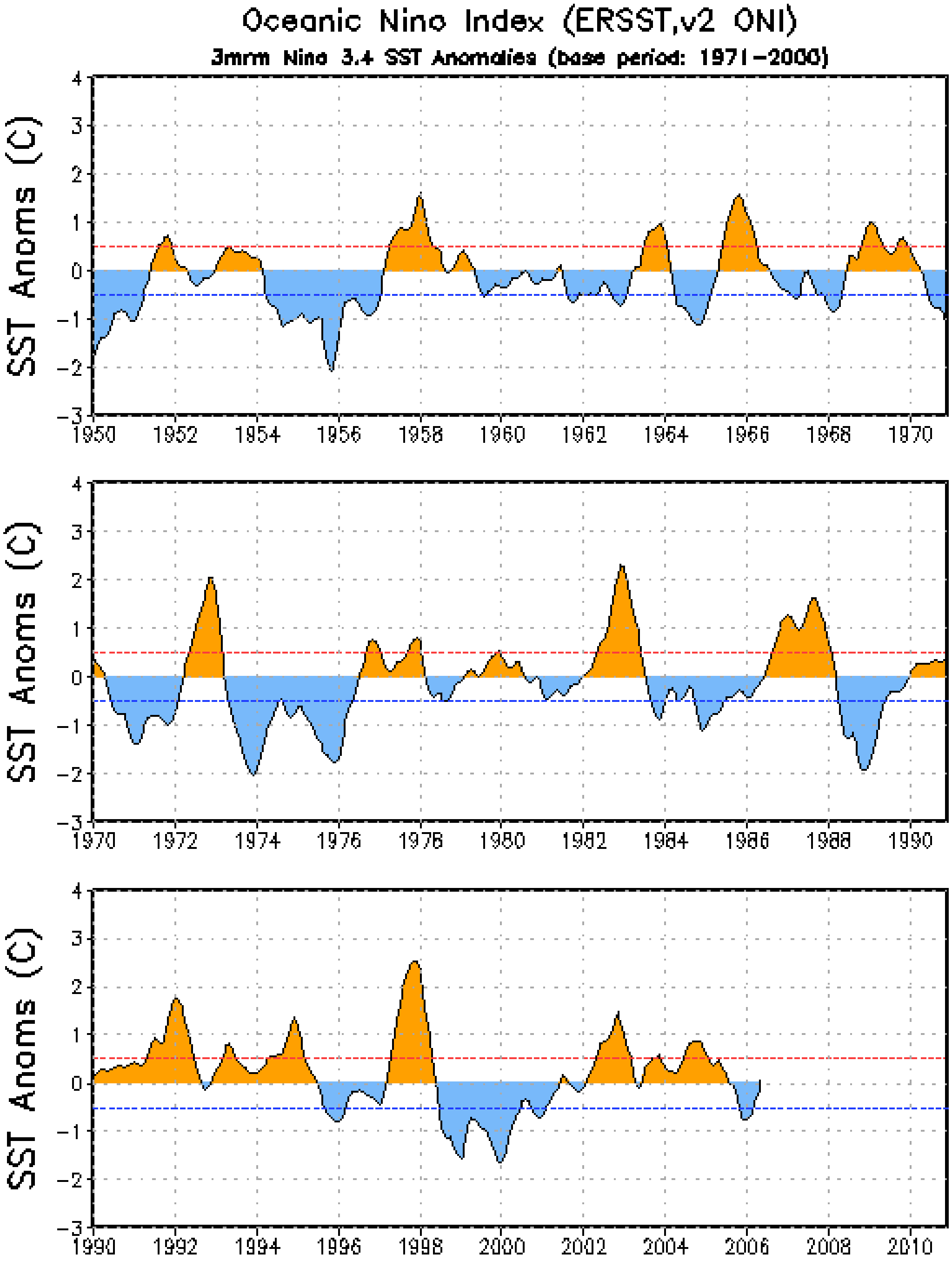


Figure 11. The Oceanic Niño Index (ONI) is the running 3-month mean SST anomaly for the equatorial Pacific and is the standard used by NOAA to identify El Niño (warm) and La Niña (cool) events in the tropical Pacific.

3. North Pacific

3.1 Atmospheric Circulation

In the winter of 2005/06, the atmospheric circulation was characterized by a high degree of variability. Specifically, December 2005 featured an anomalously strong Aleutian low, with sea-level pressure (SLP) in its center being 12 hPa below the long-term average. The North Pacific index (NPI), which is the area-weighted SLP over the region 30˚N-65˚N, 160˚E-140˚W (Trenberth and Hurrell, 1994), was 999.5, the record lowest value for December since 1899. It is particularly unusual that this abnormally low pressure occurred in the absence of an El Niño event, which is considered as one of the major factors leading to a stronger-than-normal Aleutian low (Lau 1996). Overall, the atmospheric circulation in December 2005 can be classified as W1, which is the most typical pattern associated with positive surface air temperature anomalies (SAT) in the eastern Bering Sea (Rodionov et al. 2005).

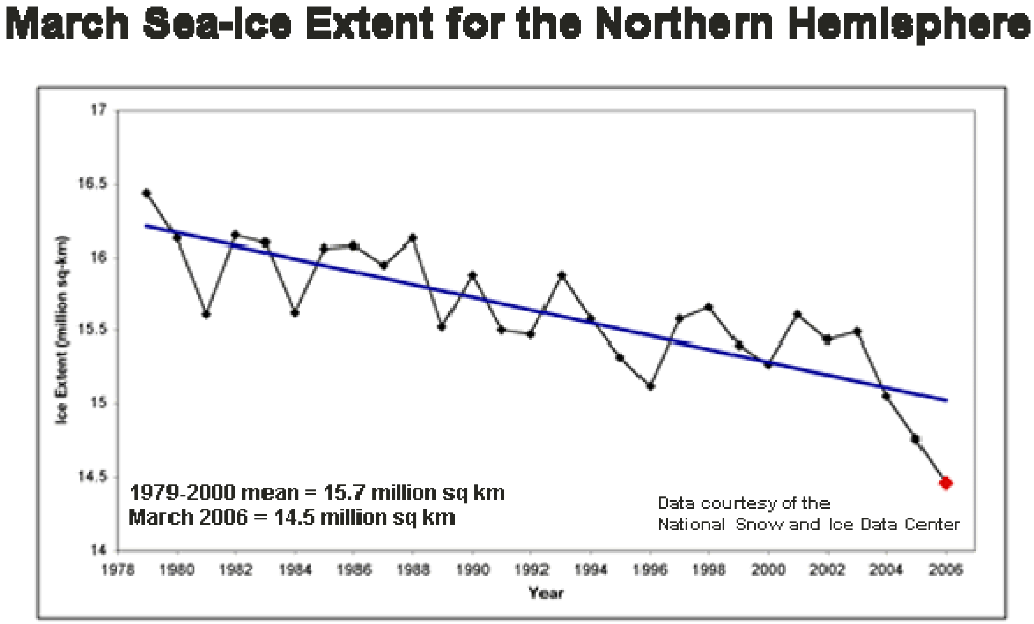


Figure 12. March sea-ice extent (in millions of square kilometers) across the Northern Hemisphere.

In January 2006, the Aleutian low was weak and split into two centers, one in the northwestern Pacific and the other one in the Gulf of Alaska. This pattern is classified as C1, which is the major circulation pattern for anomalously cold temperatures in the Bering Sea (Rodionov et al. 2005). Indeed, January SATs in the Bering Sea and Alaska were much below normal (see Temperature and Ice Cover in the Bering Sea, this report). The atmospheric circulation also featured anomalous middle to upper tropospheric troughing from the Gulf of Alaska into western Canada. This resulted in a near zonal flow over much of the Pacific-North American sector and advection of warm Pacific air masses deep into the continent, where monthly temperatures in much of the U.S. and Canada were above the 90th percentile of occurrences.

In February 2006, an anomalously high pressure cell in the central North Pacific strengthened even further, with SLP anomalies exceeding 12 hPa, and pushing the storm activity far north into the Bering Sea. The monthly NPI was the 6th largest for all Februaries since 1899. This extreme variability in atmospheric circulation over the North pacific is illustrated in Figure 13, which shows a time-latitude plot of SLP anomalies averaged for the meridional section 150˚W-170˚W. Although the high pressure cell weakened in the subsequent months, the NPI remained positive through June 2006.

3.2 Sea Surface Temperature Evolution

A sequence of by-monthly sea surface temperature (SST) anomaly maps from January-February 2006 to July-August 2006 is presented in Figure 14. These maps demonstrate two important features of SST evolution during the winter and spring of 2006: 1) the disappearance of negative SST anomalies in the central and eastern equatorial Pacific in association with the final stages of the weak La Niña episode, and 2) the development of a SST anomaly pattern in the North Pacific, with some elements of a negative Pacific Decadal Oscillation (PDO) phase. One of those elements is the strengthening and southward expansion of negative SST anomalies in the northeastern Pacific from January-February through, at least, May-June. This process was associated with the prevalent northwesterly anomalous wind over the eastern North Pacific in the first eight month of this year (Figure 15).

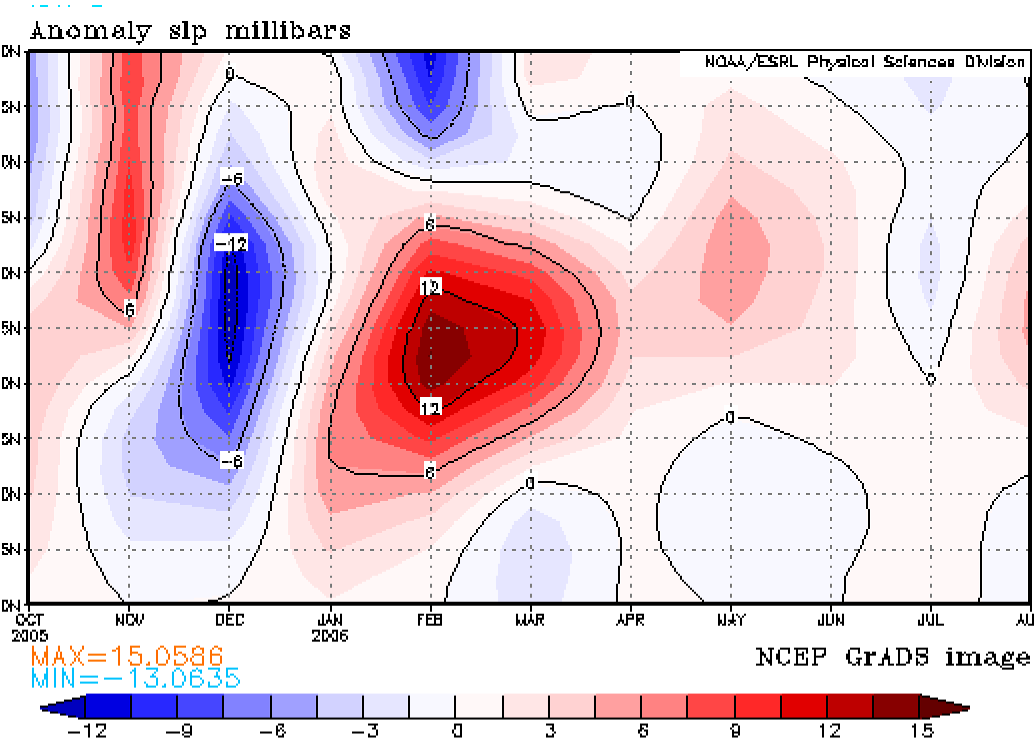
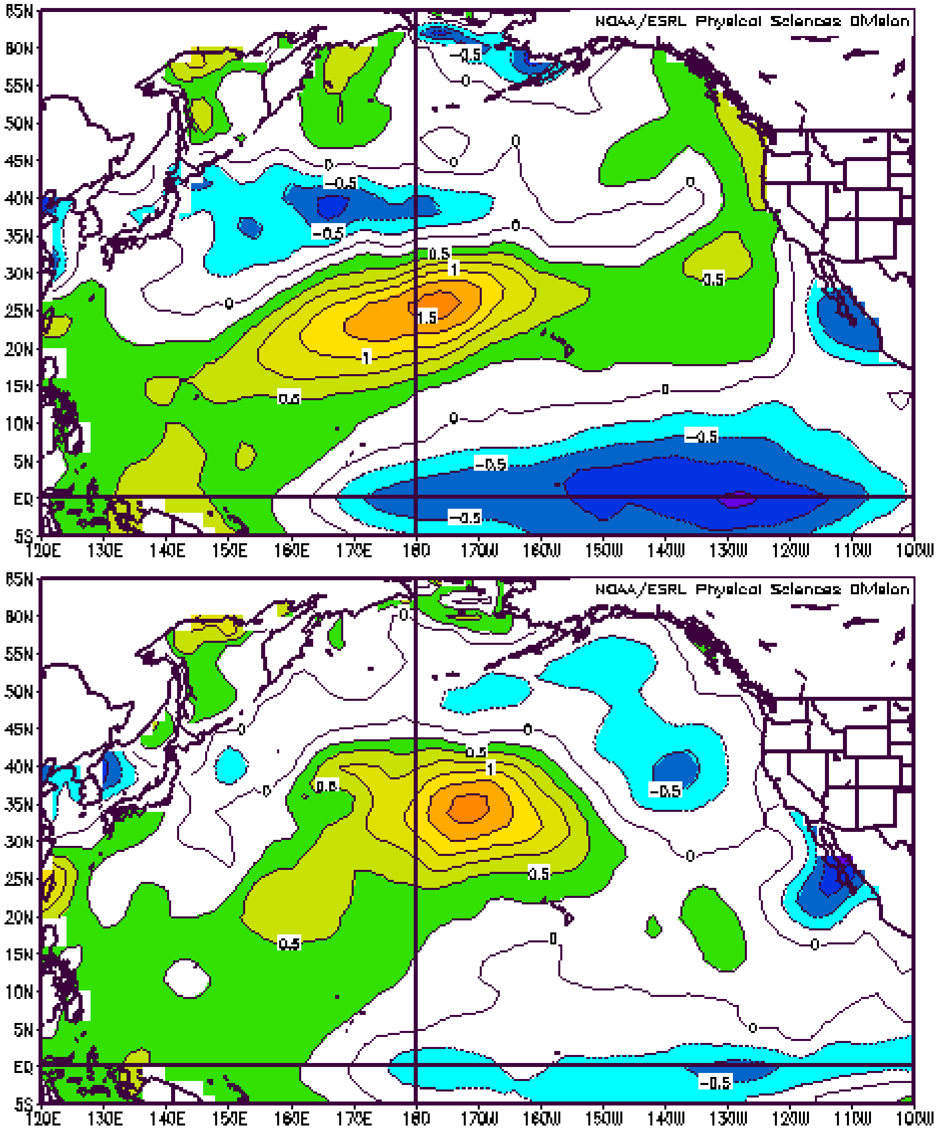


Figure 13. Time-latitude plot of SLP anomalies averaged over the meridional sector 150˚W-170˚W.

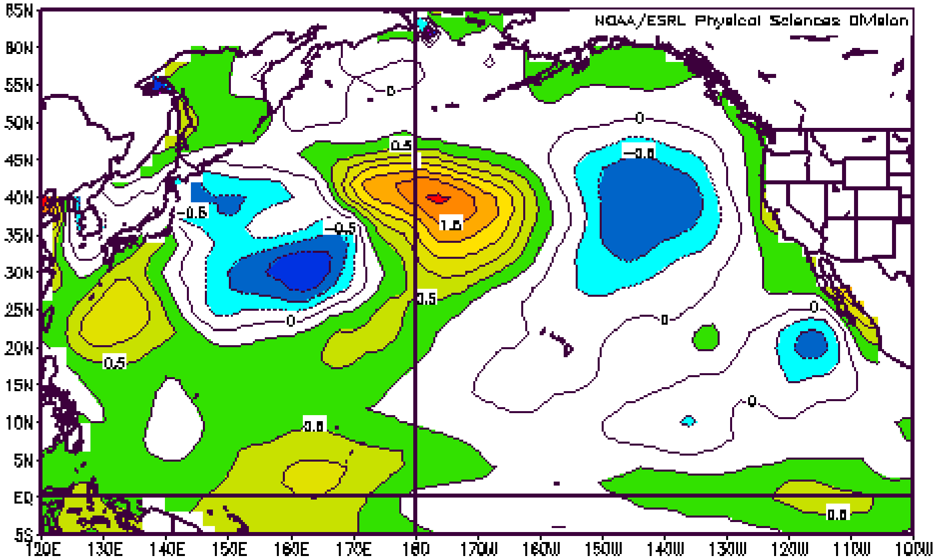


a) Jan-Feb 2006

b) Mar-Apr 2006

Figure 14. By-monthly SST anomalies (relative to 1971-2000 climatology) from January-February 2006 through March-April 2006.

c) May-Jun 2006



d) Jul-Aug 2006

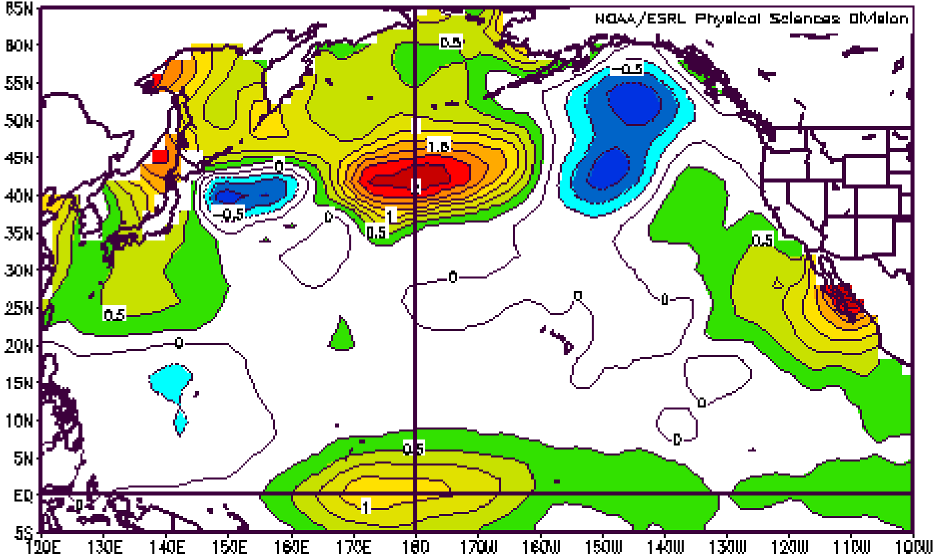


Figure 14 continued. By-monthly SST anomalies (relative to 1971-2000 climatology) from May-June 2006 through July-August 2006.

Another important aspect of the SST evolution in 2006 is the strengthening of the positive SST anomaly in the central North Pacific. The atmospheric circulation pattern, with its anomalous anticyclonic circulation over the basin (Figure 15), was conducive to this process. Several mechanisms contribute to the formation of a warm water pool under a high pressure cell over the central North Pacific. Anomalously high pressure implies less cyclonic activity in the area and hence less cloudiness, which means enhanced solar heating of the upper ocean. Strong easterly anomalous winds in the subtropical latitudes imply an enhanced transport of warm waters in the Ekman layer to the north and stronger than normal downwelling in center of the subtropical ocean gyre.

It is somewhat surprising, therefore, that in spite of atmospheric pressure and wind patterns that were characteristic of the negative PDO phase, that the monthly PDO index remained positive through the first half of 2006. A contributing factor here is that the west Pacific was colder than normal, which projects on a positive phase of the PDO.

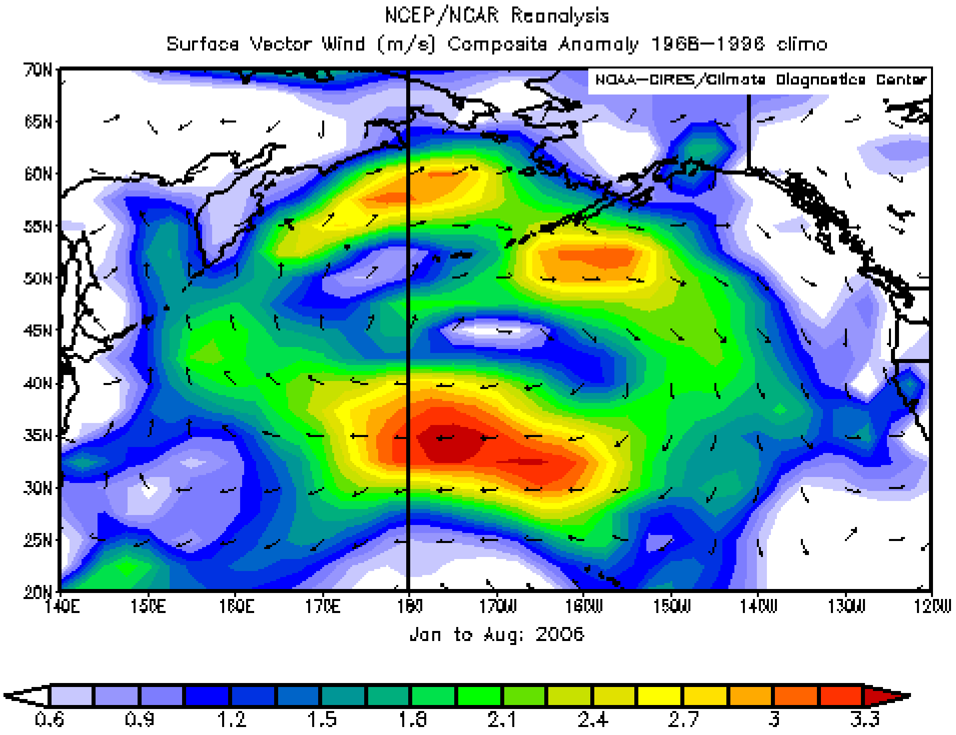


Figure 15. Surface vector wind anomalies averaged for the period from January 2006 through August 2006.

3.3 Sea Surface Temperature Forecast from NCEP

The latest seasonal forecast produced by the NCEP coupled forecast system model (CFS03) suggests that the atmospheric processes described above will continue to operate throughout the rest of the year and in winter and spring of 2007. The model suggest anomalously frequent troughing in the lower to middle troposphere along the North American west coast, which tends to promote negative SST anomalies in the Northeast Pacific. Anomalously cold waters east of Japan are forecast to warm up, and the entire pattern will resemble the negative phase of the PDO (Figure 16). Due to a probable El Niño event, a narrow strip of warmer than normal waters off the west coast of North America is likely to develop.

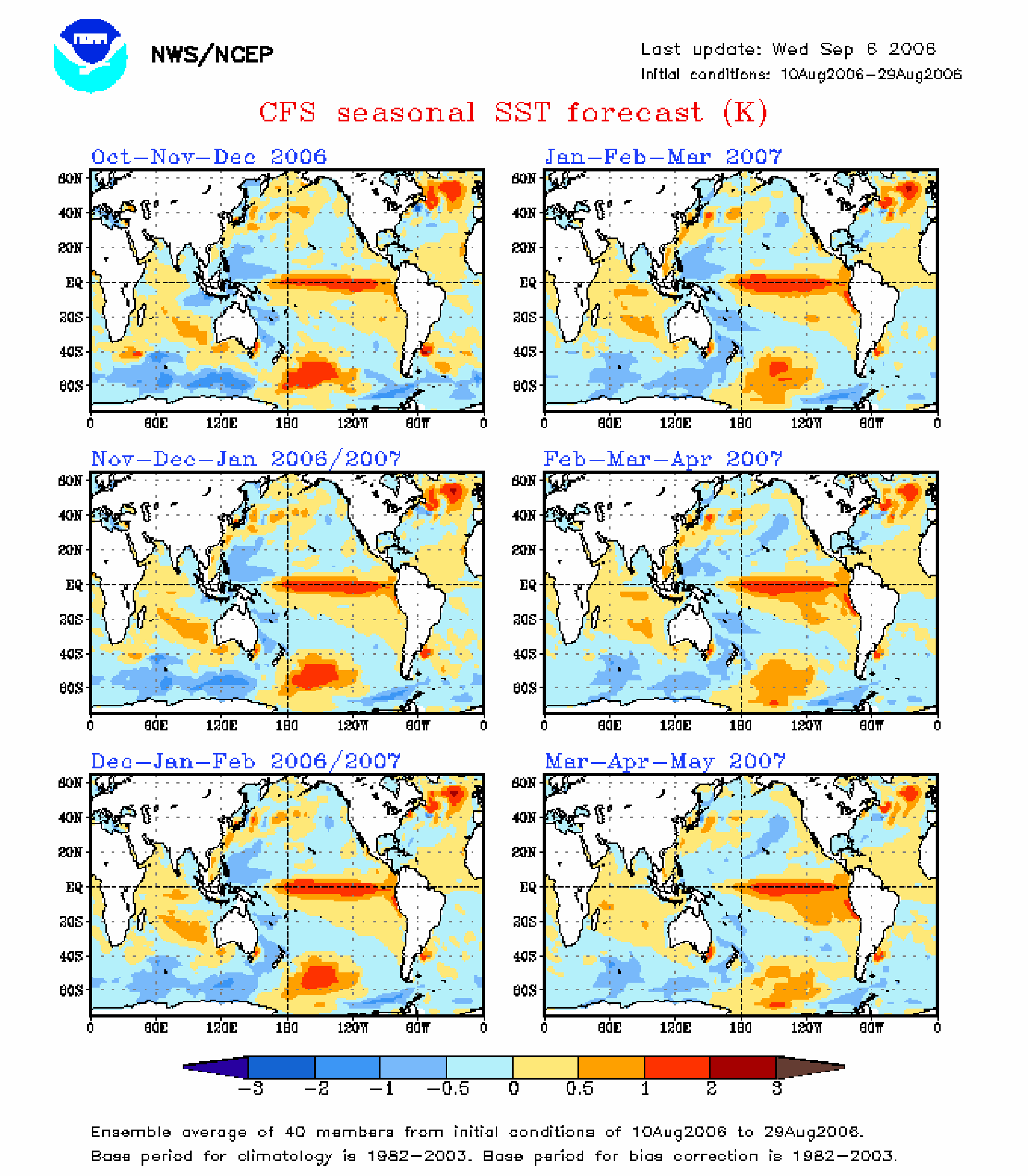


Figure 16. Seasonal forecast of SST anomalies from the NCEP coupled forecast system model.

4. Regime Shift Analysis

The NP index jumped to a positive value in the winter of 2005-06, which is characteristic of the weak Aleutian low regime of 1947-1976 (Figure 17a). Since this shift just occurred, it is uncertain whether it represents just a temporary change or actually heralds the beginning of a new regime. At the same time, the PDO index remained slightly positive (Figure 17b), which is more consistent with the current regime established since the late 1970s than for the previous regime of a PDO phase.

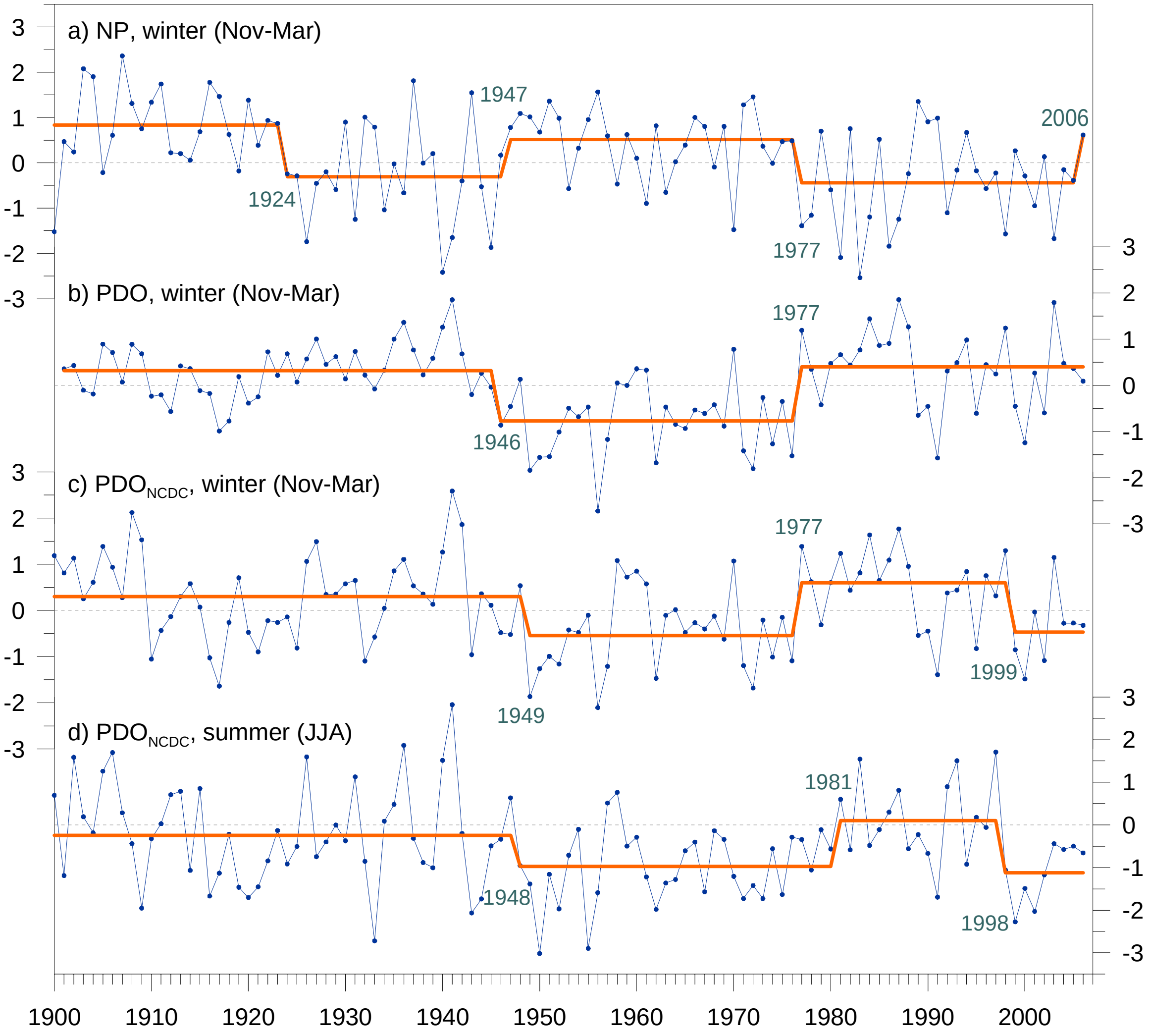


Figure 17. a) Winter (Nov-Mar) NP index from NCAR, b) Winter (DJF) PDO index from N. Mantua, University of Washington, c) Winter (DJF) PDO index from NCDC, and d) Summer (JJA) PDO index from NCDC. The stepwise trends (orange lines) were calculated using the sequential method (Rodionov 2004) with the cutoff length $l = 20$ years, probability level $p = 0.05$, and Huber weight parameter $h = 1$.

It should be noted that the data source used by N. Mantua (University of Washington) to calculate his index (Reynold's Optimally Interpolated SST) changed in 2002 from version 1 to version 2, and this could affect the values of the index. There is another PDO index calculated at the National Climate Data Center (NCDC) based on a single data source, the Extended Reconstructed SST data set. NCDC uses the same loading pattern as N. Mantua (University of Washington), but somewhat different technique to calculate the index. Although the correlation between the two variants of the PDO index is 0.87 (for the period 1901-2005), the implications for the regime shift analysis are substantial. Unlike the PDO index from N. Mantua (University of Washington), the PDO$_{NCDC}$ index has a statistically significant (at the 0.01) level shift in 1999 (Figure 17 c). Since this year, there was only one positive value of the index in 2003 (a year of El Niño). The magnitude of this shift is even greater for the summer PDO index (Figure 17d), being statistically significant at the 0.0007 level.

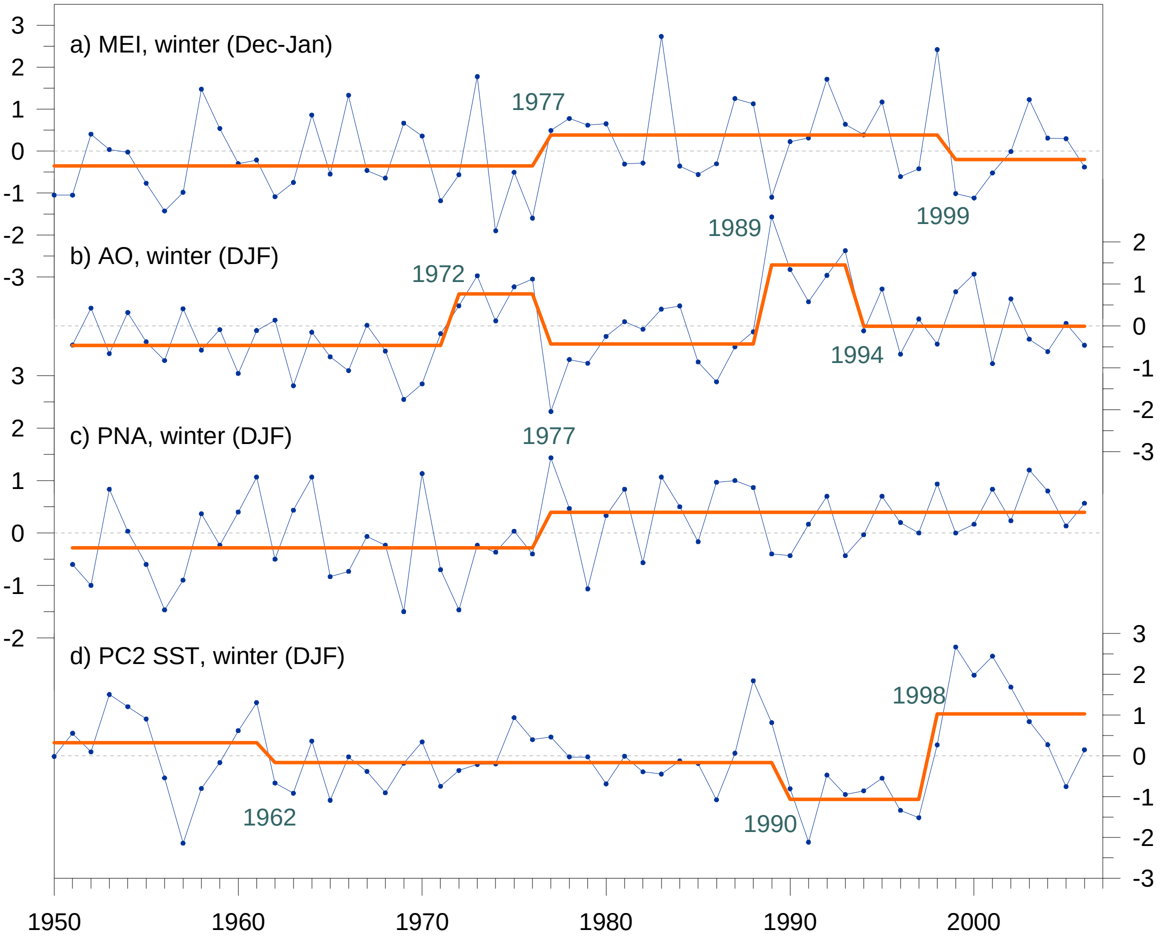


Figure 18. a) Winter (Dec-Jan) Multivariate ENSO index (*l* = 10, *p* = 0.3, *h* = 1), b) Winter (DJF) Arctic Oscillation index (*l* = 10, *p* = 0.2, *h* = 1), c) Winter (DJF) Pacific/North American index (*l* = 10, *p* = 0.1, *h* = 1), and d) Winter Victoria (PC2 SST) index (*l* = 10, *p* = 0.3, *h* = 1).

The indices presented in Figure 18 are available since the 1950s, and they were analyzed with a sequential method (Rodionov 2004) using less strict *l* (cutoff length in years) and *p* (probability level) parameters. The Multivariate ENSO index (MEI) shows an upward shift in 1977 and a downward shift in 1999 (Figure 18a). Despite relatively small magnitudes of the shifts (compared to those in the PDO), they are statistically significant at the 0.01 and 0.1 levels, respectively. The Arctic Oscillation (AO) index (Figure 18b), which jumped to its record high value in 1989, has substantially declined since then and can no longer serve as part of the explanation for the continuing Arctic warming (Overland and Wang, 2005). The Pacific/North American (PNA) teleconnection pattern is the leading mode of atmospheric circulation over the North Pacific and North America. The PNA index, obtained from the Climate Prediction Center (CPC), shows no sign of reversal from the high index regime established since 1977 (Figure 18c). The second empirical orthogonal function (EOF2) of SST in the North Pacific, also known as the Victoria pattern, accounted for much of the climate variability since 1990 (Bond et al. 2003). In the past several years, the principal component of this pattern (Figure 18d) declined to near zero values, and its role diminished. For more information on these and other climate indices, visit www.BeringClimate.noaa.gov.

GULF OF ALASKA

Pollock Survival Indices -FOCI

Contributed by S. A. Macklin, NOAA/PMEL
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Last updated: August 2006

Using a conceptual model of early-life survival of western Gulf of Alaska walleye pollock (Megrey et al. 1996) for guidance, FOCI maintains several annual environmental indices. The indices are formulaic elements of a yearly prediction, during the year the fish are spawned, of the number of fish that will recruit as two-year olds. Some indices are determined qualitatively; the two reported here, seasonal rainfall at Kodiak and wind mixing in the exit region of Shelikof Strait, are determined numerically. Although data sources have changed somewhat over the years, chiefly with information used to estimate wind-mixing energy, every effort has been expended to make inter-year comparisons accurate and reliable.

Presently, the FOCI program is developing a modified approach (Megrey et al. 2005) to its annual forecast algorithm. When modifications are complete, it is probable that new indices will become available for this report. At the same time, it is possible that the indices presented here and in past years may be discontinued. Until a significantly long time series of new annual indices is available, the old indices will continue to be updated and published in this report.

Seasonal rainfall at Kodiak

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Last updated: August 2006

FOCI uses measured Kodiak rainfall as a proxy for freshwater discharge that promotes formation of baroclinic instabilities (eddies) in the Alaska Coastal Current (ACC) flowing through Shelikof Strait (Megrey et al., 1996). Measured monthly rainfall amounts drive a simple model that produces an index of survival for age-0 walleye pollock. These young fish may benefit from spending their earliest developmental stages within eddies (Schumacher and Stabeno 1994). The model assumes that greater-than-average late winter (January, February, March) precipitation produces a greater snow pack. When the snow melts during spring and summer, it promotes discharge of fresh water through rivers and streams into the ACC. Similarly, greater than average spring and early summer rainfall, with their nearly immediate run-off, also favor increased baroclinity after spawning. Conversely, decreased rainfall is likely detrimental to pollock survival because they do not find the circulation features that promote their survival.

The time series of FOCI's pollock survival index based on measured precipitation is shown in Figure 19. 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. Since then, the survival potential has been more level. Survival potential increased in 2003 and 2004 because almost all winter and spring months experienced average or greater rainfall than their respective 30-year averages. In 2005, precipitation remained somewhat above average but less so than in the previous two years. The 2006 season began with lower than normal precipitation during January, February and March. This decreased the potential for formation of baroclinic instabilities prior to and during spawning. April and May brought a return toward normal conditions, however the potential for instabilities forming from increased freshwater input to coastal water was still lower than expected. June was wet (at 151% of the 30-yr June average), and this may have presented favorable habitat for late larval- and early juvenile-stage walleye pollock. Based on this information, the pollock survival potential for Kodiak 2006 rainfall is "weak to average". Interestingly, the precipitation-based survival index does not appear to track any of the long-term climate indices, e.g., AO, PDO, with any consistency, possibly because of the way winter and spring precipitation are used in the model. In the 3-yr running mean of the precipitation survival index, there is a change from decreasing to increasing survival potential in 1989. In that year, there was an abrupt shift in the AO.

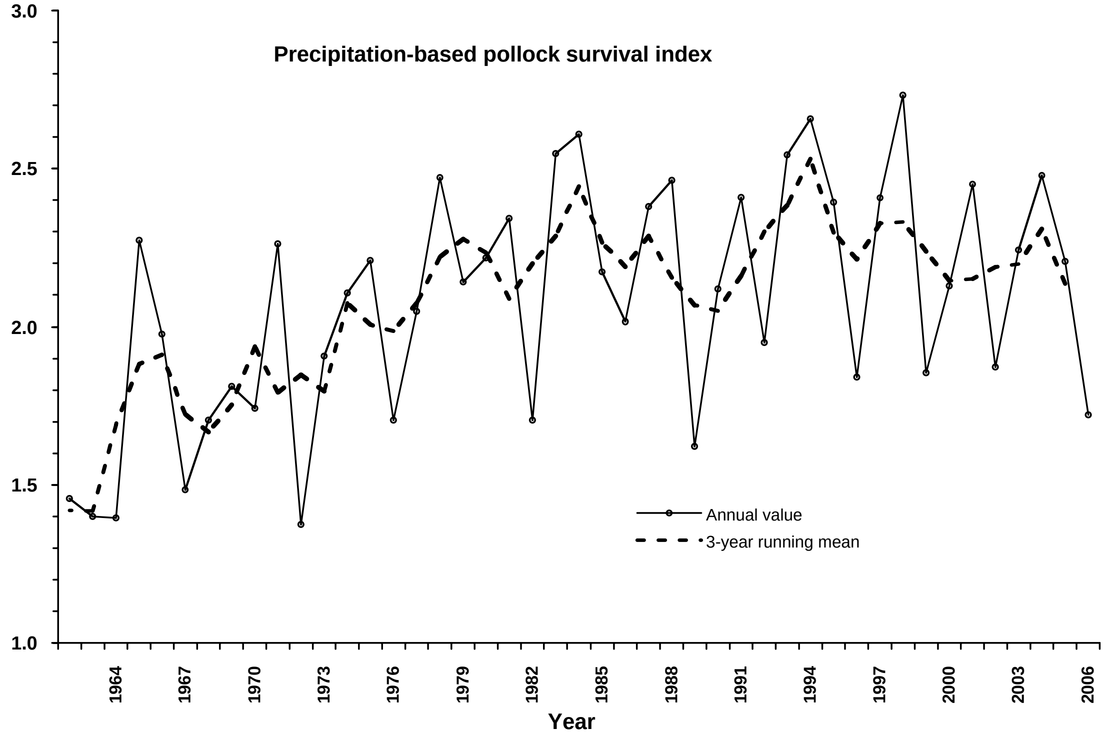

Figure 19. Index of pollock survival potential based on measured precipitation at Kodiak from 1962 through 2006. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Wind mixing at the southwestern end of Shelikof Strait

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Last updated: August 2006

Rainfall is only one indicator of early-life-stage pollock survival. FOCI hypothesizes that a series of indices (proxies for environmental conditions, processes and relationships), assembled into a predictive model, provides a method for predicting recruitment of walleye pollock. 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 wherein stronger than average mixing before spawning and weaker than average mixing after spawning favor survival of pollock (Megrey et al. 1996). The wind-mixing index is produced from twice-daily surface winds created from a model (Overland et al. 1980) using NCEP reanalyzed sea-level-pressure fields. The model is tuned to the region using information determined by Macklin et al. (1993). A time series of the wind-mixing index is shown in Figure 20. As with precipitation at Kodiak, there is wide interannual variability with a less noticeable and shorter trend to increasing survival potential from 1962 to the late 1970s. Recent survival potential has been high relative to the early years of the record. Except for March 2003, March 2005 and June 2006, monthly averaged wind mixing in Shelikof Strait has been below the 30-year (1962-1991) mean for the last nine January through June periods (1998-2006). This may be further evidence that the North Pacific climate regime has shifted in the past decade.

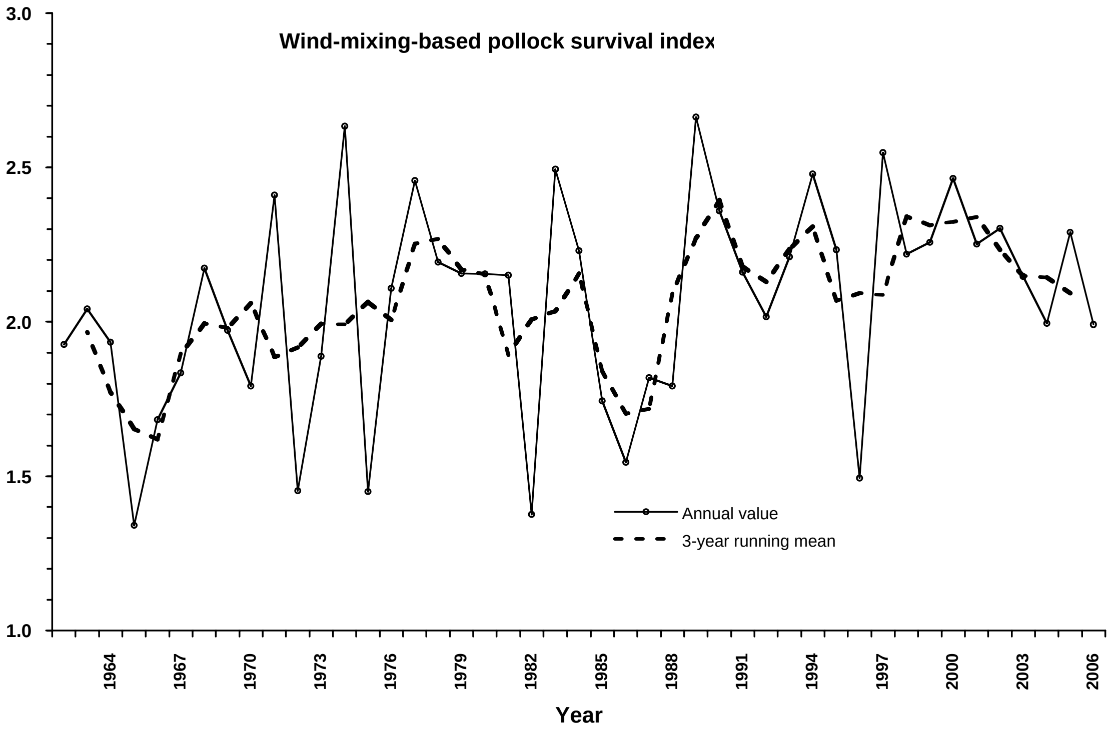

Figure 20. Index of pollock survival potential based on modeled wind mixing energy at [57°N, 156°W] near the southwestern end of Shelikof Strait from 1962 through 2006. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Ocean transport in the western Gulf of Alaska –FOCI

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Last updated: November 2003

The spring and summer seasonal strength of the Alaskan Stream and Alaska Coastal Current (ACC) is an important factor for overall productivity on the shelf of the Gulf of Alaska. FOCI uses satellite-tracked drift buoys, drogued at mid mixed-layer depths (~45 m), to measure ocean currents as a function of time and space. Animations of drifter trajectories from deployments during 2001-2003 can be found at *http://www.pmel.noaa.gov/steller/ssl_drifters.shtml*. There is a strong seasonal signal in the ACC. During late spring and summer, the flow on the Gulf of

Alaska shelf between Prince William Sound and the Shumigan Islands is weak. The many bathymetric features such as troughs and banks interact with the currents. This results in flow up the eastern side of such troughs as Amatouli, Chiniak and Barnabas. Flow over banks such as Portlock, is often recirculating, and satellite-tracked drifters can be retained in closed circulation for weeks to months. ACC flow in the western Gulf of Alaska during 2001 and 2002 was particularly weak. Later in the summer or fall, with the intensification of regional winds, the ACC becomes stronger, and the flow down Shelikof Strait becomes more organized, as shown by the animations for September of 2001 and 2002. During 2003 (Figure 21), ACC flow was more organized and stronger. Specifically, the flow in Shelikof Strait appeared more complex with more meanders and eddies than have been evident in previous years. This year, more than the typical number of drifters went aground along the Alaska Peninsula and the Kenai Peninsula west of Gore Point.

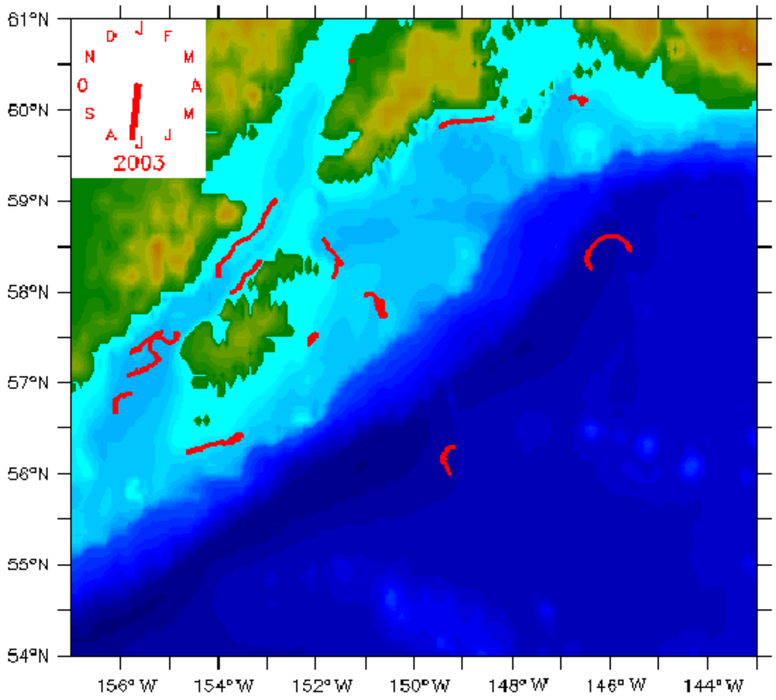

Figure 21. Tracks of satellite-tracked drifters for the period October 14-18, 2001, show sluggish flow on the shelf, except for within Shelikof Strait.

Cross-shelf fluxes are important to providing nutrients to the shelf. Each year (2001-2003) brought flow onto the shelf in the vicinity of the Seward Line, which extends south southeastward from the mouth of Resurrection Bay across the shelf and over the basin. The presence of an eddy is clearly evident from drift trajectories over the basin. Such eddies interact with the shelf, often drawing water off the shelf and into the basin, and are discussed in more detail in the next section. From the head of the gulf to Amchitka Pass, the Alaskan Stream appeared to be fairly typical during 2003, through July, with low eddy kinetic energy and relatively high velocity (>50 cm s^{-1} to the southwest). By next year, there will be enough data to allow construction of an annual Gulf of Alaska transport index that can be compared with climate indices such as PDO, AO, etc.

Eddies in the Gulf of Alaska – FOCI

Contributed by Carol Ladd, NOAA/PMEL
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Last updated: September 2005

Eddies in the northern Gulf of Alaska have been shown to influence distributions of nutrients (Ladd et al. 2005) and phytoplankton biomass (Brickley and Thomas 2004) and the foraging patterns of fur seals (Ream et al. 2005). Eddies propagating along the slope in the northern and western Gulf of Alaska are generally formed in the eastern gulf in the autumn or early winter (Okkonen et al. 2001). In most years, these eddies impinge on the shelf east of Kodiak Island in the spring. Using altimetry data from 1993 to 2001, (Okkonen et al. 2003) found an eddy in that location in the spring of every year except 1998. They found that strong, persistent eddies occur more often after 1997 than in the period from 1993 to 1997.

Since 1992, the Topex/Poseidon/Jason/ERS satellite altimetry system has been monitoring sea surface height (SSH). Gridded altimetry data (merged TOPEX/Poseidon, ERS-1/2, Jason and Envisat; Ducet et al. 2000) allow the calculation of eddy kinetic energy (EKE). A map of eddy kinetic energy in the Gulf of Alaska averaged over the altimetry record shows three regions local maxima (labeled a, b, and c in Figure 22). The first two regions are associated with the formation of Haida eddies (a) and Sitka eddies (b). Regions of enhanced EKE emanating from the local maxima illustrate the propagation pathways of these eddies. Sitka eddies can propagate southwestward (directly into the basin) or northwestward (along the shelf break). The Sitka eddies that follow the northwestward path often feed into the third high EKE region (c; Figure 22). By averaging EKE over region c (see box in Figure 22), we obtain an index of energy associated with eddies in this region (Figure 23).

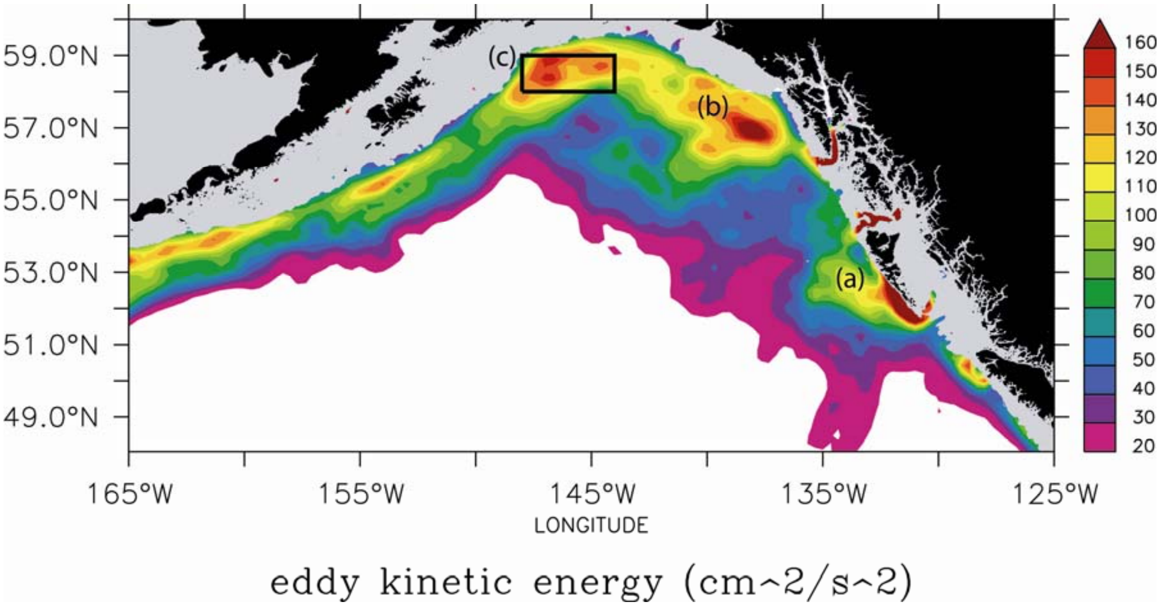

Figure 22. Sea surface height anomaly from TOPEX/Poseidon, ERS-1/2 and Jason merged altimetry. Positive anomalies imply anticyclonic circulation. Black box outlines region over which EKE was averaged for Figure 23.

The seasonal cycle (calculated from the entire time series) of EKE averaged over the box shown in Figure 22 exhibits high EKE in the spring (March – May) with lower EKE in the autumn (September – November). EKE has been high with a stronger seasonal cycle since 1999. Prior to 1999, EKE was generally lower than the ~13-year average, although 1993 and 1997 both showed periods of high EKE. Interestingly, the first 8 months of 2005 showed a return to the low EKE values observed prior to 1999. No significant eddies were observed in this region during the first half of 2005. This may have implications for the ecosystem. Phytoplankton biomass was probably more tightly confined to the shelf during this time period due to the absence of eddies. If fur seals have become dependent on eddies for foraging over the last five years of strong eddy variability, their foraging success may be negatively impacted this year. In addition, cross-shelf transport of heat, salinity and nutrients are likely to be smaller than in previous years with large persistent eddies. Research is ongoing as to the causes and implications of these patterns.

The altimeter products have been produced by the CLS Space Oceanography Division; downloaded from http://www.aviso.oceanobs.com/.

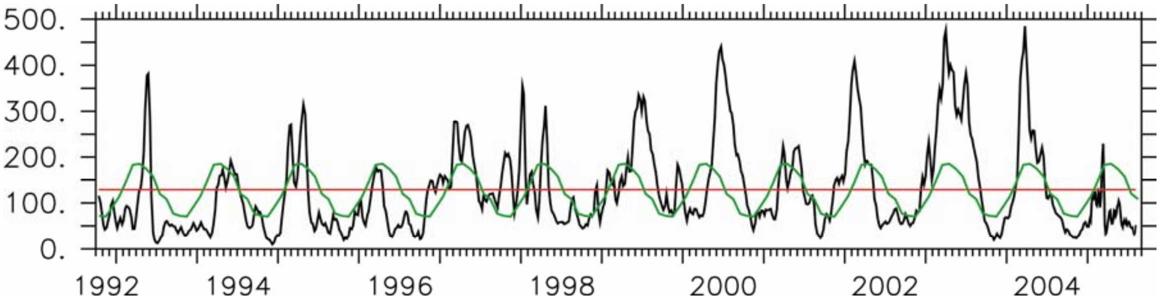

Figure 23. Eddy kinetic energy (EKE) averaged over the region shown in Figure 22 calculated from altimetry. Black: weekly EKE. Red: mean over entire time series. Green: annual cycle.

Ocean Surface Currents – Papa Trajectory Index

Contributed by W. James Ingraham, Jr., Alaska Fisheries Science Center (Retired, but still contributes…Wow!)
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Last updated: August 2006

Exploring historic patterns of ocean surface currents with the "Ocean Surface CURrent Simulator" (OSCURS) provides annual or seasonal indices of ocean currents for the North Pacific and Bering Sea, and thus, contributes to our understanding of the year-to-year variability in near surface water movements. This variability has been shown to have an important effect on walleye pollock survival and spatial overlap with predators (Wespestad et al. 2000) and have an influence on winter spawning flatfish recruitment in the eastern Bering Sea (Update on EBS winter spawning flatfish recruitment and wind forcing, this volume; and Wilderbuer et al. 2002). Simulation experiments using the OSCURS model can be run by the general public on the World Wide Web by connecting to the live access server portion of the NOAA-NMFS Pacific Fisheries Environmental Lab's (PFEL) web site. See the information article, Getting to Know OSCURS, for a summary of such experiments that have already been run.

The Papa Trajectory Index (PTI) is an example of long-term time-series data computed from a single location in the Gulf of Alaska. OSCURS was run 105 times starting at Ocean Station Papa (50° N, 145° W) on each December first for 90 days for each year from 1901 to 2005 (ending February 28 of the next year). The trajectories fan out northeastwardly toward the North

American continent and show a predominately bimodal pattern of separations to the north and south. The plot of just the latitudes of the end points versus time (Figure 24) illustrates the features of the data series.

To reveal decadal fluctuations in the oceanic current structure relative to the long-term mean latitude (green horizontal line at 54.74º N), the trajectories were smoothed in time with a 5-year running mean boxcar filter. Values above the mean indicate five winters adjacent to that year have an average of anomalously northward surface water circulation in the eastern Gulf of Alaska; values below the mean indicate winters with anomalous southward surface water circulation.

In the winter of 2005 the long expected change in modes from north to south narrowly occurred in the 5-year running mean centered on the winter 2003. This winter (2006) the downward trend in the running mean plot has continued despite the yearly value for this winter is slightly above average.

The century plot of the 5-year running mean shows four complete oscillations but the time intervals of the oscillations were not constant; 26 years (1904-1930), 17 years (1930-1947), 17 years (1947-1964), and 39 years (1964-2003). The drift from Ocean Weather Station Papa has fluctuated between north and south modes about every 25 years over the last century. The time-series has been updated with winter 2006 calculations and shows southward values (below the mean) yet still near normal conditions compared to some of the earlier extremes. The 5-year running mean has fallen to the mean value four times since 1975 (1980, 1987, 1991, and 1995), only to rise again and stay in the northern mode. Once the 5-year running mean crosses the zero line it usually stays there for several years. In further support for this decadal change, Murphree et al. (2003) has reported unusual ocean circulation in the eastern North Pacific Ocean driven by large scale atmospheric anomalies in 2002.

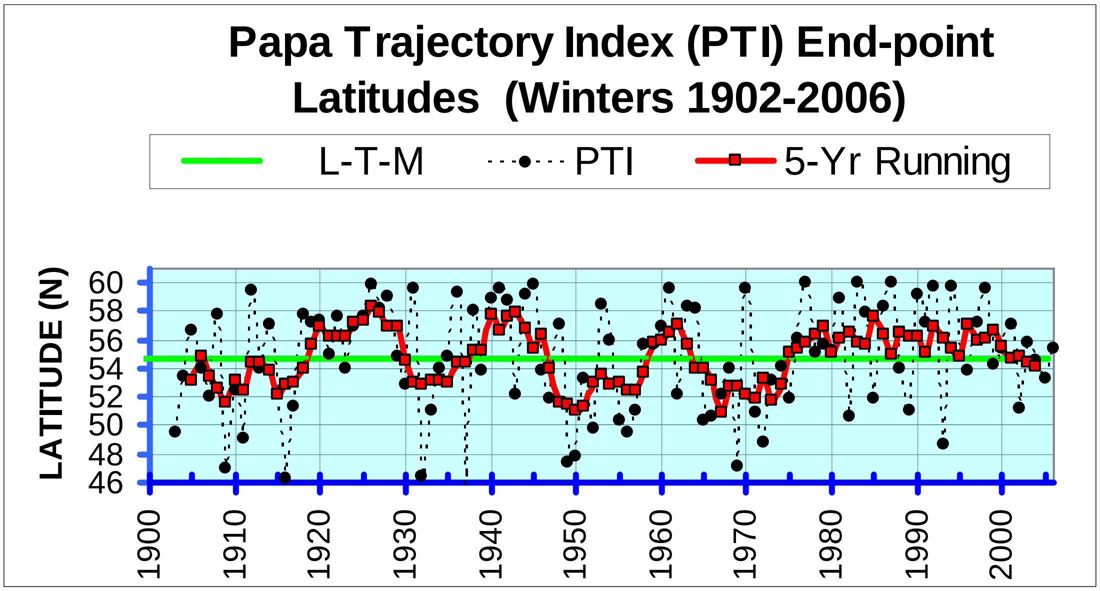

Figure 24. Annual, long-term mean and 5-year running mean values of the PAPA Trajectory Index (PTI) time-series from winter 1902-2006. Large black dots are annual values of latitude of the end points of 90-day trajectories which start at Ocean Weather Station PAPA (50º N, 145º W) each December 1, 1901-2005. The straight green line at 54º 44' N is the mean latitude of the series. The thick red oscillating line connecting the red squares is the 5-year running mean. This shows the variations in the onshore (eastward) flow, eras when winter mixed layer water drifting from PAPA ended farther north or south after 90 days.

Gulf of Alaska Survey Bottom Temperature Analysis

Contributed by Michael Martin, AFSC, RACE Division
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Last updated: November 2005

Groundfish assessment surveys in the Gulf of Alaska have been conducted every two or three years since 1984 between Islands of Four Mountains (170°W) and Dixon Entrance (132°30'W) at depths between 15 and 1000 m. The area and timing of the surveys have been inconsistent from year to year. The maximum depth of sampling has also varied between 1000 m (1984, 1987, 1999, 2005), 750 m (2003) and 500 m (1990, 1993, 1996, 2001). These inter-annual differences complicate the comparison of bottom temperature data and require that the analysis consider date and location for the results to be meaningful. The method of temperature data collection has also changed over time. Prior to 1993, bottom temperature data were collected with expendable bathythermographs (XBTs) when available, usually after completion of the survey trawl for fish. Since 1993, data have been collected using micro-bathythermographs (MBTs) attached to the headrope of the trawl during each tow.

To examine inter-annual bottom temperature differences, data were binned into depth ranges (< 50, 51-100, 101-150, 151-200, 201-300, 301-400, 401-500, 501-700 and 701-1000 m). For each depth stratum, a generalized additive model was constructed with the form:

Bottom Temperature = loess (Julian Date) + loess (Latitude, Longitude)

Each survey year's data was given equal weight in the analysis to account for different sample sizes between years. The mean and standard error of the residuals were then calculated by year to examine inter-annual differences in bottom temperature. Figure 25 shows the results plotted by depth with year on the x axis, while Figure 26 presents the same information by year with depth plotted on the x axis. Values appearing above the horizontal line can be considered as being warmer than normal and those below, cooler.

The data indicate that water temperatures in 1984, 1987, 2001 and 2003 were above normal for this period with 1984 and 2003 representing the warmest years of the period for all depths combined. Temperatures during the 2003 survey were the warmest yet recorded in depths less than 150 m. Temperatures were also quite warm in 1984 between 151 and 200 meters, with unusually cool temperatures in the shallowest waters, similar to the pattern seen in 1987. Temperatures throughout the 1990s appear to have been generally cooler than normal, with 1999 being the coolest year. At water depths between 51 and 150 meters the coolest years were in 1990 and 1999. Perhaps the most notable result is the general warming pattern in depths less than 50 meters over the entire time series (Figure 25). Bottom temperatures appeared to be near normal in 2005 with the notable exception of the large positive anomaly at depths less than 50 m.

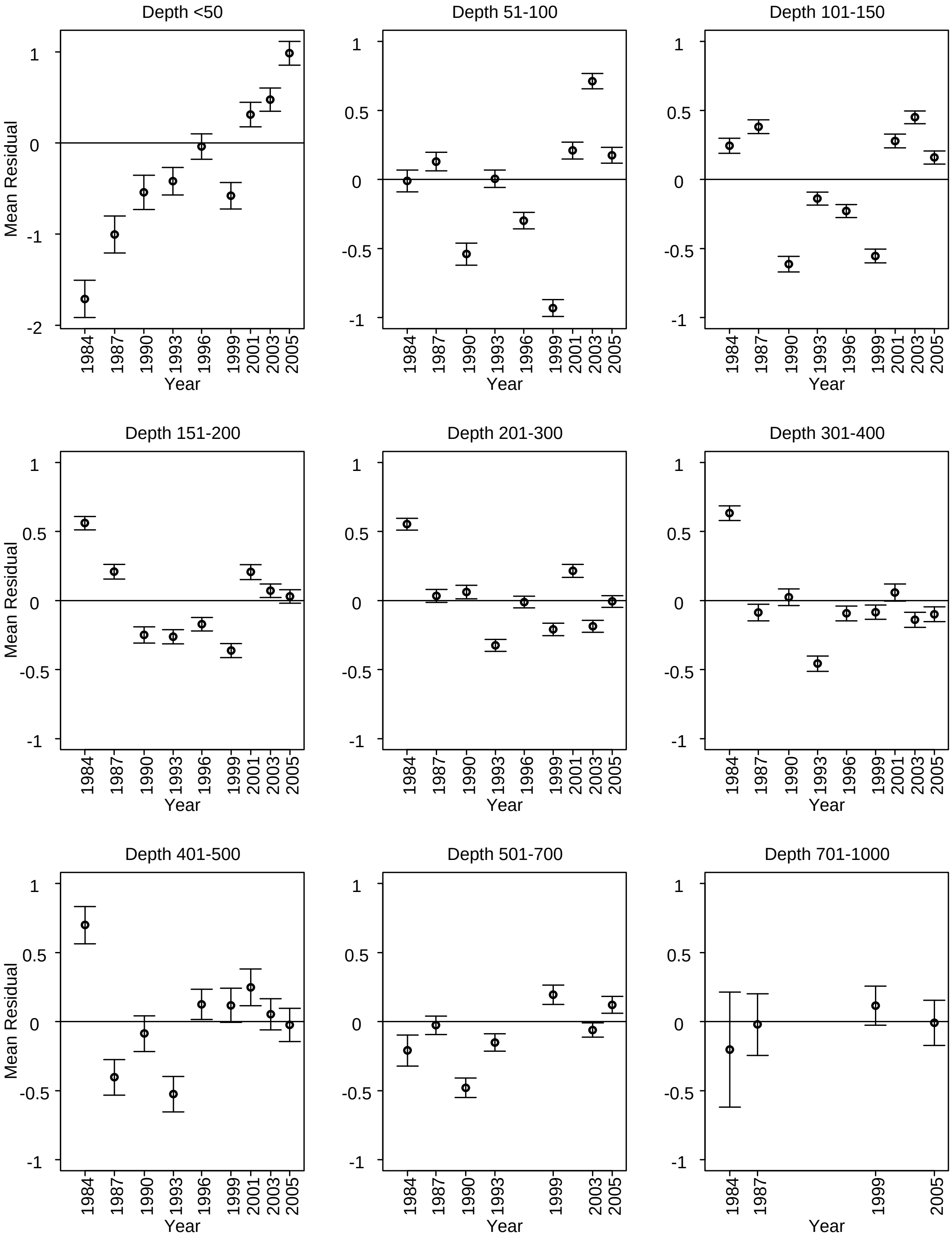

Figure 25. Mean temperature anomalies plotted by year within each depth stratum. Error bars are standard errors. Note expanded scale in < 50 m plot.

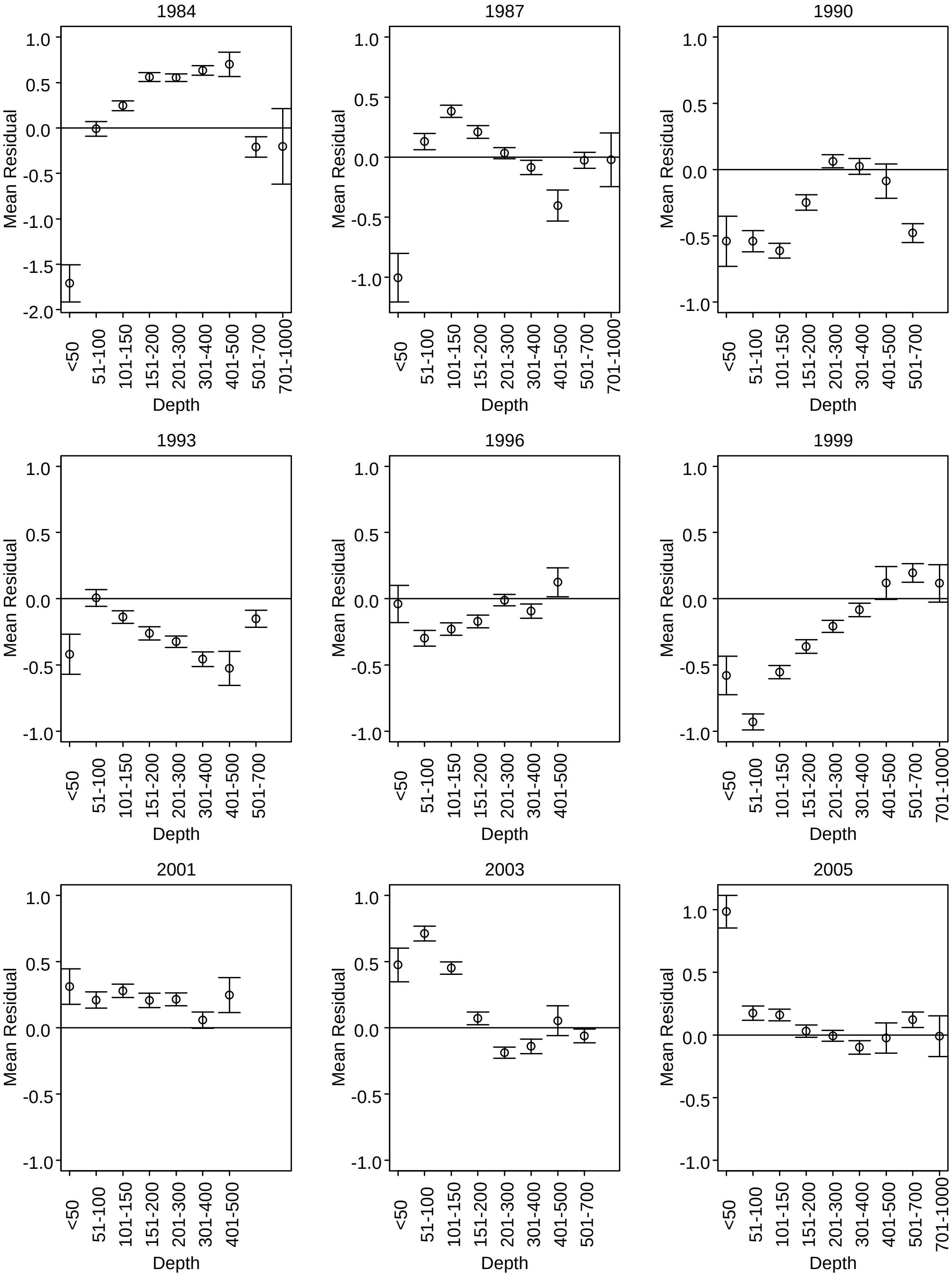

Figure 26. Mean temperature anomalies plotted by depth stratum within each year. Error bars are standard errors. Note expanded scale in 1984 plot.

Winter Mixed Layer Depths at GAK 1 in the Northern Gulf of Alaska

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Last updated: November 2006

The coastal northern Gulf of Alaska is forced predominately by downwelling inducing winds. In spite of this, the shelf is a region of high biological productivity. Various mechanisms have been suggested for the transport of nutrients across the shelf. One method of moving nutrients from the deep ocean to the shelf could be cross shelf transport of nutrient rich waters along the shelf bottom, especially within submarine canyons during periods of relaxed downwelling. In this scenario, mixed layers at certain times of the year could reach deep enough to mix nutrient-rich waters into the euphotic zone. In the northern Gulf of Alaska, mixed layers are deepest in the winter, when air and water temperatures are low, salinity is high as freshwater is locked up as snow and ice, and evaporation and wind stress are high.

Hydrographic station GAK 1 is located at 60˚N, 149˚W, at the mouth of Resurrection Bay in the Northern Gulf of Alaska. Temperature and salinity measurements have been made at various times of the year at this location since 1973. We have estimated the deepest winter mixed layer depths (MLDs) using the Freeland et al. (1997) algorithm. This algorithm performs well at estimating winter MLDs (each winter is defined here as December of one year and January to May of the following year), but overestimates the summer and spring MLDs. For our purposes, this method is adequate as it also conserves the integrated mass, and thus the potential energy of the water column (Sarkar et al. 2005).

The deepest winter MLDs at GAK 1 from 1974 to 2006 (Figure 27) range from a minimum of 105 m in February 2003 to a maximum of 214 m in March 1987. The mean value is 163 m, with a standard deviation of 29 m. The record has only one missing value; that for the winter of 1979-1980. The deepest MLD of the 2002-2003 winter is the shallowest of the 32 year record. However, the winters of 2003-2004, 2004-2005 and 2005-2006 had deeper than average mixed layers.

The deepest winter MLDs from 1974 to 2006 show a deepening linear trend. Nevertheless, this trend is not statistically significant. Thus the only conclusion is that during 1974-20065, there have been no significant changes in the deepest winter MLDs at GAK 1. This is in contrast to studies by Freeland et al. (1997) who report a significant shoaling trend at Ocean Station P at the center of the Alaska gyre from 1956 to 1994. If this dissimilarity of trends at the center and edge of the gyre did exist, it would indicate that the gyre is spinning up. However, all that can be said is that the deepest winter MLD at the coast in the northern Gulf of Alaska is not changing.

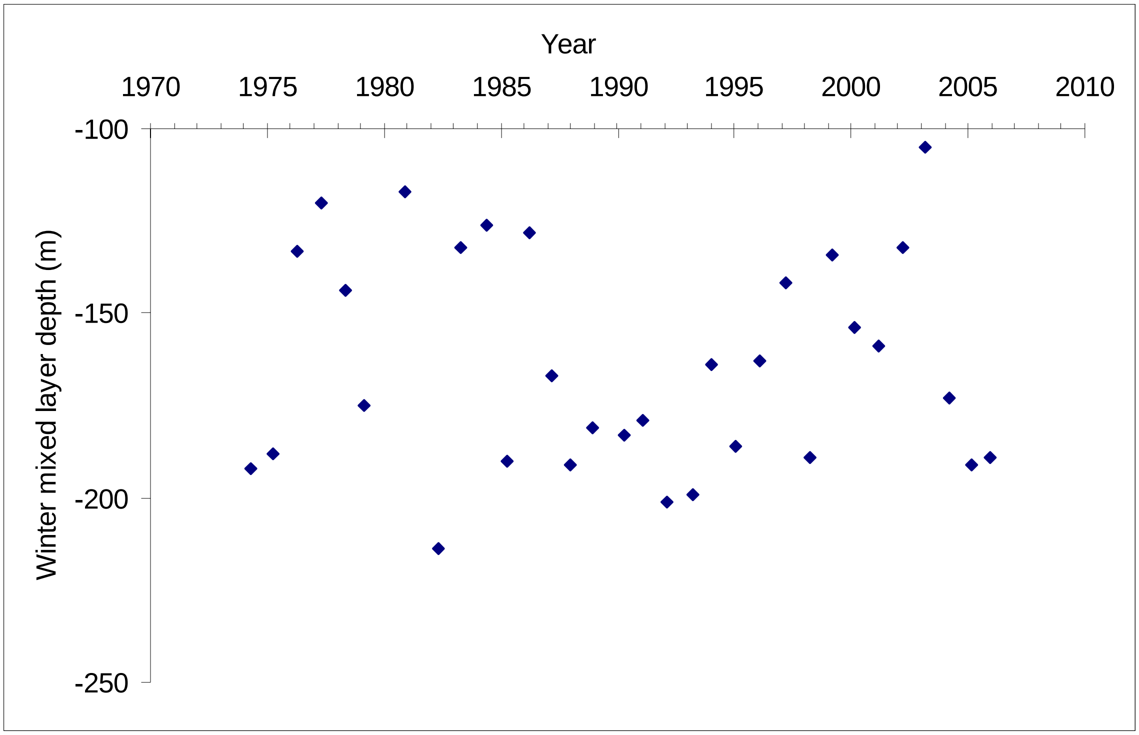

Figure 27. Winter mixed layer depth (m) at GAK 1 from 1974-2006.

EASTERN BERING SEA

Temperature and Ice Cover – FOCI

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Last updated: November 2006

Summary. *Although the average seasonal characteristics of thermal conditions in the Bering Sea were close to normal, the winter of 2006 was characterized by a significant degree of month-to-month variability. In January surface air temperature (SAT) in St. Paul plunged to almost 2 standard deviations below normal. In the next two months SAT anomalies became positive, exceeding one standard deviation in March. These temperature swings were associated with a restructuring of atmospheric circulation patterns over the North Pacific. Spring months were colder than normal, and ice extent was south of its normal position. The ice retreat index indicates that ice stayed in the vicinity of Mooring 2 for almost 1.5 months after March 15, which is much longer than in the previous six years. Sea surface temperatures in May were the coldest since 1999, which suggests a more extensive cold pool than normal in the summer of 2006. A cold spring and late ice retreat were, probably, the most important features of the physical environmental conditions in 2006.*

In an overall sense, the winter of 2006 in the Bering Sea was close to normal, but contrasts to the warm conditions of the recent decade. The mean winter (DJFM) surface air temperature (SAT) at St. Paul was -3.18˚C, or 0.44˚C above the average for the base period 1961-2000 (Figure 28a). The Bering Sea pressure index (BSPI) remained negative, as it had been since 1998. Negative (positive) values of the BSPI indicate predominance of cyclonic (anticyclonic) conditions in the region. The ice cover index (a combination of several highly correlated ice-related variables) was slightly positive (Figure 29a) and the ice retreat index (IRI) indicates that ice stayed for 46 days after March 15 in a 2° x 2° box (56-58°N, 163-165°W) around Mooring 2 in the southeast Bering Sea (Figure 29b).

These average numbers, however, do not reflect the substantial month-to-month variability that occurred in the Bering Sea. As shown in Figure 30, after a relatively mild December, SAT at St. Paul dropped in January to -8˚C, which was 4.7˚C below the 1961-2000 average. It was the coldest January since January 2000. In February 2006, SAT rebounded to 1.6˚C above the average, and in March it was 3.5˚C above the average. Later in the spring, however, SAT anomalies were on the cold side again. These month-to-month variations in SAT are associated with a restructuring of atmospheric circulation over the North Pacific from a strong Aleutian low in December to a weak and split Aleutian low in January. A high pressure anomaly that formed over the central North Pacific in January strengthened even further in February and March. During these last two months, however, storms were frequent in the high latitudes bringing warm Pacific air into the Bering Sea (For details on atmospheric circulation see the Pacific Climate Overview section).

The high degree of variability within the 2006 winter season is also seen in ice cover, presented in Figure 31 as a percentage of ice in the 2˚ x 2˚ box (56-58°N, 163-165°W) surrounding Mooring 2. Ice appeared in the box in mid-January, which is an average start date of the ice season there (Figure 32). Due to very cold weather in January, ice quickly extended south, covering more than 80% of the box. Anomalously mild and stormy weather occurred in February and March causing ice to retreat as quickly as it arrived. Because of cold weather spells later in spring, ice peaked again around April 1 and May 1. Ice finally cleared the box in the second week of May, which made the IRI the highest since 1999 (Figure 29b).

It is interesting that the Bering Sea was about the only place in the Arctic where sea ice extent anomalies in January 2006 were positive and ice extent was south of its median position for the period 1979-2000 (Figure 33, top panel). By March 2006, however, sea ice concentration anomalies were negative practically everywhere along the periphery of Arctic ice extent (Figure 33, middle panel). The total Arctic sea ice extent for this month was 14.5 million sq. km., or 1.2 million sq. km. below the 1979-2000 mean value. This makes March 2006 the record low March for the entire period of observations since 1979. In April sea ice in the Bering Sea advanced again. Figure 34 illustrates how far south the ice edge was compared to the previous five years. In May, sea ice concentration anomalies in the Bering Sea remained positive, and sea ice extent was much father south than its median position for this month (Figure 33, bottom panel).

Due to anomalous ice cover extent, average sea surface temperature (SST) over the eastern Bering Sea in May was sharply lower (Figure 35). May SST is a good predictor of summer bottom temperatures and the extent of the cold pool. Although sea ice concentration in the eastern Bering Sea between 57°N and 58°N (Figure 36) was not particularly high after early February, especially as compared with other heavy ice years, ice stayed longer in the area than in any other year since 1999. Mooring 2 records indicate 2006 has been a remarkably cold year, mainly because the ice persisted into May and heating of the water column did not really begin until late May (Figure 37). In contrast, 2005 was the warmest year on record at the Mooring 2 site, since 1995 (Figure 37). Bottom temperature data for the summer of 2006 was unavailable at the time of writing, but given the relatively late ice retreat, it is strongly suspected that the cold pool was the most prominent it has been since 1999. The extent of the cold pool relates not only to the near-bottom habitat, but also impacts the overall thermal stratification and ultimately the mixing of nutrient-rich water from depth into the euphotic zone. Regarding the latter process, June-July wind mixing at M2 during 2006 (not shown) was the strongest since 1996, and the second strongest since 1979. We do not know yet whether the upper mixed layer was anomalously thick in 2006 like it was in 1996. All in all, it appears that the most important aspect of the physical environmental conditions in the eastern Bering Sea during 2006 was the unusually late retreat of the sea ice in the spring.

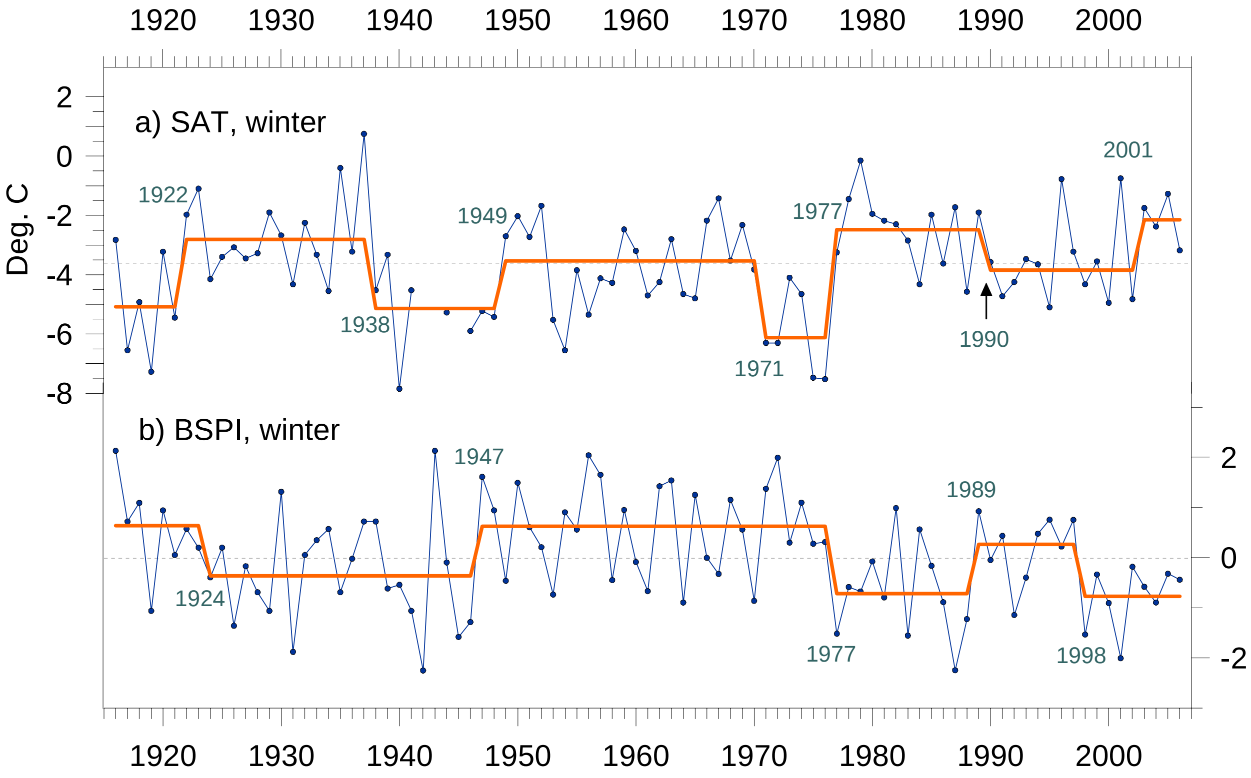

Figure 28. Mean winter (DJFM) a) surface air temperatures in St. Paul, Pribilof Islands and b) Bering Sea pressure index. The dashed line for the top graph indicates the mean SAT value of -3.62˚C for the base period, 1961-2000. The stepwise functions (orange lines) characterize regime shifts in the level of fluctuations of the variables. Shift points were calculated using the sequential method (Rodionov 2004), with the cutoff length of 10 years, significance level of 0.2, and Huber weight parameter of 1.

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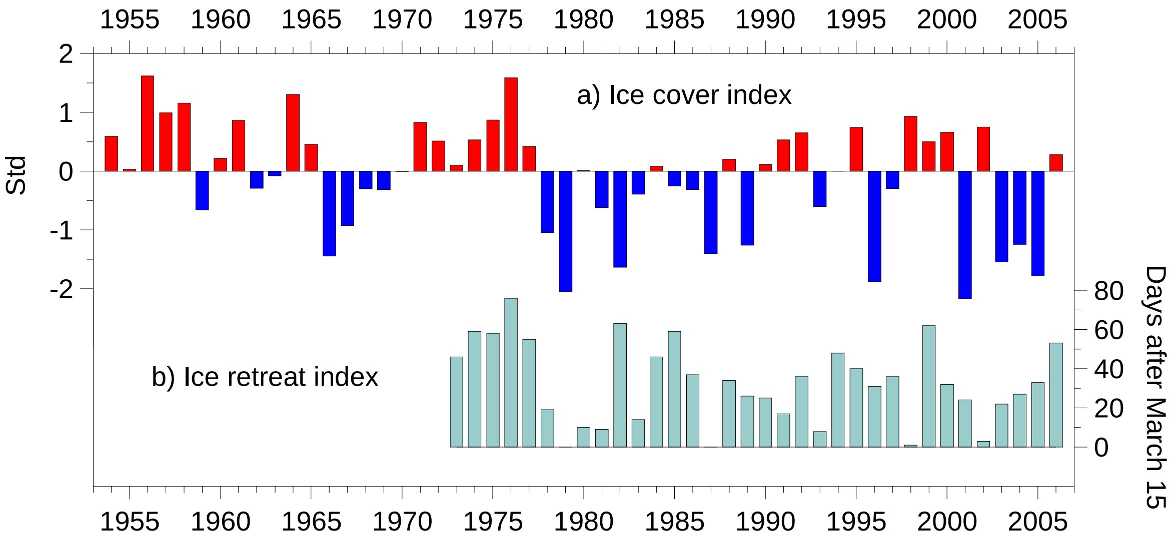

Figure 29. a) Ice cover index, 1954-2006, and b) ice retreat index, 1973-2006.

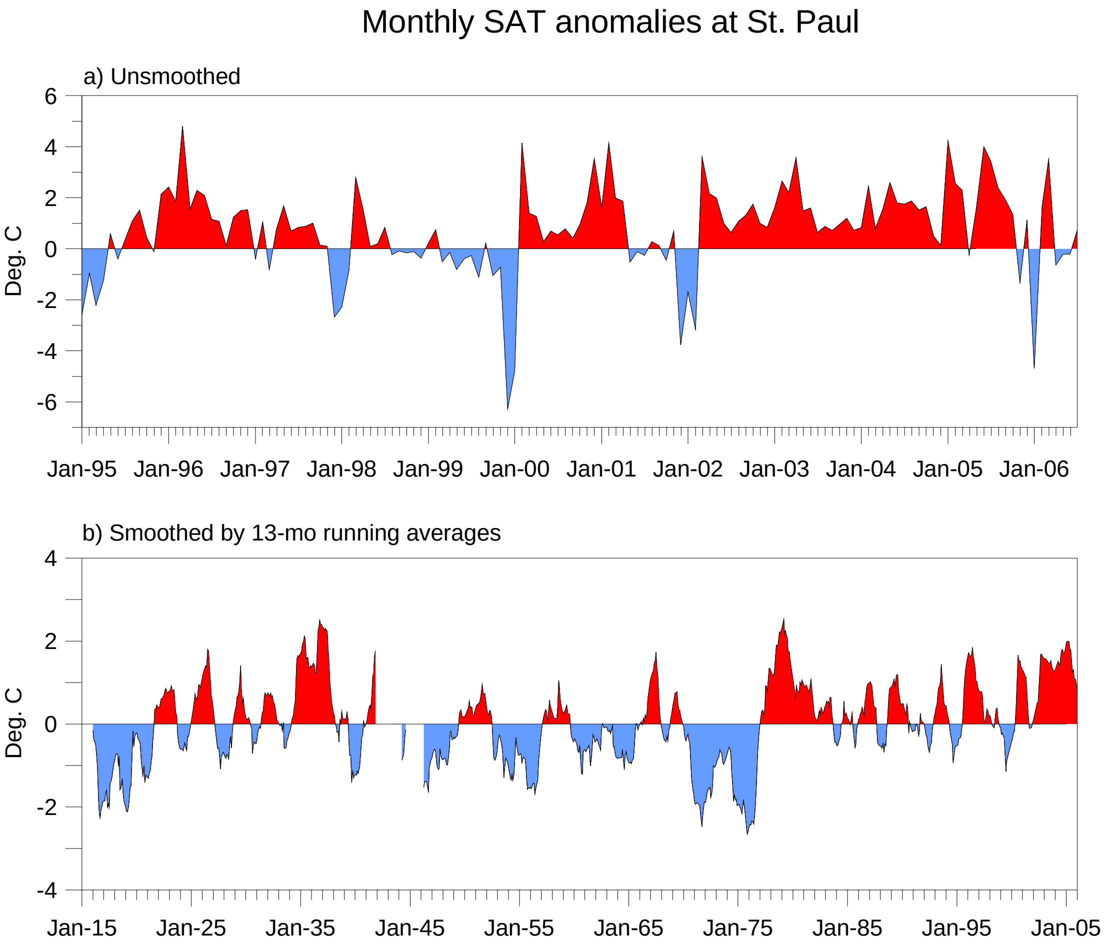

Figure 30. Mean monthly surface air temperatures anomalies in St. Paul, Pribilof Islands, a) unsmoothed, January 1995 through July 2006, and b) smoothed by 13-mo running averages and referred to the central month of the window, January 1916 through January 2006. The base period for calculating anomalies is 1961-2000.

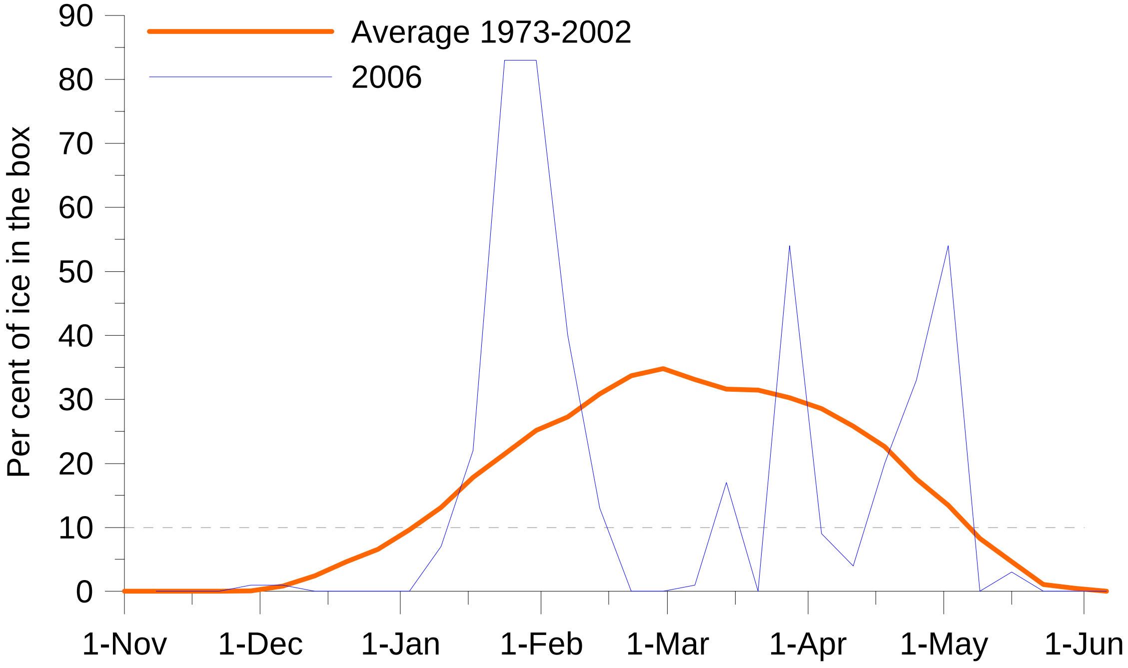

Figure 31. Percentage of ice in the 2˚ x 2˚ box (56-58°N, 163-165°W) during the winter of 2006.

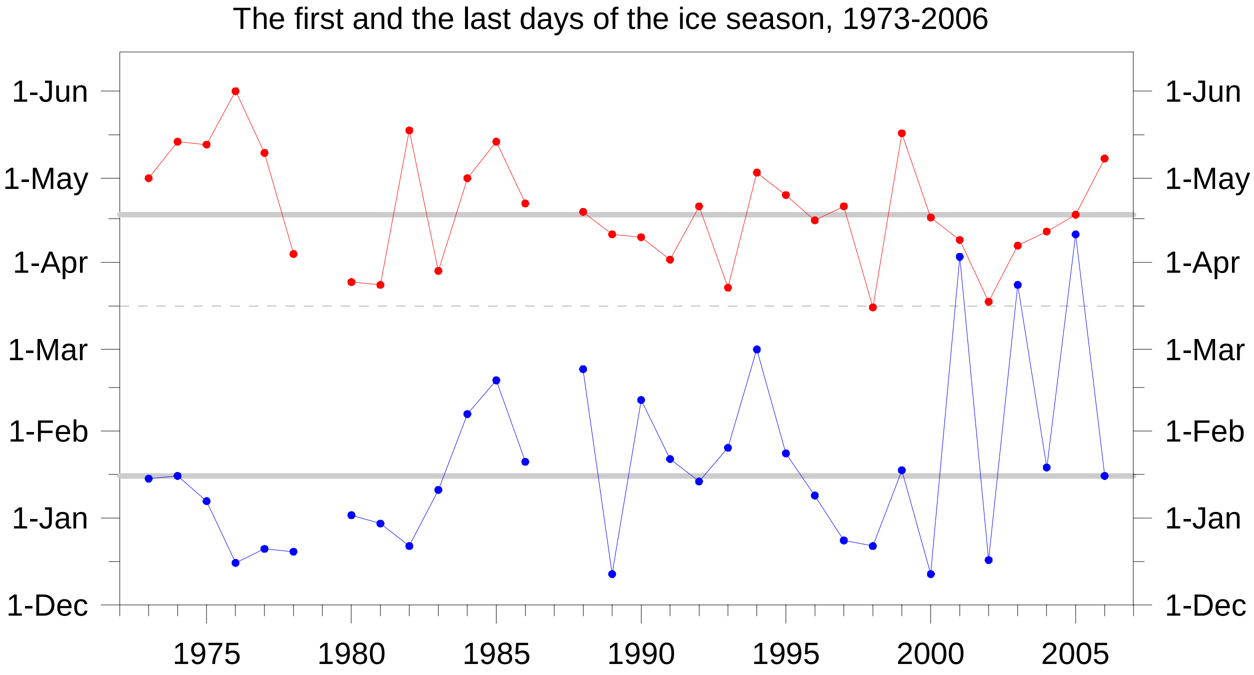

Figure 32. The first and last days of the ice season, 1973-2006. The gray solid horizontal lines are the mean dates for these two variables. The dashed line (March 15) is used as a threshold to calculate the ice retreat index. No ice was present in the box in 1979 and 1987.

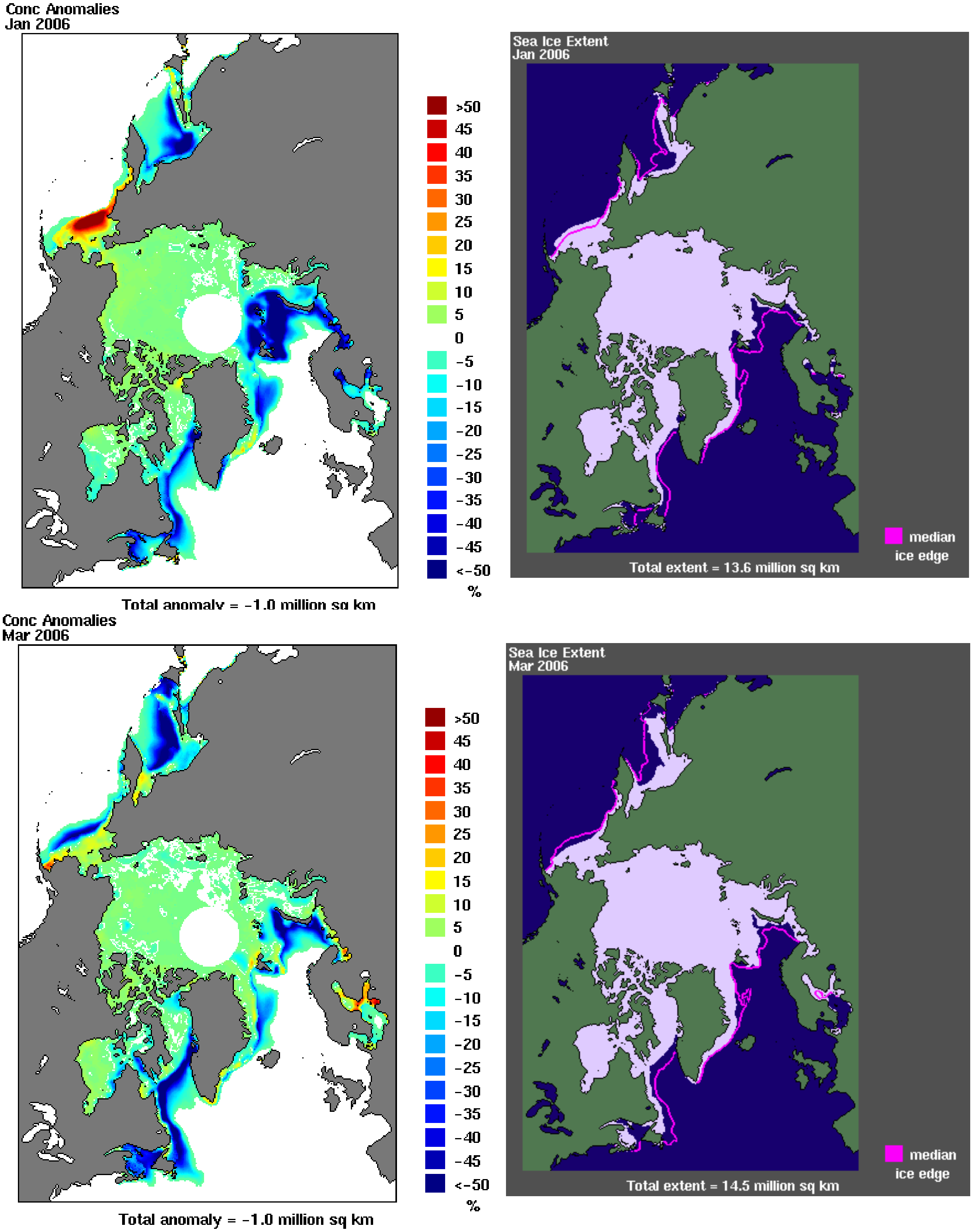

Figure 33. Sea ice concentration anomalies (left column) and extent (right column) in the Arctic during January (top panel), March (bottom panel) and May (next page) 2006.

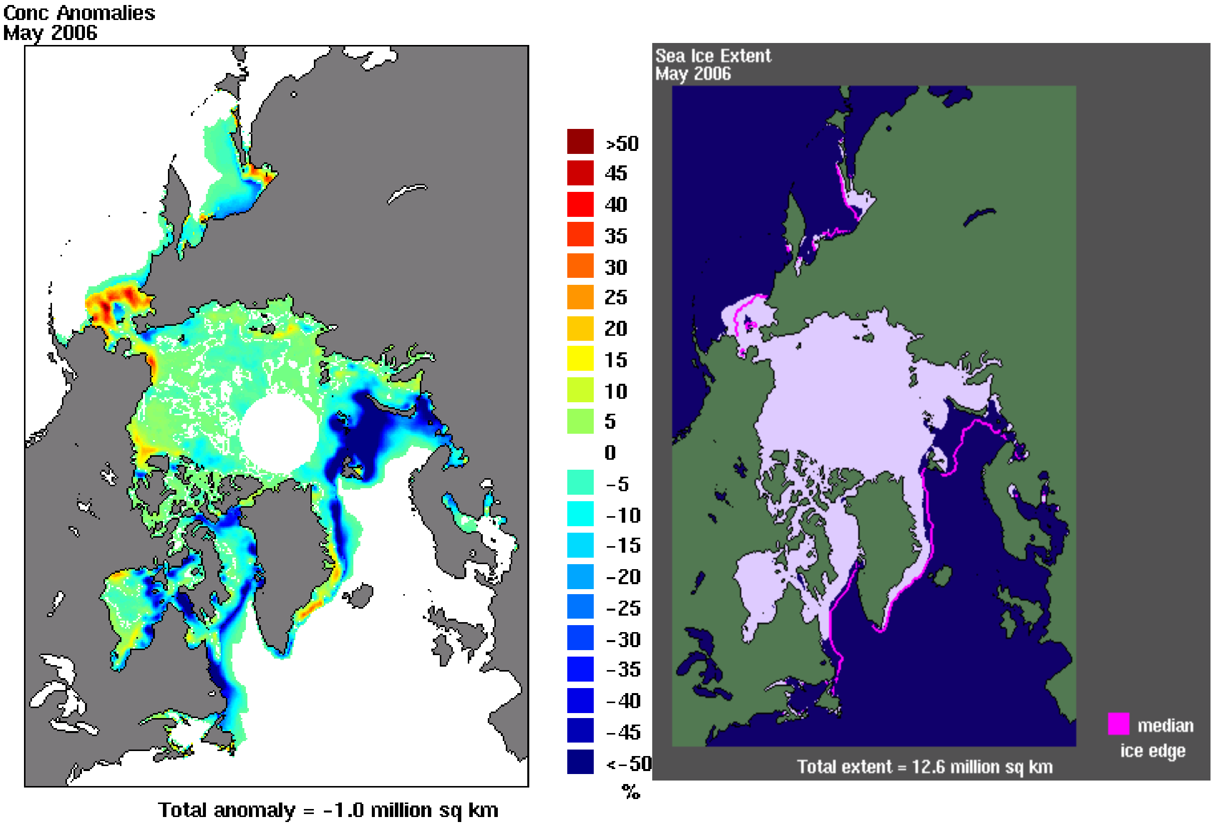

Figure 33. (continued). Sea ice concentration anomalies (left column) and extent (right column) in the Arctic during May 2006.The base period for anomalies is 1979-2000.

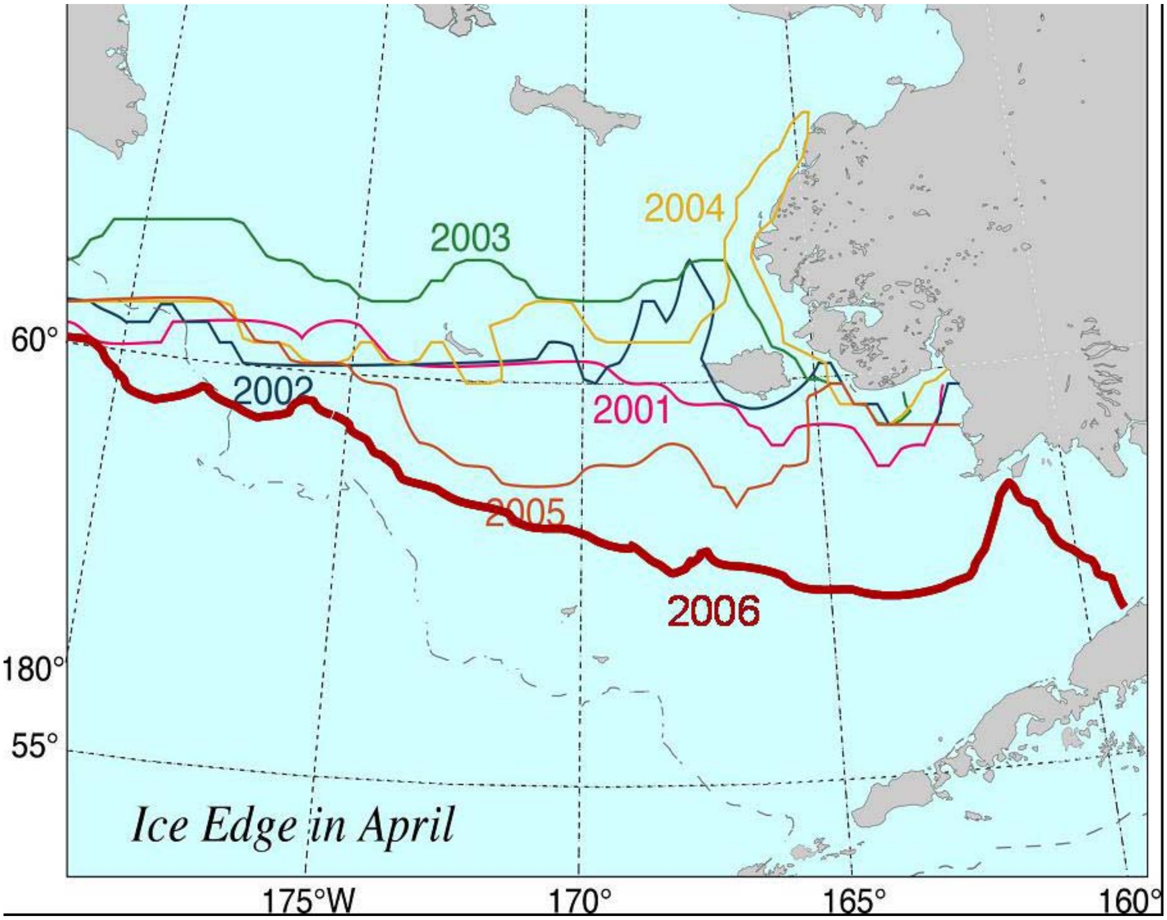

Figure 34. Ice edge in April 2006 in comparison to the previous five years.

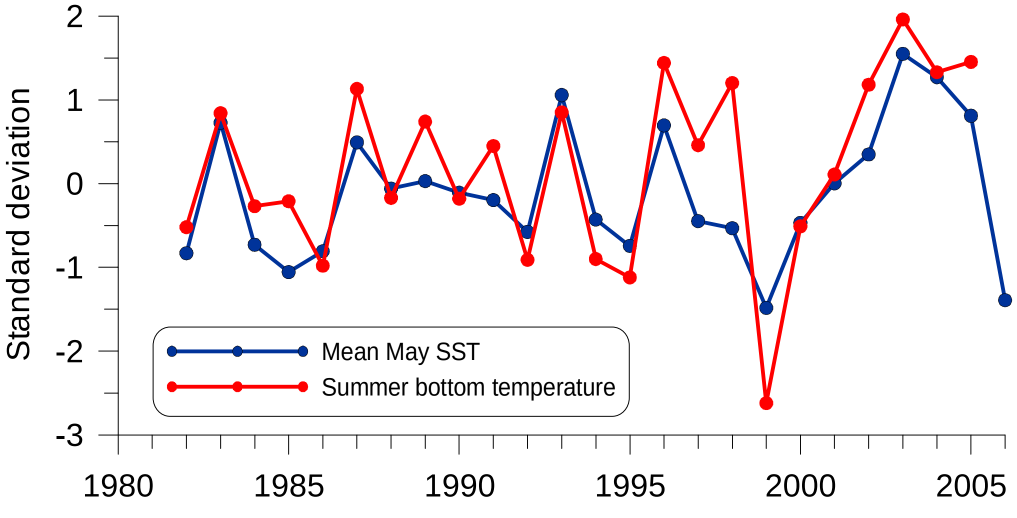

Figure 35. The MaySST index and mean summer bottom temperature in the southeastern Bering Sea, 1982-2006.

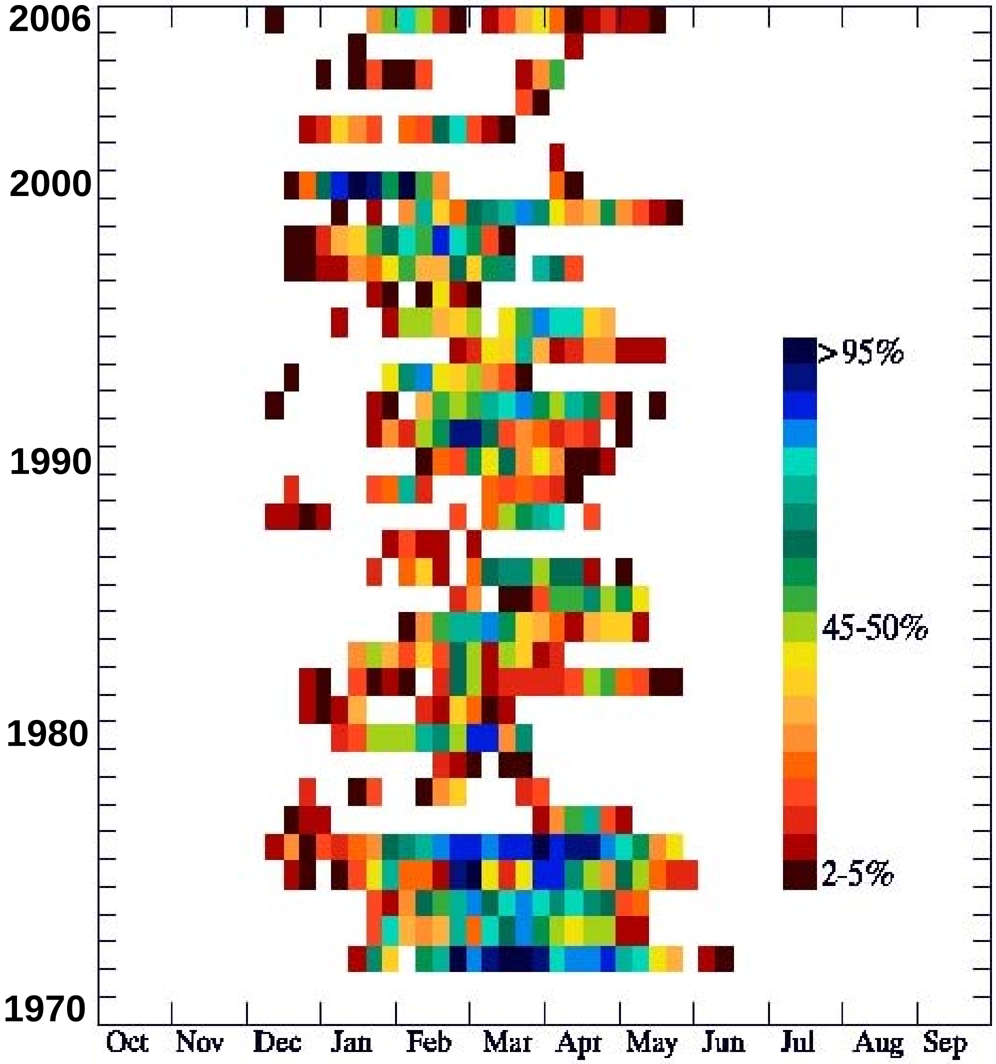

Figure 36. Percent of ice coverage between 58°N and 60°N in the eastern Bering Sea, 1972-2006.

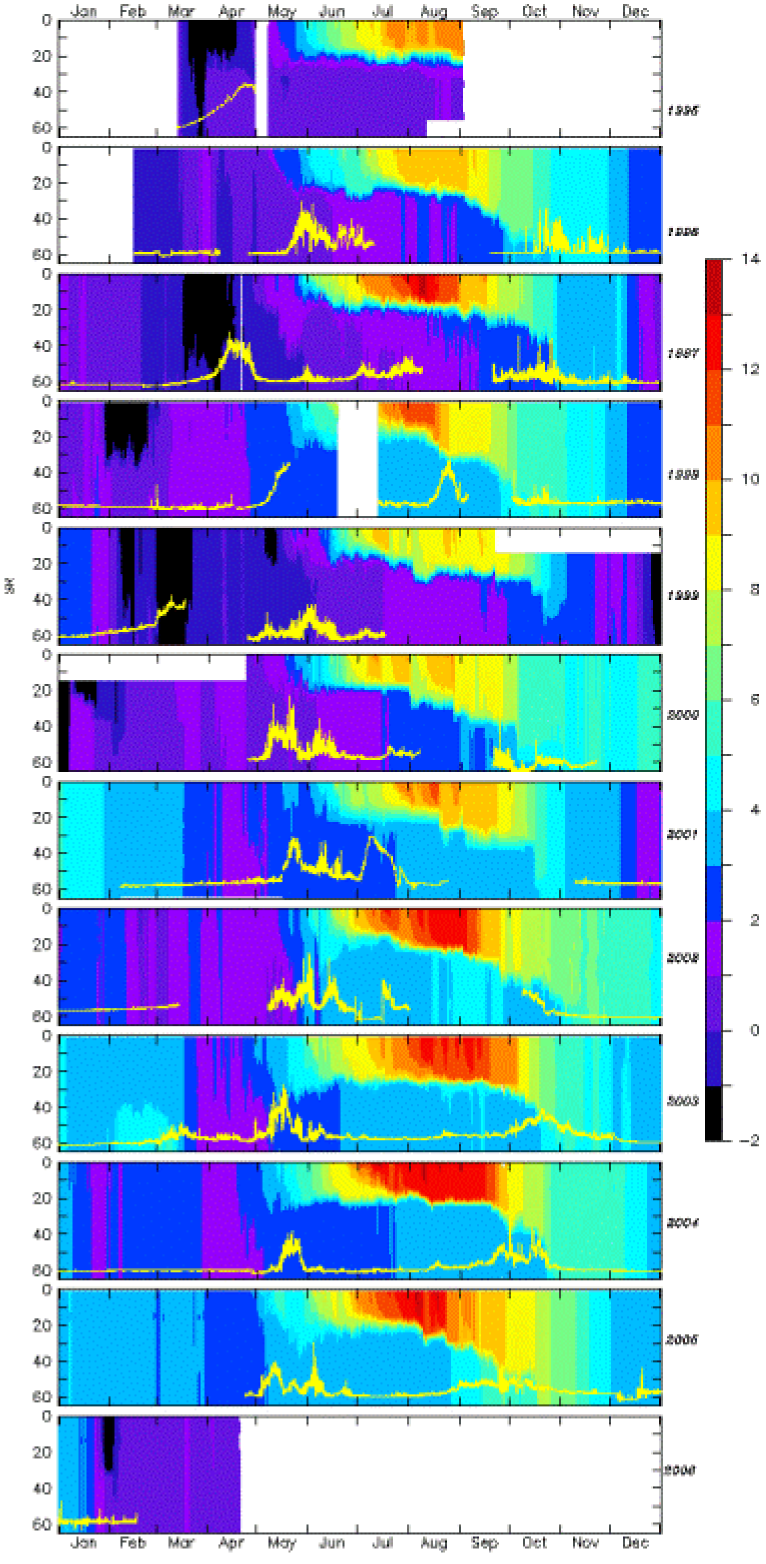

Figure 37. Contours of temperature measured at Mooring 2, 1995-2006. The coldest temperature (black) occurred when ice was over the mooring. The yellow line is fluorescence measured at ~11 m. Note that early blooms are associated with the presence of ice.

Simulated Drift Trajectories in the Southeast Bering Sea –FOCI

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Last updated: November 2004

One of the most important resources in the Bering Sea (both for economic value and for its role in the ocean ecosystem) is the walleye pollock (*Theragra chalcogramma*) fishery. In the 1998, 50% of the world ocean catch of pollock came from the Bering Sea (Napp et al. 2000). At the same time walleye pollock (especially juveniles) are the main prey of other fishes, seabirds and marine mammals, meaning changes in stock size exert pressure on the entire Bering Sea food web. There are large inter-annual variations in pollock recruitment (Wespestad 1993) that must be understood in order to successfully manage this fishery. Climate variability and physical forcing play an important role in recruitment of fish and shellfish species (Wespestad et al. 2000; Wilderbuer et al. 2002; Zheng and Kruse 2000). Pollock recruitment is understood to be mainly set by their first year (Kendall and Duker 1998) and one fate that young pollock meet is cannibalism by adult pollock. Thus, transport of pollock eggs and larvae to regions of high adult density should adversely affect survival. Wespestad et al. (2000) test this hypothesis by using a surface transport model (OSCURS, (Ingraham and Miyahara 1988)) to simulate egg/larvae trajectories, and hindcasting survival rates. We attempt to improve on this work by using a full primitive equation ocean model to calculate trajectories instead.

We have used the northeastern Pacific Regional Ocean Model System (ROMS) to simulate trajectories in the southeastern Bering Sea. Drifter tracking in ROMS is done using a fourth order predictor-corrector scheme and allows vertical movement. We currently have results for the years 1996-2003. The simulated drifters are initialized in the Bering Sea just north of Unimak Island and to the northeast of Unimak Pass. This is known to be an area of spawning for walleye pollock (Hinckley 1987). The initial drifter positions fill out a seven by seven grid with horizontal separations of about 10 km (Figure 38). Vertically, there are 15 drifters initialized at each grid point with maximum depths just over 40 m. The drifter initial positions are denser near the surface, replicating vertical egg distribution data collected in the Bering Sea (Kendall et al. 1994). Drifters are released on April 1 of each year and are tracked for 90 days.

Endpoints after 90 days for drifter trajectories from the 1998-2003 runs are shown in Figure 39 (this plot shows all drifters at all depths). In all years there is a strong tendency for trajectories to move to the northeast up the Alaskan peninsula. The other common path is movement to the northwest along the 100-m isobath. The split between these two paths is seen clearly in the 1998, 1999, 2001 and 2003 drifter endpoints. The full trajectory plots (not shown here) show that the endpoints in 2000 are the result of a strong turning to the northwest of trajectories that had been moving up the Alaskan peninsula. In 2002 the drifters initialized at deeper points follow the common paths along the peninsula and the 100-m isobath. But drifters nearer the surface seem influenced by local winds and first move to the northeast, then turn to the northwest, resulting in endpoints spread evenly across the entire shelf. Further study of possible forcing mechanisms is needed to understand what leads to these years departing from the archetypal two-limbed flow.

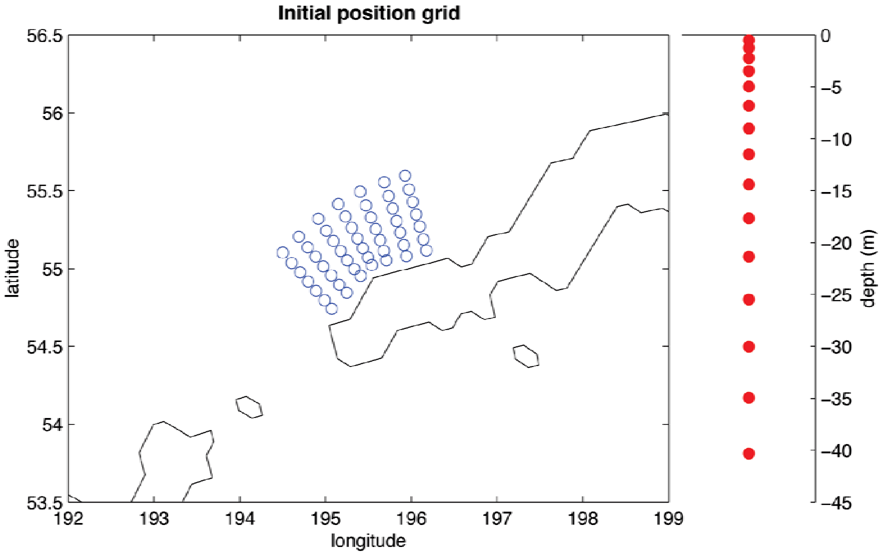

Figure 38. Simulated drifter initial horizontal (left) and vertical (right) positions.

The initial goal of this work was to compare simulated trajectories from a full primitive equation model with those from the Ocean Surface Current Simulations (OSCURS) numerical model. OSCURS computes daily surface current fields using daily sea level pressure and long-term mean geostrophic current data. As such, it is a simpler model in terms of the physics involved but is much more computationally inexpensive. Wespestad et. al. (2000) used OSCURS to create simulated trajectories in the Bering Sea. The initial grid used here was centered on the initial release point they used. Our trajectories for drifters released near the surface (0 to 5 m depth) show good agreement with the OSCURS results. But our results show variation of trajectory endpoints with changes in both horizontal and vertical initial position. Figure 40 shows the full trajectories for the 2001 simulated drifters. The upper left panel shows the tracks of all the drifters released, while the upper right and the bottom panels show drifter tracks as a function of their release depth. Within each depth bin it is evident that there is a large dependence of drifter endpoints on initial vertical placement with each bin showing, to relative degrees, the two-limbed split flow.

There is also a strong dependence on release depth. The OSCURS 2001 trajectory (not presented here) moves a short distance to the northeast up the Alaskan peninsula as do the majority of the NEPROMS drifters released in the upper 5 m of the water column (upper right panel of Figure 40). But with deeper release points comes a stronger divergence of the trajectory fates. In the 5-20 m and 20-40 m release bins there are significant numbers of drifters that join the 100-m isobath flow to the northwest, with some even moving through Unimak Pass before turning back. OSCURS results would completely miss this variation in particle fates.

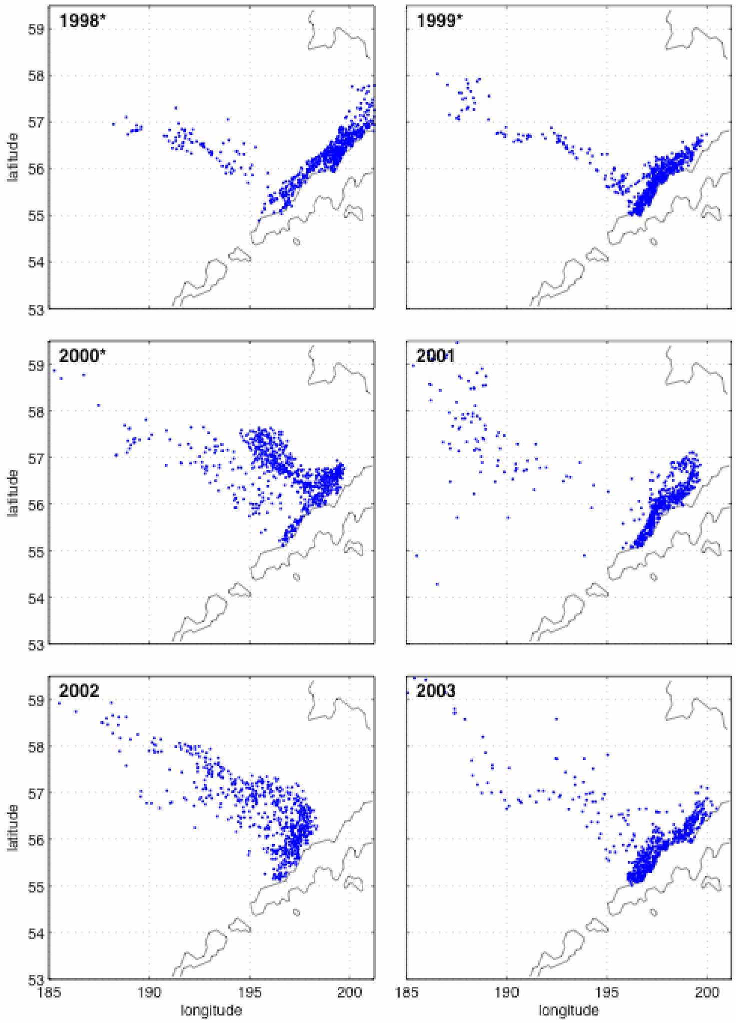

Figure 39. Endpoints for 90-day drifter trajectories for 1998-2003.

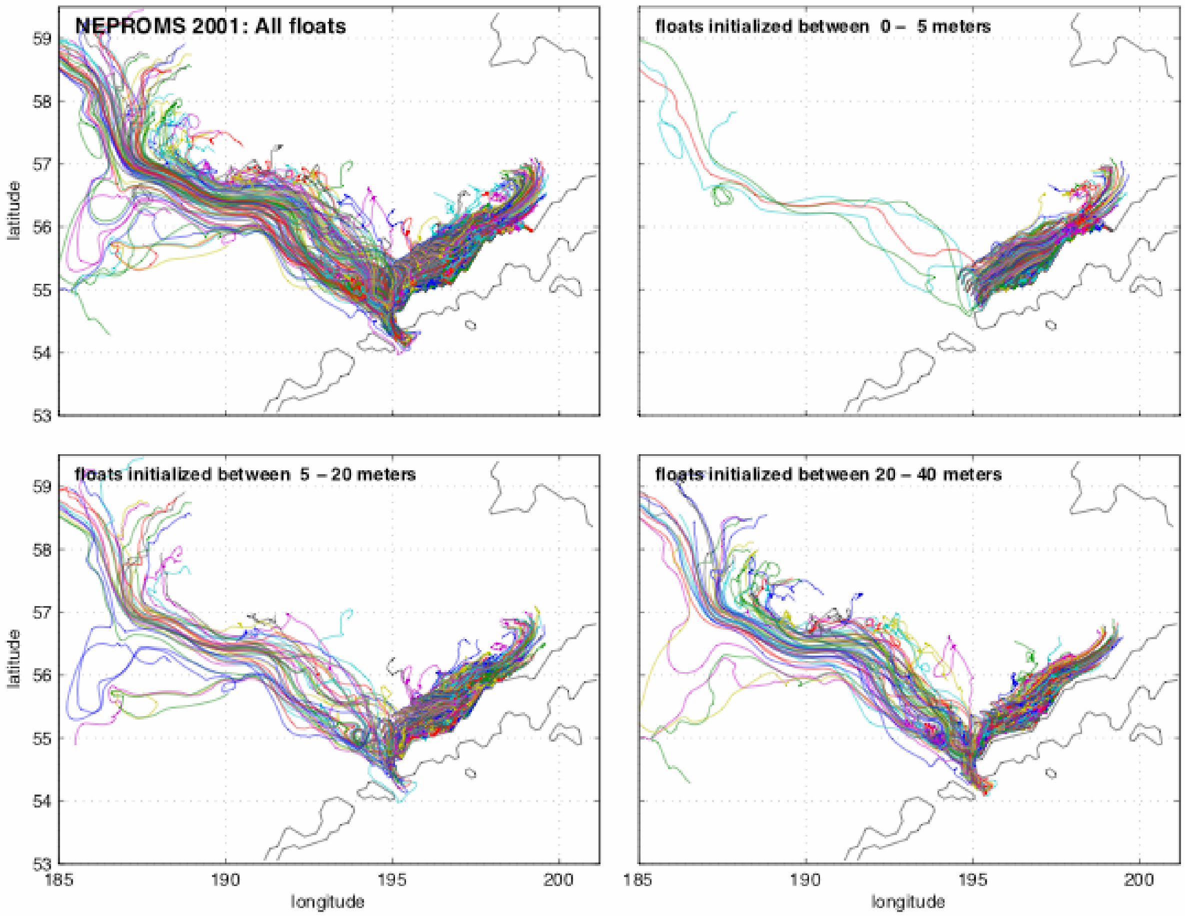

Figure 40. Full trajectories for the 2001 90-day simulated drifters. Upper left panel shows all drifters, while the upper left and bottom panels show drifters divided as a function of initial release depth.

Summer bottom and surface temperatures – Eastern Bering Sea

Contributed by Robert Lauth, Alaska Fisheries Science Center
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Last updated: November 2006

The annual AFSC bottom trawl survey for 2006 started on May 30 and finished on July 28. The average bottom temperature was 1.87˚C, well below the 1982-2005 mean of 2.62˚C (Figure 41). Bottom temperature anomalies from the long-term station means were negative over most of the shelf region except for the southwestern sections of the inner and middle shelf regions (Figure 42). Maximum anomalies occurred in the inner and middle domain where bottom temperatures were < -1˚C. The ‘Cold Pool’, usually defined as an area with temperatures < 2˚C, extended much further to the south and east into Bristol Bay compared to 2005.

The average surface temperature, 5.59˚C, was the lowest since 1999 and lower than the long-term mean 6.75˚C. A majority of the 2006 survey stations had decreases in water temperatures in the surface waters (Figure 41). The largest surface temperature differences (< -4˚C) were in the upper half of the middle and inner domains.

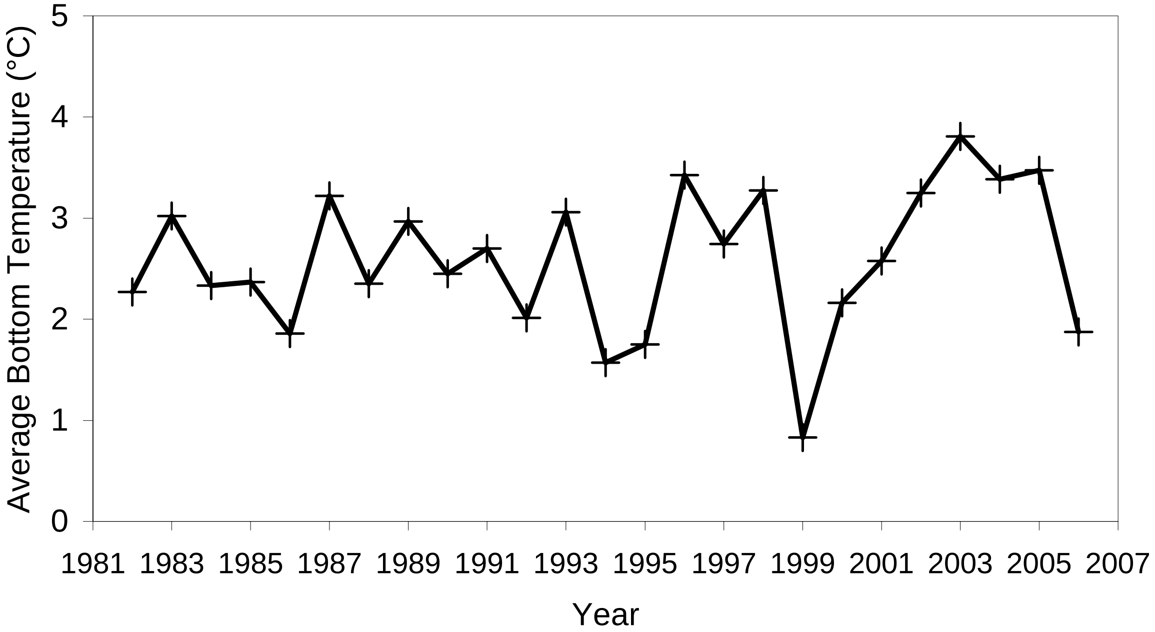

Figure 41. Mean summer bottom temperature (°C) in the standard bottom trawl survey area of the eastern Bering Sea Shelf, 1975-2006. Temperatures for each tow are weighted by the proportion of their assigned stratum area.

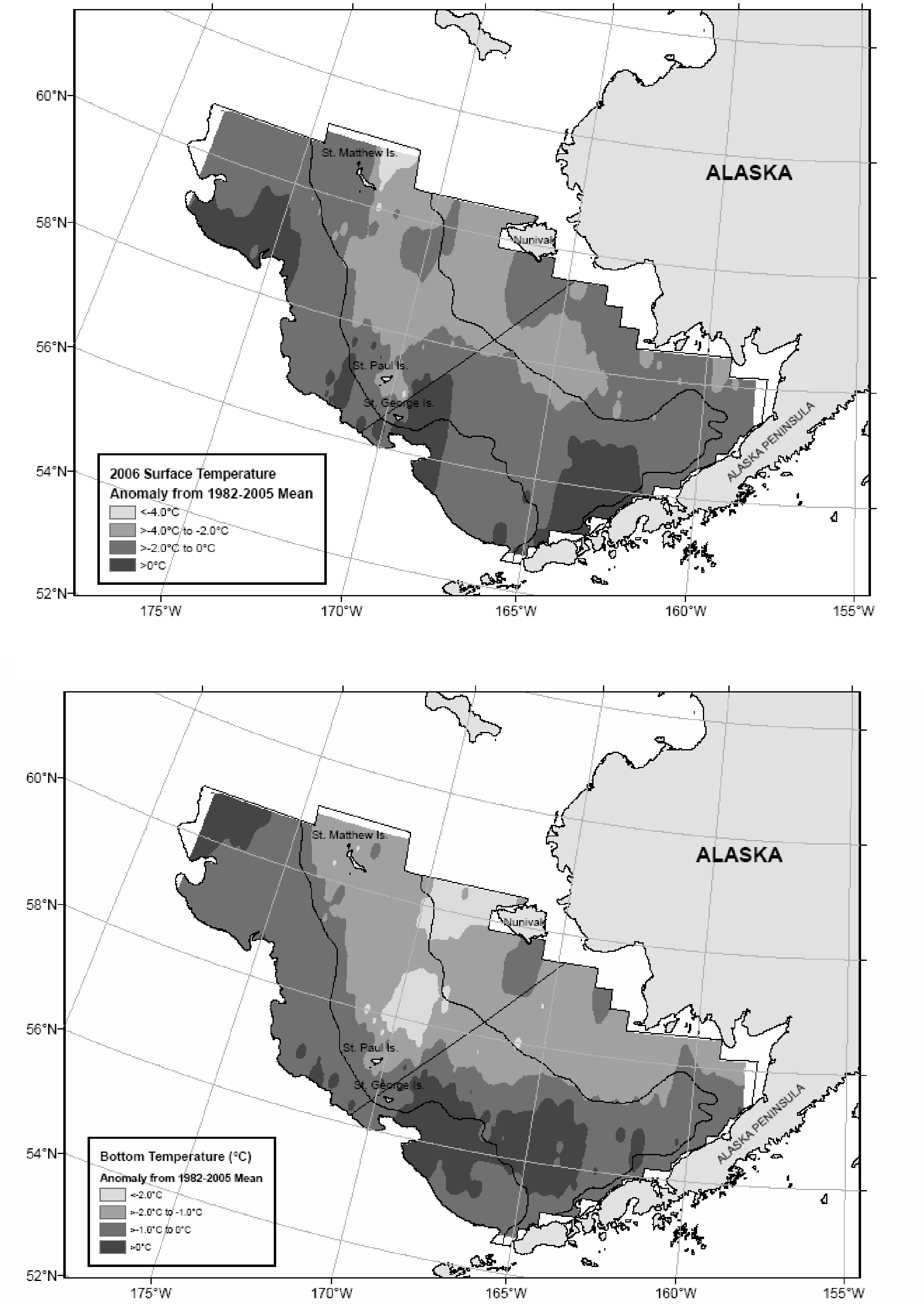

Figure 42. Summer bottom (bottom panel) and surface (top panel) temperature anomalies in 2006 from the 1982-2005 means at standard bottom trawl survey stations in the eastern Bering Sea.

Variations in water mass properties during fall 2000-2005 in the eastern Bering Sea-BASIS

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Last updated: November 2006

Oceanographic and fisheries data have been collected in the Eastern Bering Sea (EBS) during fall 2000-2005 for the U.S. component of a multiyear international research program, Bering-Aleutian Salmon International Survey (BASIS). Stations were located between 54°N and 68°N, at 30-60 km resolution, although spatial coverage varied by region and by year. Bristol Bay stations were sampled from mid August to early September during all six years. While, stations in the central and northern EBS were generally sampled from mid September to early October. Oceanographic data were obtained from vertical conductivity-temperature-depth (CTD) profiles and laboratory analyses of discrete water samples at select depths (2003, 2004, and 2005). Oceanographic variables include temperature, salinity, nutrients, chlorophyll a, and phytoplankton taxonomic characteristics (based on phytoplankton species identification and chlorophyll a size fractionation). A long-term goal of this research is to characterize interannual variations in the abundance and distribution of lower and higher trophic level organisms in relation to oceanographic features in the EBS (see *Nutrients and Productivity* and *Forage Fish* sections of this report).

The surface temperature, salinity and density (sigma-t) for 2000-2005 in the Eastern Bering Sea are shown in Figure 43. Bristol Bay surface temperatures were warmer in 2002, 2003, 2004, and 2005 than in 2000 and 2001. The lower surface salinities near the coast indicate major input from the Yukon and Kuskoquim rivers and can be used to estimate the Inner Front location. Surface density variations were largely driven by salinity. Analyses of vertical sections (data not shown) indicate that the pycnocline depths were shallower in 2002 and 2004 than in 2000 and 2001 in Bristol Bay. The location of the cold pool, deep cold water formed during ice melt, can have a large impact on fish distributions. The cold pool was observed south of St. Lawrence I. (between 168 and 174°W and 60 to 63°N) in 2002, 2004, and 2005 during mid September to early October (see *Nutrients and Productivity* section of this report).

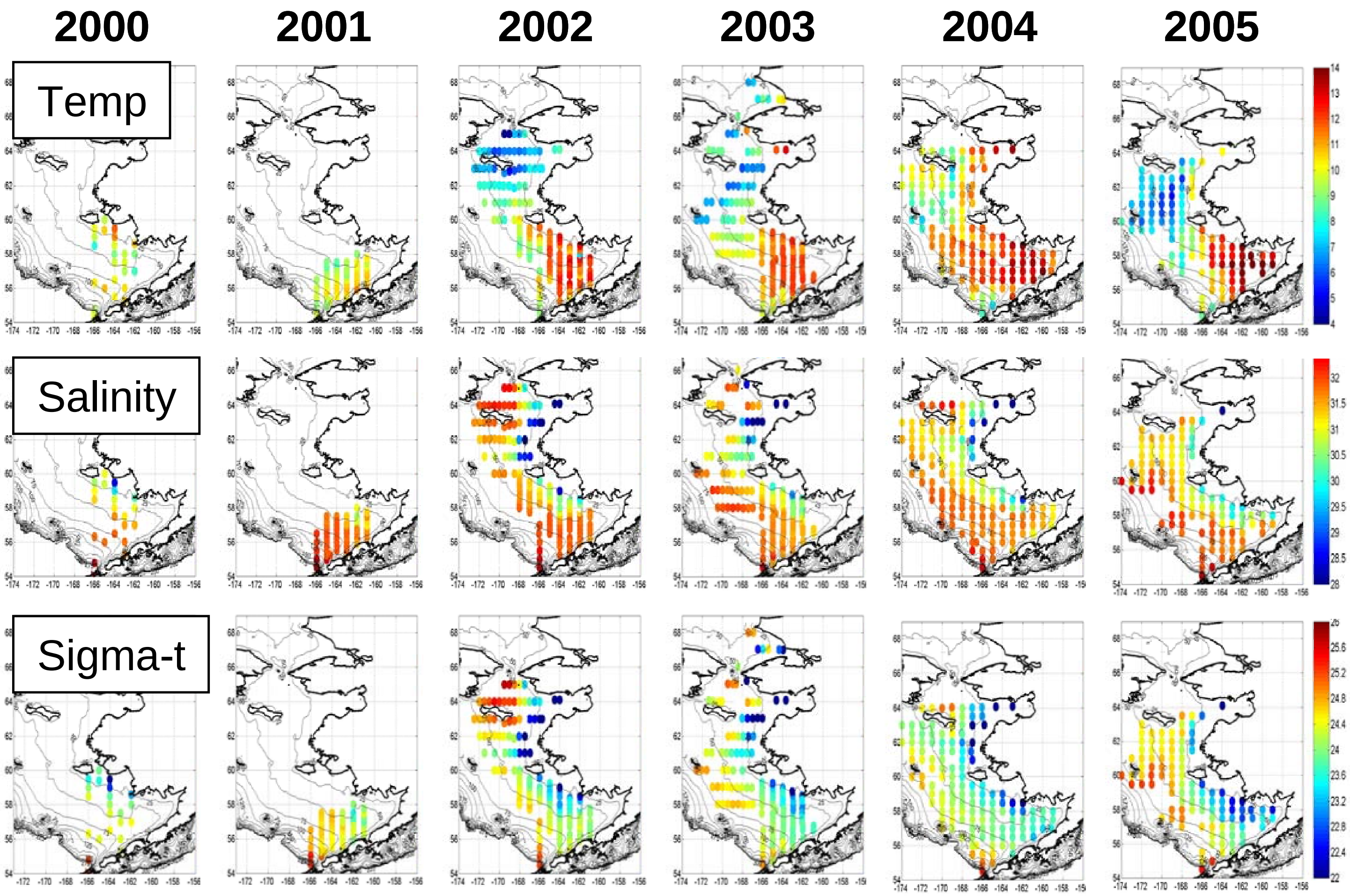

Figure 43. Surface (5 m) temperature (°C), salinity and density (sigma-t, kg m^{-3}) from CTD casts collected mid-August to mid-October, 2000-2005. Bristol Bay stations were sampled from late August to early September for all years.

ALEUTIAN ISLANDS

Water temperature data collections – Aleutian Islands Trawl Surveys

Contributed by Harold Zenger, Alaska Fisheries Science Center
Contact: Michael.Martin@noaa.gov
Last updated: November 2004

A Brief Description of Water Flow in the Aleutian Islands

The oceanographic characteristics of water flowing through passes in the Aleutian Archipelago have been summarized and reported by Favorite et al. (1976), Stabeno et al. (1999) and Reed and Stabeno (1999) among others. The following two introductory paragraphs are drawn from largely complementary parts of their papers on the oceanography of the subarctic Pacific Ocean, the physical oceanography of the Bering Sea, and the Aleutian North Slope Current, respectively.

The water currents that flow around the Aleutian Islands are most heavily influenced by the Alaskan Stream, the northern edge of the North Pacific subarctic gyre that moves westward along the continental slope, south of the archipelago. Parts of the Alaskan Stream flow in an intermittent fashion through passes between the islands supplying much of the water that circulates in the Bering Sea. The strength of this flow varies on a scale of days or weeks or more. Water flow into the Bering Sea can change by a factor of two or more. Tides play an important part in mixing water masses as they encounter each other and prominent topographical features. The Alaskan Stream occasionally may be dislocated southward, possibly contributing less transport through the passes.

South to north water movement through two deep passes, Amukta Pass and Amchitka Pass, is the primary source of the Aleutian North Slope Current, a relatively narrow flow that moves northeastward along the north side of the islands and bends northward and westward to become the Bering Slope Current. Further west the Alaskan Stream flows through Buldir Pass and Near Strait near Stalemate Bank and branches eastward along the north side of the islands toward Petrel Bank. Some of this water flows south through the many passes between the islands.

The presence of Alaskan Stream water is usually typified by temperatures warmer than 4° C to depths of 200 m or more. In general, Alaskan Stream water moves northward through the eastern side of the major passes. Occasionally the westward margin curves to the west and south arcing around to rejoin the inflow or sometimes to rejoin the Alaskan Stream. The Aleutian North Slope Current commonly forms eddies, ultimately sending water southward through the shallower passes (specifically cited, Seguam Pass), where it may flow westward along the southern continental shelf or rejoin the Alaskan Stream to flow west again, possibly reentering the Bering Sea at a later time.

Implications for Groundfish Reproduction and Recruitment

Although representing a relatively small volume of water, eddies that re-circulate water over or near the shelf might be important to concentrate primary production. They may also contribute to successful reproduction and recruitment of the major Aleutian semi-pelagic species such as Atka mackerel, Pacific Ocean perch, northern rockfish, and walleye pollock. For example Seguam Pass is a known area of Atka mackerel spawning off Seguam and Amlia Islands and at probable locations on offshore rock outcrops south of Seguam Island (personal video observations of typical male nest guarding behavior). The implications of clockwise movement of water flowing past spawning grounds and then westward over the southern shelf, or within the northern margin of the Alaskan Stream, to ultimately deposit post-larval or young-of-the-year fish in favorable feeding and protective habitat should be investigated.

Trawl Survey Temperature Profiles – What They Can Show

Stabeno et al. (1999) report on two vertical sections of temperatures across Amukta Pass between Amukta I. and Seguam I. collected in August. The 1994 data reflect a vertically mixed temperature distribution during a period of strong south to north flow through the pass. Relatively warm Alaskan Stream water (~ 4.5° C) reached almost to a depth of 400 m on the eastern (inflow) side of the pass. This is contrasted with a period of low inflow one year later during which the water column temperature distribution was much more stratified with a cold water outflow (~ 3.5° C) on the western side of the pass. These distinct situations might be detectable by viewing trawl survey temperature profiles from middle-depth and deep trawl stations.

Groundfish assessment survey periods have ranged from early May to late September, with no fixed sampling pattern or time schedule. Generally, sampling progresses from east to west, but notable exceptions exist especially for the earliest three surveys and for the 2002 survey. Surface to bottom temperature profiles have been routinely collected in conjunction with bottom trawl hauls. Of the eight survey years cited in the figure below, all except 1991 had temperature profiles from throughout the Aleutian survey area.

Wolter and Timlin (1993, 1998) produced a multivariate El Niño/Southern Oscillation (ENSO) index (MEI) that is presented graphically and regularly updated at the following website: Klaus Wolter (kew@cdc.noaa.gov). Comments on the timing of ENSO events cited herein reference that graph. The year 2000 produced the coldest bottom temperatures yet detected during summer AFSC groundfish surveys (Figure 44). The warmest years tend to be associated with El Niño events. The three coldest years thus far detected (1994, 2000, and 2002) have occurred within the last eight years, with one of the warmest (1997) occurring in their midst (Figure 44). Those colder years were associated with La Niña events (2000 and 2002) or a strongly decreasing El Niño event (1994). The warm 1997 temperatures were associated with a very strong El Niño event. Generally mean temperatures at depth intervals shallower than 300m vary more than those deeper than 300m. Perhaps the year 2000 temperatures are not as anomalous as they appear, but many individual fish weighed and measured during the survey were notably lighter than during other surveys. Unfortunately, we have no data to compare for the intervening years. The 2004 data fall in the middle of the year-specific bottom temperatures and correspond to a moderate, increasing MEI.

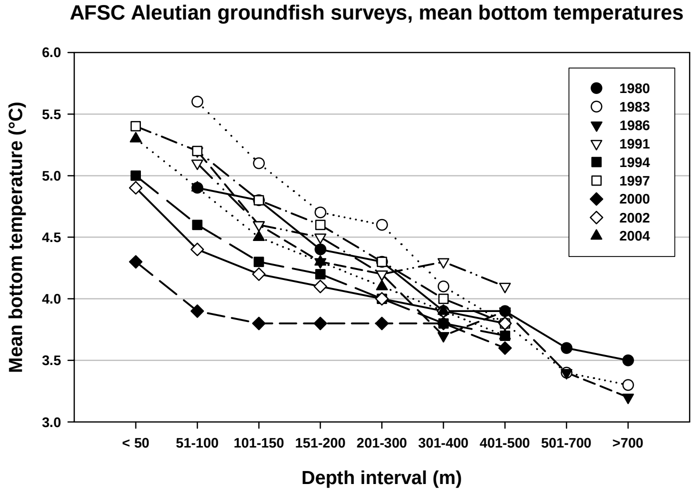

Figure 44. Mean bottom temperatures from the Alaska Fisheries Science Center (AFSC) groundfish surveys (1980-2004).

ENSO events are monitored using the Multivariate ENSO Index (MEI) which is based on six observed variables over the tropical Pacific: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. Given the apparent correlation between the within-year MEI trends and summer mean bottom temperatures in the

Aleutian archipelago, further investigation seems promising. If a correlation exists between the MEI and oceanographic events controlling Aleutian survey bottom temperatures, it might be demonstrated graphically as a linear relationship between mean MEI for the period from slightly before the start to the end of the groundfish survey period. Low MEI should correspond to low bottom temperatures and high mean MEI should correspond to higher bottom temperatures. Mean MEIs for the period from March to the end of each survey period were plotted against mean bottom temperature for four depth intervals (Figure 45). March was used as a starting point because most of the ENSO events began in spring or early summer (Hollowed et al. 2001). Correlation coefficients are included for each trend line and range from 0.67 and 0.81 suggesting that mean MEI and bottom temperatures to a depth of 300 m are somehow related (Figure 45). The weakest correlation is in the shallowest depth interval, where one might expect to find the most influence of seasonally warmed surface water and storm-caused mixing. Such short term, within-year effects are likely the result of atmospheric forcing and the position and strength of the Aleutian low-pressure phenomenon (Hollowed et al. 2001).

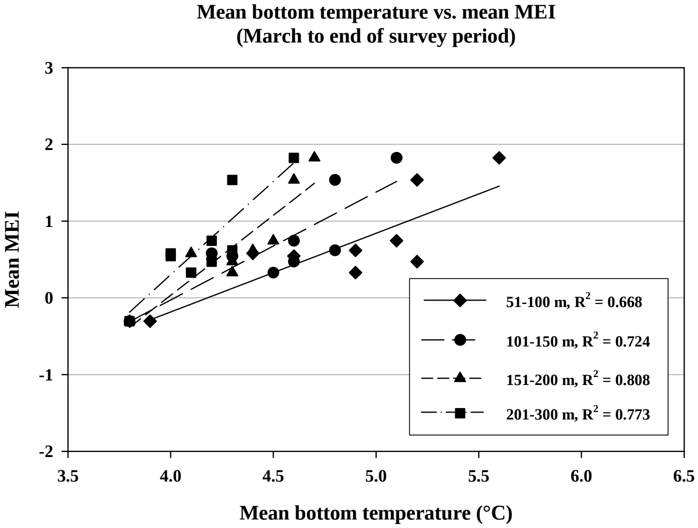

Figure 45. Multivariate ENSO Index (MEI) as a function of mean summer bottom temperatures in the Aleutian archipelago.

<u>Water Temperatures Across the Survey Area</u>

Figure 46 summarizes station-specific bottom temperature distributions by longitude for the 1994, 1997, 2000, 2002, and 2004 Aleutian Islands bottom trawl surveys. Several features appear to reoccur and warrant further comment along with some exceptions. Relatively warm bottom temperatures appear between 173°E and 176°E longitudes probably resulting from Alaskan Stream water washing over Tahoma Bank and Walls Plateau. Relatively cold temperatures found between 172°W and 174°W longitudes were probably the result of Bering Sea water flowing along the northern slope and onto the lower shelf. While the mean temperatures for 1997 were warmer than all survey years except 1983, the spread of temperatures was generally broader than other post-1991 surveys. The warm temperatures noted near the western end of the survey area were not as evident during the 2002 survey. This may have resulted from earlier than usual sampling in that area. The warm temperatures detected between about 170°W and 172°W longitudes in 2002 were probably caused by seasonal warming and may have resulted from much later than usual sampling in that area.

Figure 47 shows 2004 survey water temperatures at 12 depths from near surface to near bottom, by longitude. There were areas of warm near-surface water between approximately 170°E to 176°E and

175°W to 177°W longitudes. Generally, 2004 summer water column temperatures shallower than 200 m were somewhat warmer than in 2002. Below 200 m, temperatures were similar in both years.

Judging by past survey results, the elevated late summer, near-surface temperatures at the western end of the survey area appear to be more the rule than the exception. In 2002 sampling occurred earlier than usual and that might have contributed to the low temperatures in 25 m or shallower noted in last year's edition of this summary.

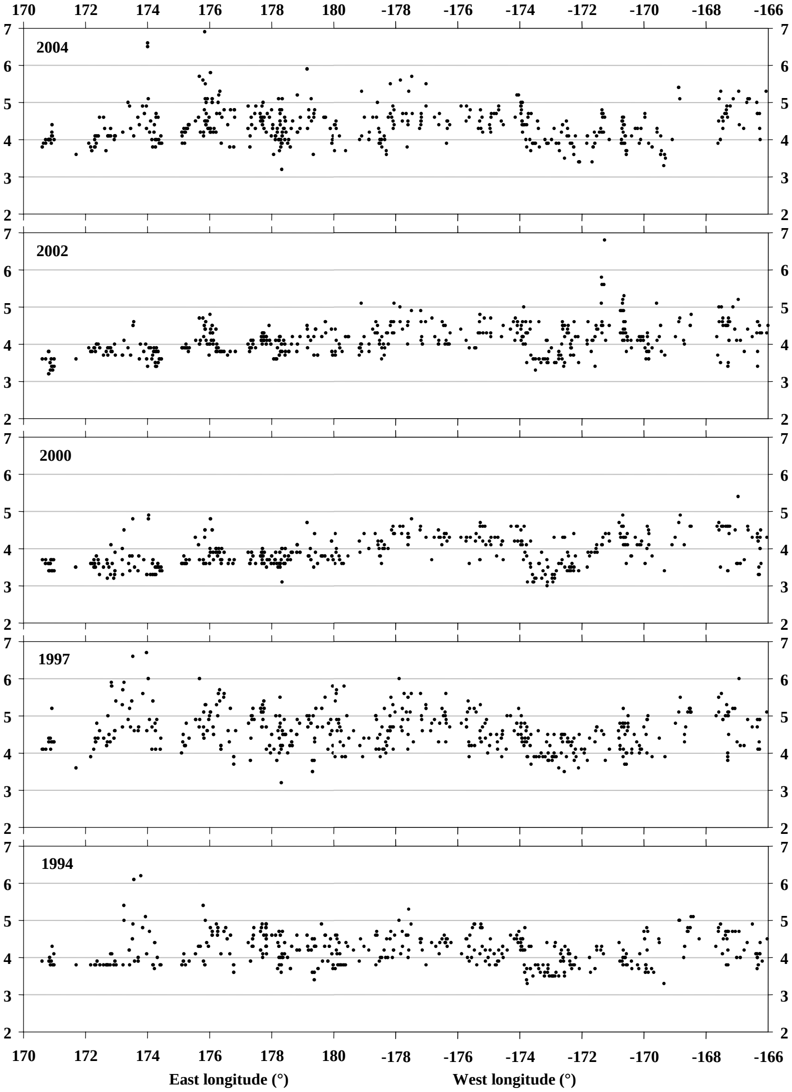

Figure 46. Bottom temperatures collected during the five most recent AFSC Aleutian Islands bottom trawl surveys, by longitude.

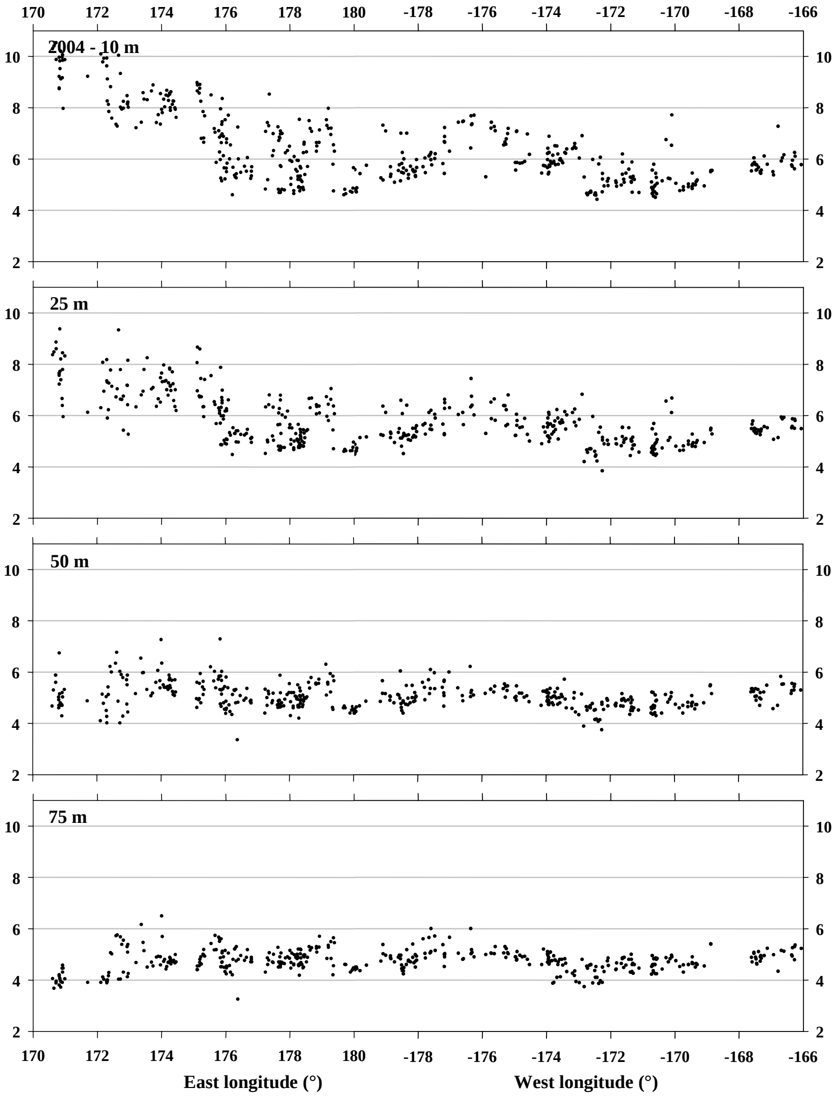

Figure 47. Temperatures at 12 depths by longitude, collected during the 2004 AFSC Aleutian Islands bottom trawl survey.

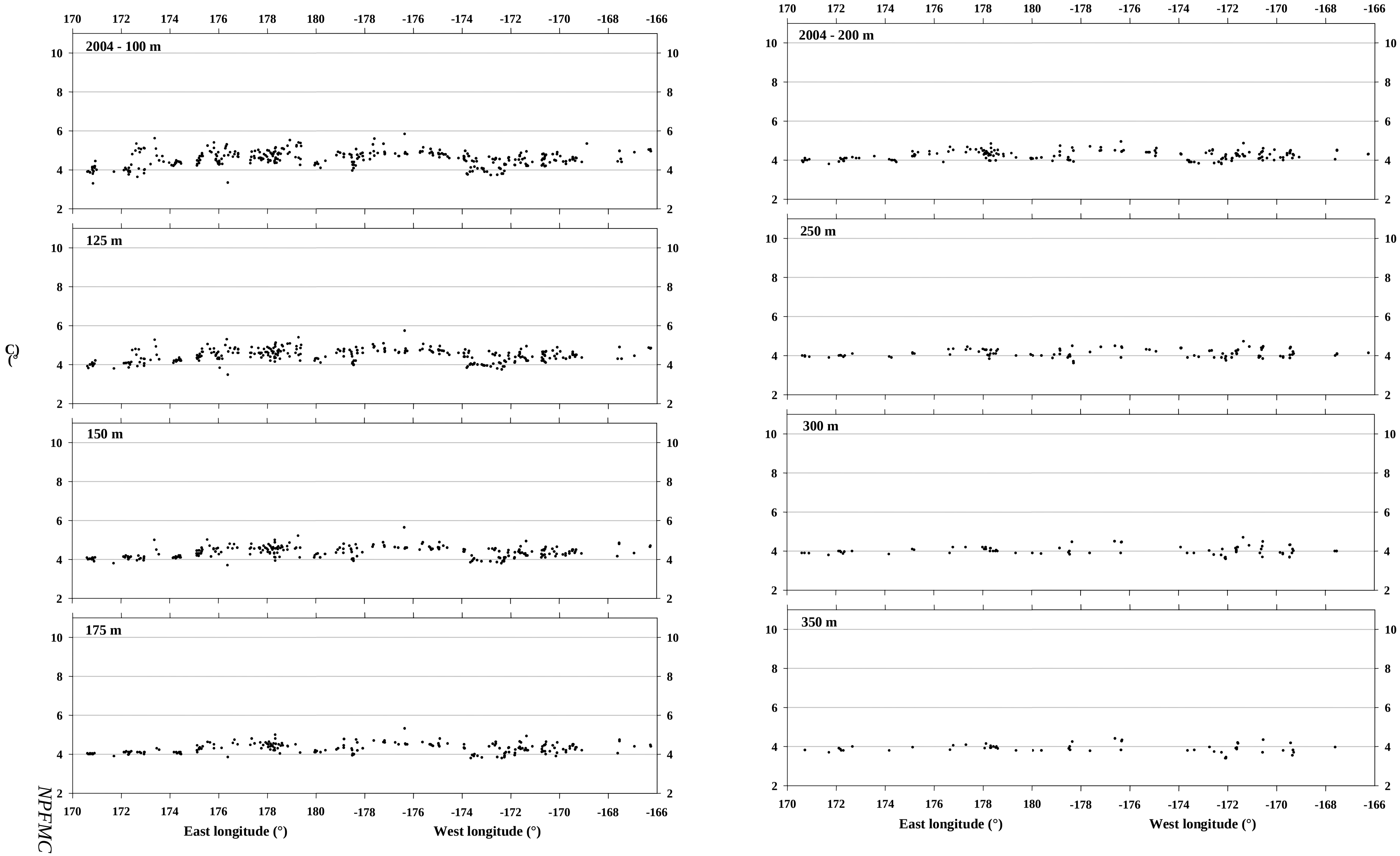

Figure 47 continued. Temperatures at 12 depths by longitude, collected during the 2004 AFSC Aleutian Islands bottom trawl survey.

Habitat

HAPC Biota – Gulf of Alaska

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Last updated: November 2006

Groups considered to be Habitat Area of Particular Concern (HAPC) biota include seapens/seawhips, corals, anemones, and sponges. The biennial survey in the Gulf of Alaska (GOA) does not sample any of the HAPC fauna well. The survey gear does not perform well in many of the areas where these groups are thought to be more prevalent and survey effort is quite limited in these areas as a result. Even in areas where these habitats are sampled, the gear used in the survey is ill suited for efficient capture of these groups. Variability in mean CPUE is also an important issue as point estimates are often strongly influenced by a very small number of catches. Another complicating factor in interpreting these results is the fact that the gears used by the Japanese vessels in the surveys prior to 1990 were quite different from the survey gear used aboard American vessels and likely resulted in different catch rates for many of these groups. Therefore, the survey results provide limited information about abundance or abundance trends for these organisms. For each species group, the largest catch over the time series was arbitrarily scaled to a value of 100 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error.

Despite the caveats, a few general patterns are clearly discernible, however. Sponge and sea anemone abundances seem to generally decrease from west to east across the GOA (Figure 48). The frequency of occurrence for both of these groups seems to have increased over time in all areas. Gorgonians seem to be most abundant in the eastern GOA, but the frequency of occurrence is quite low and the pattern may therefore be deceiving (Figure 48). Sea pen and soft coral frequency of occurrence rates are also very low and no abundance trends are discernible from this limited information. Stony corals appear to be much more abundant in the areas sampled in the western GOA, and are also captured more frequently in this area (Figure 48).

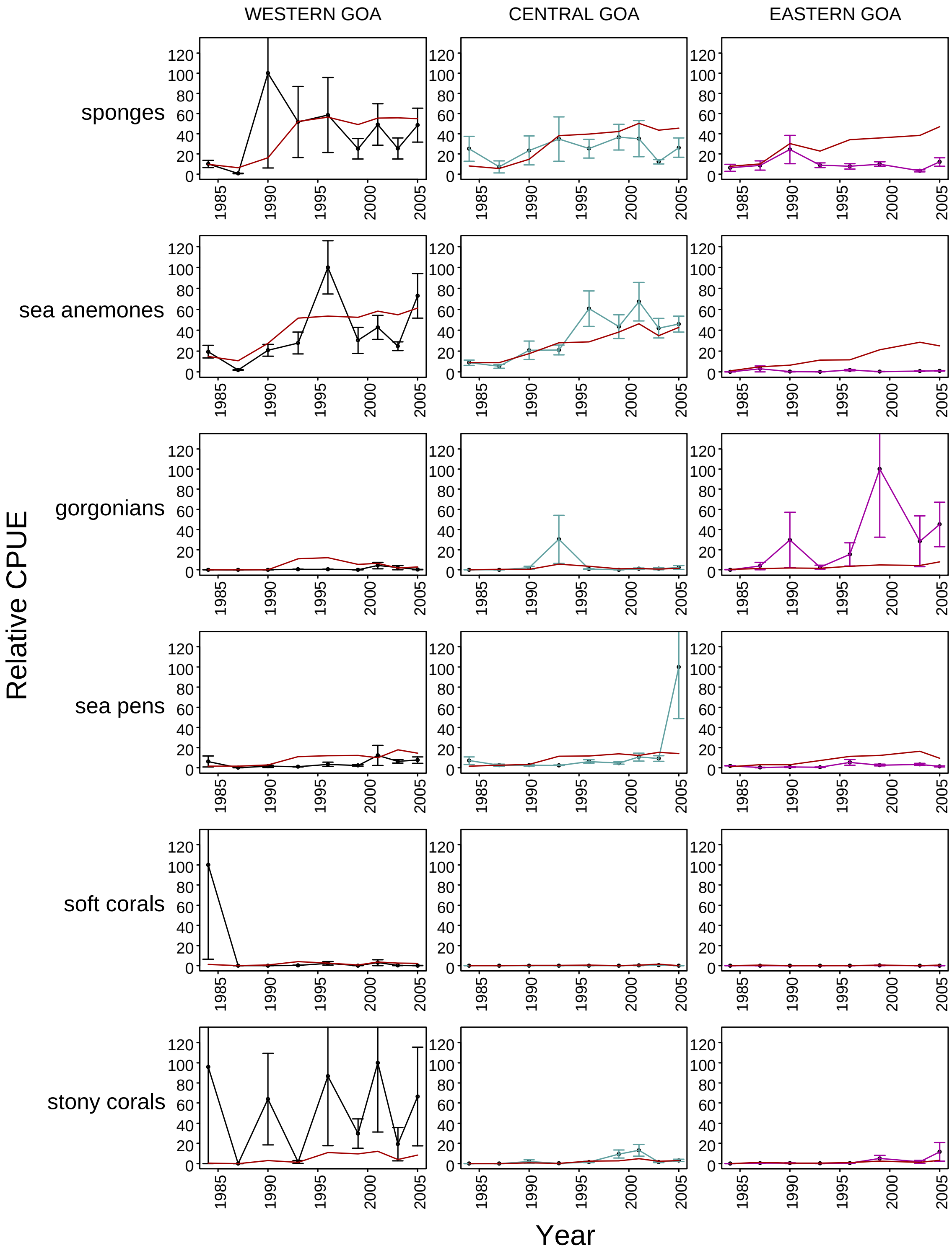

Figure 48. Mean catch per unit effort of HAPC species groups by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2005. Error bars represent standard errors. The red line shows the percentage of all hauls that contained the species group.

HAPC Biota – Bering Sea

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Groups considered to be HAPC biota include: seapens/whips, corals, anemones, and sponges. Corals are rarely encountered on the Bering Sea shelf so were not included here. For each species group, the largest catch over the time series was arbitrarily scaled to a value of 1 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative SE. It is difficult to detect trends of HAPC groups on the Bering Sea shelf from the RACE bottom trawl survey results from 1982 to 2006 because of the relatively large variability in Relative CPUE (Figure 49). Further research on gear selectivity and the life history characteristics of these organisms is needed to interpret these trends.

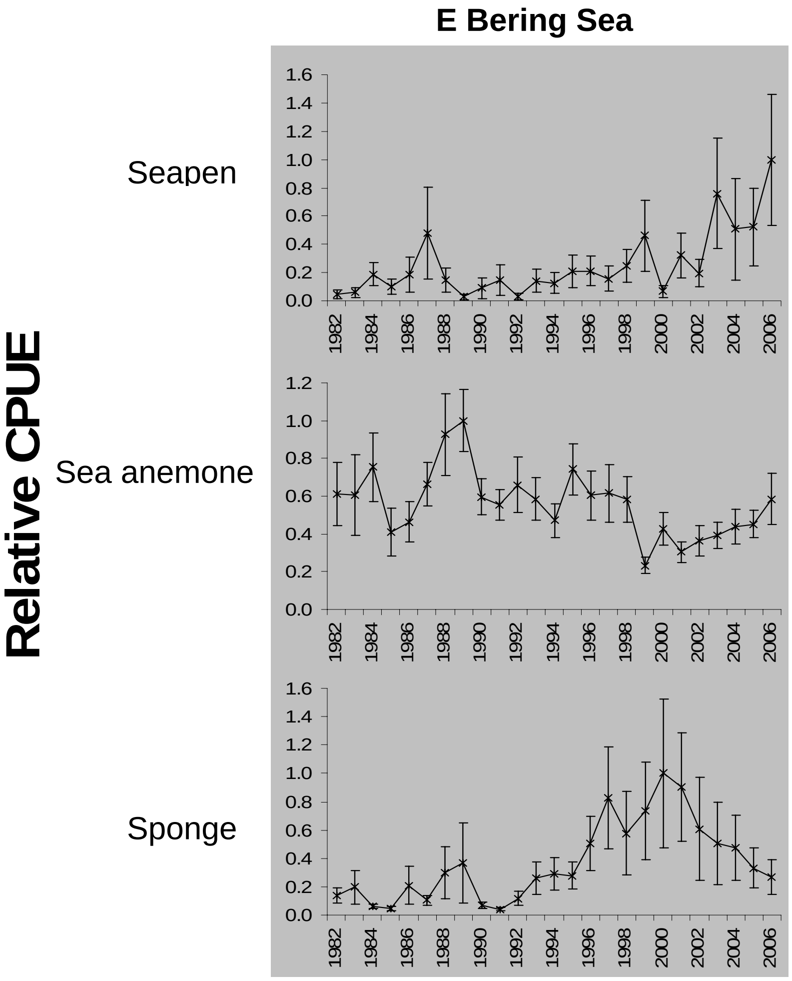

Figure 49. Relative CPUE trends of HAPC biota from the RACE bottom trawl survey of the Bering Sea shelf, 1982-2006. Data points are shown with standard error bars.

HAPC Biota – Aleutian Islands

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Groups considered to be Habitat Area of Particular Concern (HAPC) biota include seapens/seawhips, corals, anemones, and sponges. The biennial survey in the Aleutian Islands (AI) does not sample any of the HAPC fauna well. The survey gear does not perform well in many of the areas where these groups are thought to be more prevalent and survey effort is quite limited in these areas as a result. Even in areas where these habitats are sampled, the gear used in the survey is ill suited for efficient capture of these groups. Variability in mean catch per unit effort (CPUE) is also an important issue as point estimates are often strongly influenced by a very small number of catches. Since most of the AI stations are repeated from survey to survey, apparent decreases in abundance for many of the slow growing HAPC organisms could result from repeated trawling of these areas by the survey. Another complicating factor in interpreting these results is the fact that the gears used by the Japanese vessels in the survey in the 1980s were quite different from the survey gear used aboard American vessels and likely resulted in different catch rates for many of these groups. Therefore, the survey results provide limited information about abundance or abundance trends for these organisms. For each species group, the largest catch over the time series was arbitrarily scaled to a value of 100 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error.

Despite these problems, a few trends are clearly discernible. The frequency of occurrence of sponge in survey tows has been quite high and remarkably stable over the entire survey area with the exception of the 1983 and 1986 surveys where the use of different gear likely had a large influence on the sponge catches (Figure 50). Likewise, the relative abundance of sponges has been quite stable with the exception of the large estimated mean CPUE in the central AI in 1994.

While gorgonians and stony corals occur in a relatively large number of tows, mean CPUE typically is strongly influenced by a small number of tows. Both the mean CPUE and frequency of occurrence of gorgonians seem to have decreased since 1994 in all areas (Figure 50). This is in contrast to the increase in frequency of occurrence and mean CPUE noted in the stony corals over the same time period (Figure 50). Soft corals are rarely encountered and the data collected from the survey probably do not provide a reliable estimate of soft coral abundance.

Sea anemones are also common in survey catches but abundance trends are not clear for most areas. There does seem to have been a general increase in sea anemone abundance in the southern Bering Sea in recent years, however (Figure 50). Sea pens are much more likely to be encountered in the southern Bering Sea and eastern AI than in areas further west. Abundance estimates are low across the survey area and large spikes, such as the one seen in the eastern AI in 1997, are typically based on a single large catch (Figure 50).

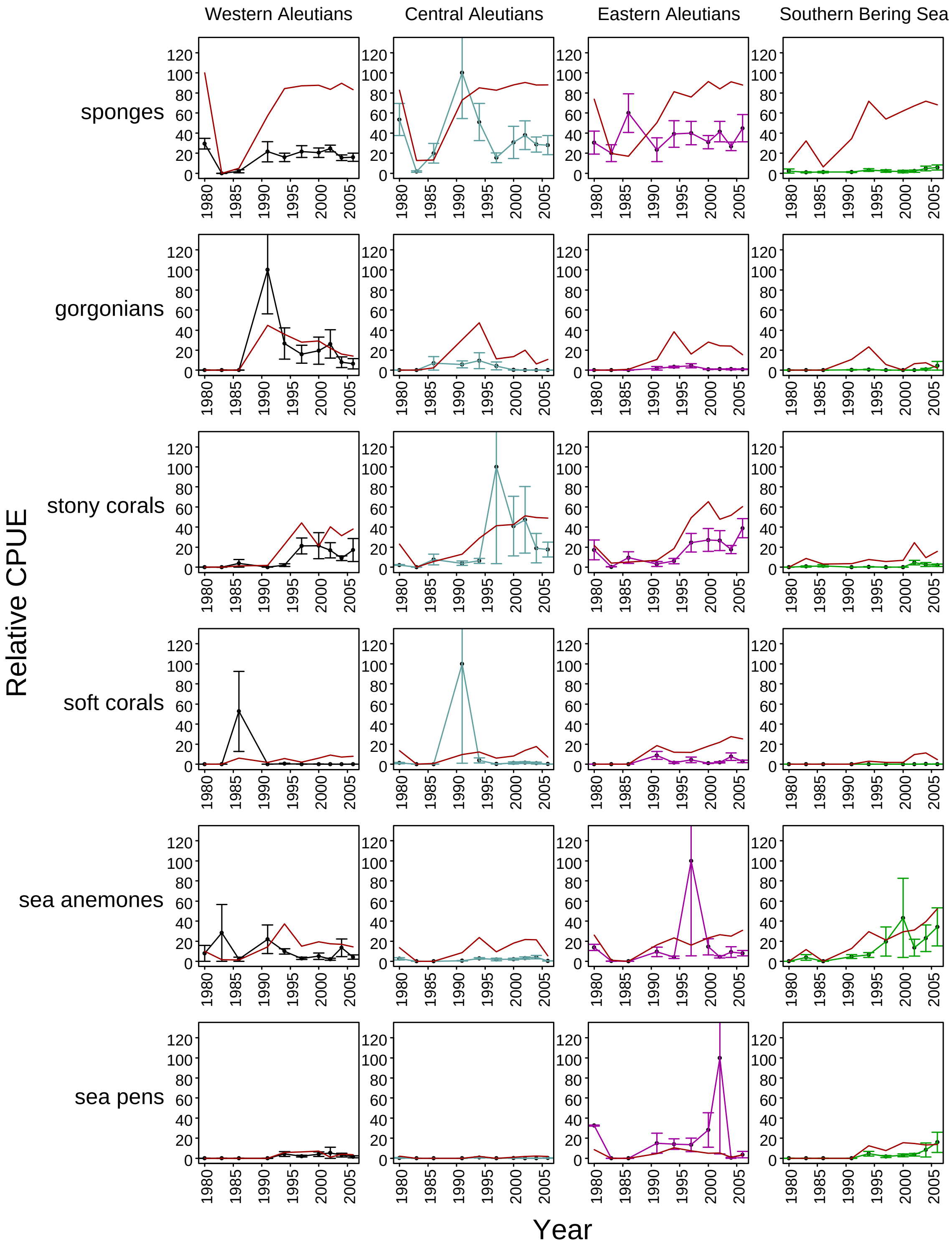

Figure 50. Relative mean CPUE of HAPC species groups by area from RACE bottom trawl surveys in the Aleutian Islands from 1980 through 2006. Error bars represent standard errors. The red line shows the percentage of all hauls that contained the species group.

Effects of Fishing Gear on Seafloor Habitat

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In 1996, the Alaska Fisheries Science Center (AFSC) initiated a number of seafloor habitat studies directed at investigating the effects of fishing on seafloor habitat (Table 7). Each year a progress report for each of the projects is completed. 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. Some of those studies are summarized in Appendix 2 along with studies of Essential Fish Habitat: Essential Fish Habitat Research by AFSC, and Effects of Fishing Gear on Seafloor Habitat – Progress Report for FY2004.

A web page http://www.afsc.noaa.gov/abl/MarFish/geareffects.htm has been developed that highlights these research efforts. Included in this web page are a research plan, previous progress reports, and a searchable bibliography on the effects of mobile fishing gear on benthic habitats. A list of recent publications follows Table 7.

Table 7. A list of habitat research projects, scientists, and contact information.

Project Title	Project Description	Location	Species Investigated	Habitat Investigated	Application to Management	Field/Lab Study	Contact
Submersible evaluation of eastern GOA corals	Determine distribution of *Primnoa* coral at pending and potential HAPC sites and study coral habitat ecology.	Eastern Gulf of Alaska	Corals, sponges, associated FMP species	Hard-bottom coral	HAPC delineation, defining EFH, evaluation of gear impacts	Field	Bob Stone (ABL)
Trawl sweep and footrope modifications to reduce seafloor effects	Investigation into the development of trawl gear to reduce the impacts of trawling on the seafloor	Bering Sea	Bering Sea flatfish & pollock and benthic invertebrates	Soft-bottom shelf	Reducing gear impacts	Field	Craig Rose (RACE)
Interannual and habitat-specific growth rates of northern rock sole	Importance of local habitat and regional oceanographic conditions on growth and survival	Northern Gulf of Alaska	Northern rock sole	Soft-bottom shelf	Defining EFH	Field	Hurst (RACE)
Atka mackerel spawning and nesting in the Aleutians	Investigaton of Atka mackerel spawning habitat/nesting and spawning behavior through use of video, diving, and time lapse photography.	Aleutian Islands	Atka mackerel	Hard-bottom	Defining EFH	Field	Bob Lauth (RACE)
Effects of experimental bottom trawling on soft-sediment sea whip habitat in the Gulf of Alaska	Determine immediate effects of bottom trawling on soft-sediment areas colonized by sea whips.	Kodiak	Sea whips and associated FMP species	Soft-bottom shelf	Gear impacts	Field	Bob Stone (ABL)
Sea whip resiliency to simulated trawl disturbance	Determine recovery of sea whips damaged by fishing gear	Southeast Alaska	Sea whips	Soft-bottom shelf	Gear impacts	Field and Lab	Pat Malecha (ABL)
Growth and recruitment of an Alaska shallow-water gorgonian coral	Assess growth and recruiment of *Calcigorgia spiculifera,* a habitat forming gorgonian coral.	Southeat Alaska	Gorgonian coral and associated FMP species	Hard-bottom coral	Dear impacts, mitigation.	Field	Bob Stone (ABL)
Video analysis of flatfish nursery habitat and gear impacts	Multivariate analysis of habitat utilization	Northern Gulf of Alaska	Flatfish	Soft-bottom shelf	Defining EFH	Field	Al Stoner (RACE)

Project Title	Project Description	Location	Species Investigated	Habitat Investigated	Application to Management	Field/Lab Study	Contact
Juvenile rockfish habitat associations	Examination of the abundance and habitat use of juvenile rockfish relative to small scale habitat features and multibeam/backscatter derived habitat type maps.	Southeast Alaska, Albatross Bank, Gulf of Alaska	Rockfish	Comprehensive - mostly offshore	Defining EFH	Field	Jon Heifetz and Kalei Shotwell (ABL)
Groundfish habitat associations	Examination of the abundance and habitat use of groundfish in fished areas relative to multibeam/backscatter derived habitat type maps.	Albatross Bank, Gulf of Alaska, Southeast Alaska	FMP species	Offshore banks	Defining EFH	Field	Jon Heifetz and Kalei Shotwell (ABL)
Aleutian Island corals and sponges	Coral and sponge ecology, taxonomy, and habitat distribution. Predictive model to determine extent of coral habitat.	Aleutian Islands	Corals, sponges, and associated FMP species	All habitats	Defining EFH, evaluation of gear impacts	Field	Bob Stone and Jon Heifetz (ABL)
Habitat Impacts Model	Model enables quantitative evaluation of mitigation strategies asnd the effects of fishing on benthic habitat.	Alaska EEZ	Comprehensive	Comprehensive	Comprehensive evaluation of gear impacts and mitigation measures	Lab	Jeff Fujioka (ABL)
Emergent structure in low-relief benthic habitats as criteria for defining EFH	Evaluate role of habitat structural complexity for flatfishes	Northern Gulf of Alaska	Flatfishes	Soft-bottom shelf	Test gear impacts and define EFH	Field & Lab	Cliff Ryer (RACE)
Defining EFH for Juvenile Flatfishes	Spatially explicit analysis of habitat utilization	Northern Gulf of Alaska	Flatfish	Soft-bottom shelf	Defining EFH	Field & Lab	Al Stoner (RACE)
Juvenile Lingcod EFH	Experimental evaluation of habitat utilization	NW & Alaska	Lingcod	Nearshore	Defining EFH	Field & Lab	Cliff Ryer (RACE)
Determining the value of habitat to juvenile rockfish in the Aleutian Islands	Mapping rockfish habitat and estimation of juvenile POP condition in study areas around the Islands of Four Mountains	Aleutian Islands	HAPC species and Pacific ocean perch	Hard and soft bottom offshore	Define EFH	Field	Chris Rooper (RACE)
Bogoslof Island mapping and colonization	Map island slopes (completed) and conduct ROV video census surveys of areas of different age eruptions	Bogoslof Island, southern Bering Sea	Long-lived sponge and corals	Hard-bottom	Determine proxy for hard-bottom sessile invert. recovery from bottom contact fishing gear.	Field	Mark Zimmermann (RACE)

Project Title	Project Description	Location	Species Investigated	Habitat Investigated	Application to Management	Field/Lab Study	Contact
Sediment database-usseabed	Combine historic sediment data in a database to define habitat	North Pacific	Habitat	All types	Help define seafloor habitat types	Lab	Mark Zimmerman (RACE)
Trawl database	Locate and enter historic trawl data to define habitat	North Pacific	Habitat	All types	Help define seafloor habitat types	Lab	Mark Zimmerman (RACE)
Groundfish habitat characterization	Develop statistical models to explain groundfish distribution and abundance.	Eastern Bering Sea	Most groundfish & benthic invertebrates	Offshore; soft-bottom shelf	Define EFH	Lab	RACE Habitat Research Team
Acoustic seabed mapping	Evaluate acoustical tools for characterizing seabed properties affecting the distribution and abundance of groundfish/benthic invertebrates. Develop processing methods for producing standardized quantitative measurements (data). Use statistical methods to compare costs and benefits of the various instruments and processing methods.	Eastern Bering Sea	Most groundfish & benthic invertebrates	Offshore; soft-bottom shelf	Define EFH and support effects of fishing investigations.	Both	RACE Habitat Research Team
Spatial and temporal patterns in Bering Sea invertebrates	Define distinct benthic communities as basis for systematic study of fishing gear effects on EFH.	Eastern Bering Sea	Epifauna and some infauna taken in RACE bottom trawl surveys.	Offshore; soft-bottom shelf	Define EFH and study effects of fishing gear on EFH.	Both	RACE Habitat Research Team
Bottom trawl effects on soft-bottom habitat	Quantify bottom trawl effects on soft-bottom habitat in naturally disturbed areas. Use experimental methods to study both long-term (chronic) and short-term (acute) disturbances, as well as recovery.	Eastern Bering Sea	Most groundfish & benthic invertebrates	Offshore; soft-bottom shelf	Effects of Fishing on EFH	Field	RACE Habitat Research Team

Project Title	Project Description	Location	Species Investigated	Habitat Investigated	Application to Management	Field/Lab Study	Contact
Identification of skate nursery areas in Bering Sea	The project will look at habitat use spatially and temporally and species and benthic associations to help characterize skate nurseries.	Eastern Bering Sea	Two species of skates, Alaska Skate Bathyraja parmifera and the Aleutian Skate Bathyraja aleutica	Offshore; soft-bottom shelf	Define EFH	Field	Jerry Hoff (RACE)
Statewide monitoring and mapping	Shorezone mapping coupled with fish assessments	Southeast Alaska in FY05, Prince William Sound in FY06, and other areas in future years	Plant and fish communities including juvenile FMP species	Nearshore	Define EFH	Field	Jeep Rice and Scott Johnson (ABL)
Berners Bay monitoring and mapping	Evalute impacts of mine development	Berners Bay, southeast Alaska	Plant and fish communities including juvenile FMP species	Nearshore	Evaluate mining development impacts	Field	Jeep Rice and Pat Harris (ABL)
Juneau Borough monitoring and mapping	Evaluate impacts of urban development	Juneau Borough, southeast Alaska	Plant and fish communities including juvenile FMP species	Nearshore	Evaluate urban development impacts	Field	Jeep Rice and Pat Harris (ABL)
Aleutian Islands monitoring and mapping	Define fish use in the Aleutian nearshore	Aleutian Islands	Plant and fish communities including juvenile FMP species	Nearshore	Define EFH	Field	Jeep Rice and Scott Johnson (ABL)
Beaufort Sea monitoring and mapping	Evaluate impacts of gravel extraction and shore erosion	Beaufort Sea	Plant and fish communities including juvenile FMP species	Nearshore	Evaluate impacts of gravel extraction to rebuild eroded beaches	Field	Jeep Rice and Scott Johnson (ABL)

Project Title	Project Description	Location	Species Investigated	Habitat Investigated	Application to Management	Field/Lab Study	Contact
Shorezone and Atlas	Combine shorezone mapping with fish utilization assessments	Southeast Alaska in FY06 and other areas in future years	Plant and fish communities including juvenile FMP species	Nearshore	Compendium of biotic and habitat information to assess potential development impacts, quantify habitat types, and monitor climate change effects	Lab	Jeep Rice (ABL)
Southeast Alaska Estuarine Habitat Survey	Describe estuarine fish habitat and estimate fish abundance by habitat type	Southeast Alaska	Substrate, plant and fish communities including juvenile FMP species	Estuaries	Define EFH and provide baseline information for habitat assessments	Field	Mitch Lorenz (ABL)

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Nutrients and Productivity

Nutrient and Chlorophyll Processes on the Gulf of Alaska Shelf

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The northern Gulf of Alaska shelf is a productive coastal region that supports several commercially important fisheries. The mechanisms supporting such high levels of productivity over this shelf however are not understood since it is a downwelling-dominated shelf. Furthermore, the annual nutrient cycle in this region was completely unknown prior to this research. In an effort to understand the mechanisms driving such high biological productivity cross-shelf nutrient distributions were sampled by the GLOBEC Long-term Observation Program (LTOP) 18 times throughout 1998, 1999 and 2000. Deep water (>75 m) nitrate, silicate and phosphate were positively correlated with salinity indicating an offshore nutrient source. The average annual cycle was established, in which nitrate, silicate and phosphate responded seasonally to physical and biological processes. Ammonium concentrations were generally low and uniform (<1.2 μM) with occasional patches of higher concentrations. Throughout the summer months, the upper 10-20 m across shelf was depleted of nitrate, silicate and phosphate over the inner and middle shelves and depleted of nitrate and phosphate over the shelf break and slope; however, just below this nutrient- poor layer the water column was nutrient-replete. During each summer, there was an onshore flux of dense nutrient-rich bottom water onto the shelf when the downwelling relaxed. This seasonal flux created a nutrient reservoir near the bottom of the inner and middle shelves. The reservoir was eventually mixed throughout the water column during the winter months. This annual evolution may be vital to the productivity of this shelf. There was a large degree of interannual variability among the three years, which included El Niño (1998) and La Niña (1999) years. Nutrient concentrations and phytoplankton chlorophyll biomass were generally highest in 2000, except in May 1999, when a large eddy traveling along the continental slope greatly enhanced phytoplankton chlorophyll biomass. Daily new production estimates based on nitrate disappearance averaged over the spring-summer season ranged from 2.46-6.97 mmol nitrate m^{-2} day^{-1}. Analysis of the LTOP data continues and will be updated with the final 2004 field season information.

Nutrients and Productivity Processes in the southeastern Bering Sea

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The southeastern Bering Sea shelf experienced dramatic changes in large-scale climate conditions and local weather conditions during 1997, 1998, and 1999. We investigated the changes in nutrient distribution and primary production in response to the changing physical condition over the shelf region (Rho et al. 2005). Temperature and salinity profiles showed that sea ice conditions and wind-mixing events strongly influenced hydrographic conditions. Biological utilization and physical process, such as horizontal advection below the pycnocline, played an important role in the distribution and interannual variation of nutrients. The distribution of temperature and ammonium across the shelf suggested that there was offshore transport of the middle shelf water at mid-depths over the outer shelf, which may export materials from the middle shelf to the outer shelf and shelf break. The distribution of carbon and nitrogen uptake rates showed large interannual differences due to variations in the development of stratification and nutrient concentrations that resulted from variations in sea ice dynamics and wind mixing over the shelf region. The occurrence of high ammonium in early spring may affect nitrate utilization and result in an increase of total primary production (Rho et al. 2005).

The timing of ice advance and retreat was favorable for an ice-edge phytoplankton bloom in 1997 but not in 1998 or 1999 (Rho et al. 2005). The early ice retreat in 1998 and 1999 in combination with strong wind mixing may have prevented the development of density-driven stratification, resulting in higher nitrate concentrations and a lack of an obvious spring bloom in those years (Rho et al. 2005). Conditions in 1998 and 1999, high ammonium concentrations and strong wind mixing, may have favored dinoflagellate growth (Rho et al. 2005).

Variations in phytoplankton and nutrients during fall 2000-2005 in the eastern Bering Sea- BASIS

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Last updated: November 2006

Oceanographic and fisheries data have been collected in the Eastern Bering Sea (EBS) during fall 2000-2005 for the U.S. component of a multiyear international research program, Bering-Aleutian Salmon International Survey (BASIS; Figure 51). Stations were located between 54°N and 68°N, at 30-60 km resolution, although spatial coverage varied by region and by year. Bristol Bay stations were sampled from mid August to early September during all six years. While, stations in the central and northern EBS were generally sampled from mid September to early October. Oceanographic data were obtained from vertical conductivity-temperature-depth (CTD) profiles and laboratory analyses of discrete water samples at select depths (2003, 2004, and 2005). Oceanographic variables include temperature, salinity, nutrients, chlorophyll a, and phytoplankton taxonomic characteristics (based on phytoplankton species identification and chlorophyll a size fractionation). A long-term goal of this research is to characterize interannual variations in the abundance and distribution of lower and higher trophic level organisms in relation to oceanographic features in the EBS (see the *Physical Environment* and *Forage Fish* sections of this report).

Upwelling through Unimak Pass provided nitrate that fueled phytoplankton growth, indicated by high surface chlorophyll a and nitrate in coastal waters near Amak I., south Bristol Bay in both 2003 and 2004 (Figure 52). Surface phytoplankton cells were generally small (< 10 µm) except in a few locations near-shore (where diatoms were likely abundant). High nitrate concentrations were seen below the pycnocline in the Middle Domain in Bristol Bay (Figure 51). Subsurface phytoplankton blooms were observed near the base of the pycnocline in Bristol Bay (mid August to early September) at depths where nitrate was replete. In contrast to Bristol Bay, low 40 m nitrate concentrations were observed below the pycnocline in the central EBS (mid to late September). High ammonium concentrations were observed below the pycnocline in low temperature waters (3.5 – 4 °C) in Bristol Bay (Figure 51). These ammonium values may provide a broad indicator of prior production over the growing season.

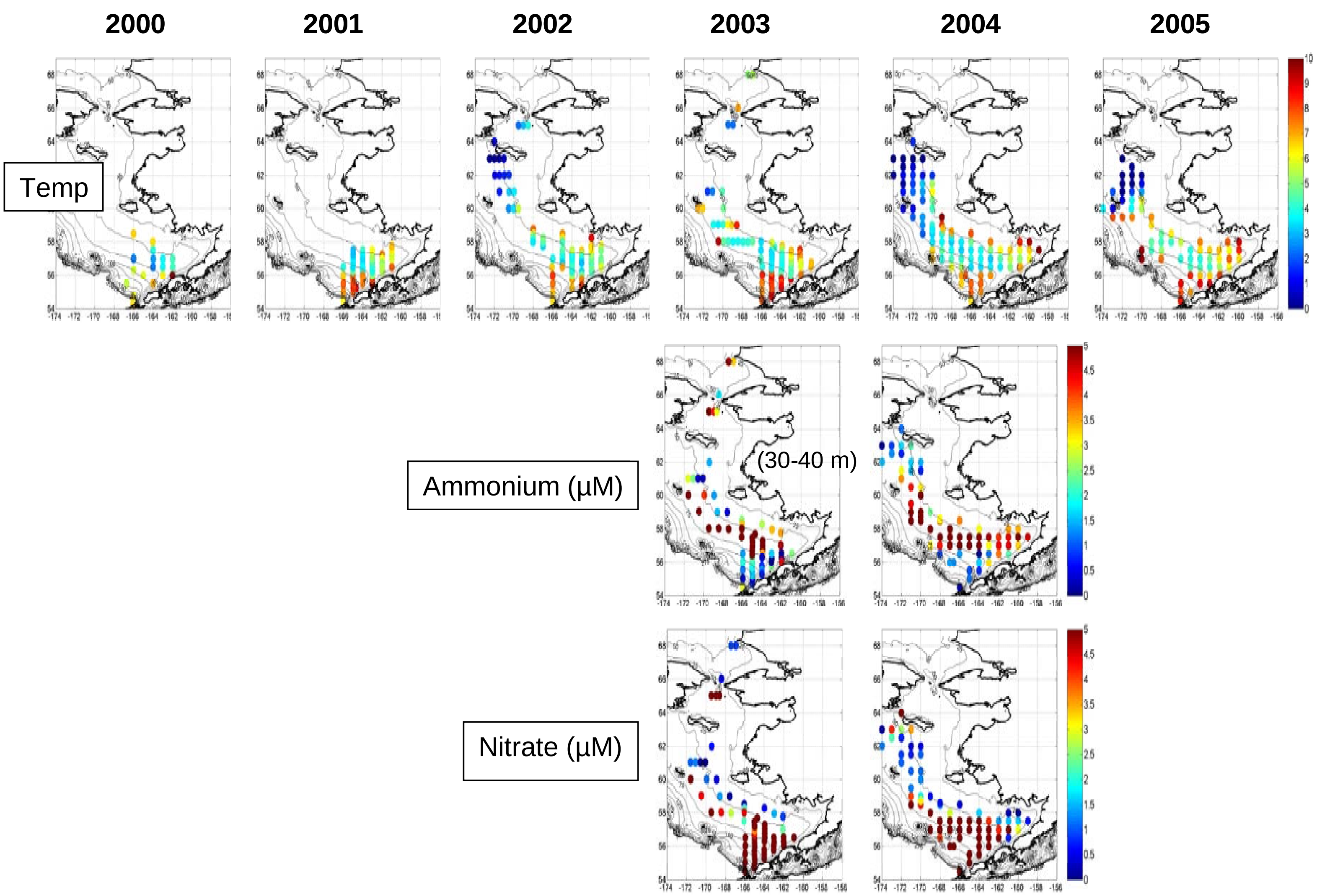

Figure 51. Deep (40 m, unless indicated) temperature, ammonium and nitrate concentrations during fall in the EBS.

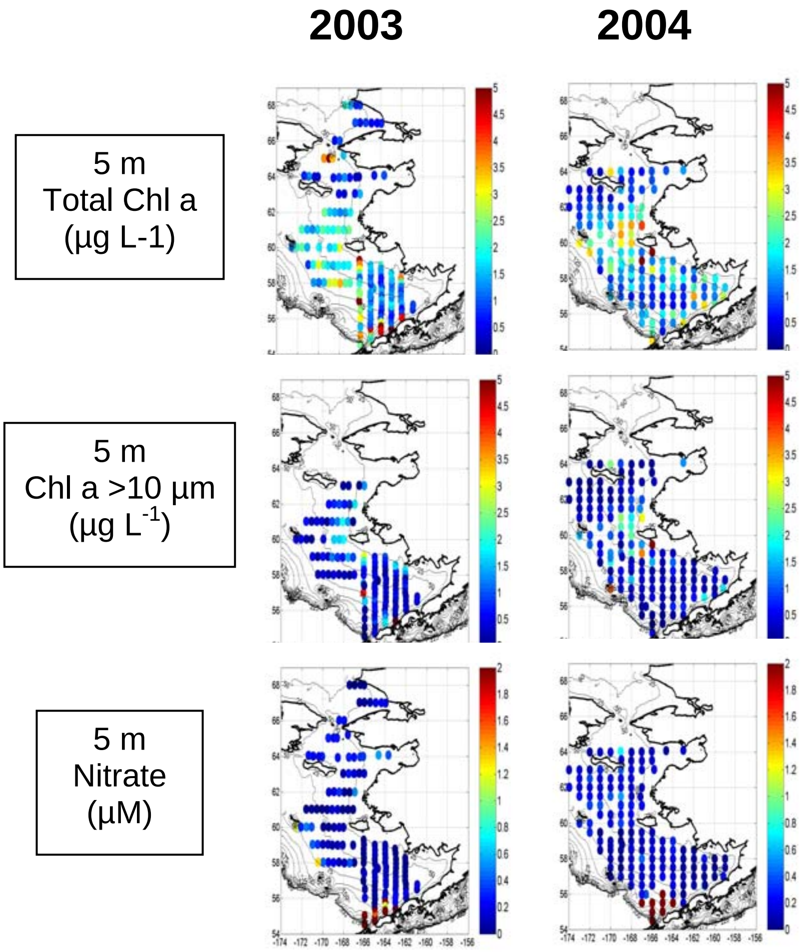

Figure 52. Surface (5 m) total chlorophyll a, chlorophyll a size fraction > 10 µm, and nitrate concentrations in the EBS during fall 2003 and 2004.

Zooplankton

Gulf of Alaska Zooplankton

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Last updated: August 2006

Description of index: Zooplankton samples were taken along the Seward Line from 1998 through 2003 during the production season in March, April, May, July, August and October as a part of GLOBEC LTOP research effort. Large zooplankton and micronekton were collected with a 1-m^2 MOCNESS (Wiebe et al. 1976) with 500 µm mesh nets. The net was fished at night and five oblique samples were collected in 20 m increments from 100 m depth to the surface.

Status and trends: Zooplankton on the northern GOA shelf contains a mixture of oceanic and neritic species common in the subarctic North Pacific (Cooney 1986, Incze et al. 1996, Napp et al. 1996, and Coyle and Pinchuk 2005). The oceanic community is dominated by large copepods (*Neocalanus* spp. and *Eucalanus bungii*) and is consistently observed in the Alaskan Stream and adjacent waters near the shelf break. *Neocalanus* copepods also commonly occur on the inner shelf, dominating in May, and there is a resident population in deep waters of Prince William Sound during all seasons. The neritic community occupies the inner shelf, Alaska Coastal Current and adjacent fjords and estuaries and comprises small and medium size copepods (*Pseudocalanus* spp., *Acartia* spp., *Centropages abdominalis*, *Calanus marshallae*, *Metridia* spp.). The mid-shelf transition zone contains a mixture of both oceanic and neritic species. The zooplankton community undergoes strong seasonal changes (Figure 53). Large interzonal copepods of the genera *Neocalanus* and *Eucalanus* dominate zooplankton biomass on the GOA shelf in spring and early summer (Incze et al. 1996, Coyle and Pinchuk 2003, and Cooney et al. 2001). The *Neocalanus* species complete their foraging cycle and begin migrating to overwinter depths in the mesopelagic zone in May and June (Tsuda et al. 1999, and Kobari and Ikeda 2001a,b). Their contribution to zooplankton biomass in the upper mixed layer therefore declines and they are largely absent from shelf water by July and August (Cooney et al. 2001, and Coyle and Pinchuk 2003). In contrast the highest population densities of the neritic species are observed in mid-summer. In addition, cnidarians, including scypho- and hydrozoans as well as ctenophores, often develop large blooms in fall, dominating zooplankton biomass (Coyle and Pinchuk 2003).

Although copepods dominate mesozooplankton biomass throughout the production season both in shelf and oceanic domains (Figure 54), larger micronektonic species are common and can be important components in the diets of fish and other large predators (Boldt and Haldorson 2003, Coyle and Paul 1992, and Albers and Anderson 1985). The most abundant micronekton species on the northern GOA shelf include euphausiids, which are the second dominant group in terms of biomass averaged annually, hyperiid and gammaridean amphipods, and some shrimp species (Incze et al. 1996, and Sugisaki et al. 1998). The euphausiid fauna of the northern GOA comprises seven species of which three are predominant: neritic *Thysanoessa inermis*, *T. spinifera*, and oceanic *Euphausia pacifica* (Coyle and Pinchuk 2003). The boundary separating the shelf *T. inermis* and *T. spinifera* species from the oceanic domain lies along the shelf break 120-130 km offshore (Figure 55), although the exact position and structure of the shelf break front is often altered by wind forcing and the passage of large mesoscale eddies (Musgrave et al. 1992, and Okkonen et al. 2003). In contrast, *E. pacifica* was most abundant beyond 150 km from shore. However, the cross-shelf distribution of *E. pacifica* also showed substantial seasonal variability: in spring (March-May) it was virtually absent from the shelf, but was abundant over the slope, while by the end of the summer it appeared on the shelf in quantities similar to those beyond the shelfbreak.

Factors causing observed trends: In summer the attachment of the bottom-advected front separating buoyant shelf water from homogeneous offshore water migrates onshore until it reaches an equilibrium isobath (Weingartner et al. 2005). Since GOA shelf depths usually drop to ~150 m within a few kilometers of the coast, the shoaling of the equilibrium isobath allows the saline waters to move inshore along the bottom. Effectively, this not only traps euphausiids originating from the shelf, but provides a mechanism whereby offshore species can be moved onto the shelf. Substantial amounts of *E. pacifica* usually occurring on the shelf in the summer coincide with the development of the deep onshore flow. Since *E. pacifica* undergo extensive diel vertical migrations, spending most of the daytime below 100 m depth (Lu et al. 2003), the shoreward migration of bottom water during summer is probably an important conduit for *E. pacifica* from offshore to onshore. Other mechanisms might include flow up canyons intersecting the shelfbreak (e.g. Allen 2000), topographically induced upwelling (Freeland & Denman 1982), and shelf break eddies and flow meanders forming primarily in years of anomalously strong cyclonic winds (Bower 1991, Meyers and Basu 1999, Crawford and Whitney 1999, and Okkonen et al. 2003). Analysis of seasonal changes in pollock diet from the northern GOA inner shelf showed an increasing role of *E. pacifica* as a prey item in August (Adams et al. in review), indicating that the summer influx of *E. pacifica* on the shelf might have important consequences for shelf
biota.

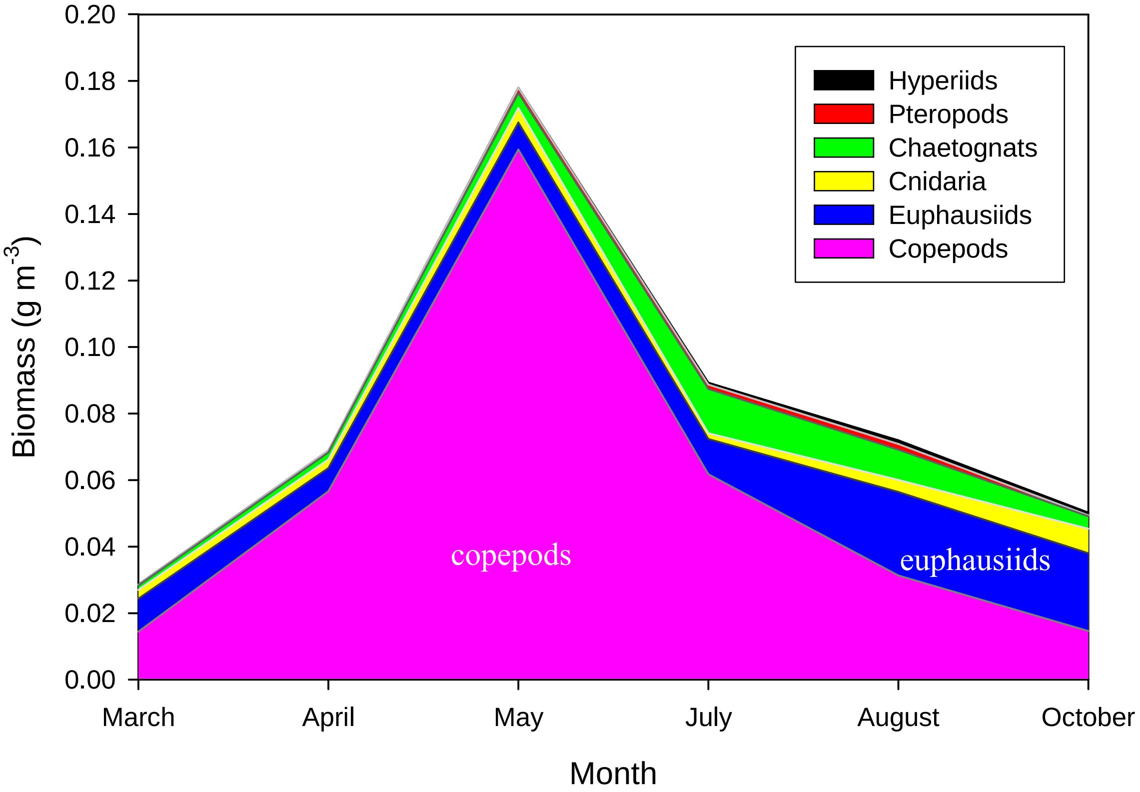

Figure 53. Seasonal changes in zooplankton biomass along the Seward Line in 1998-2003.

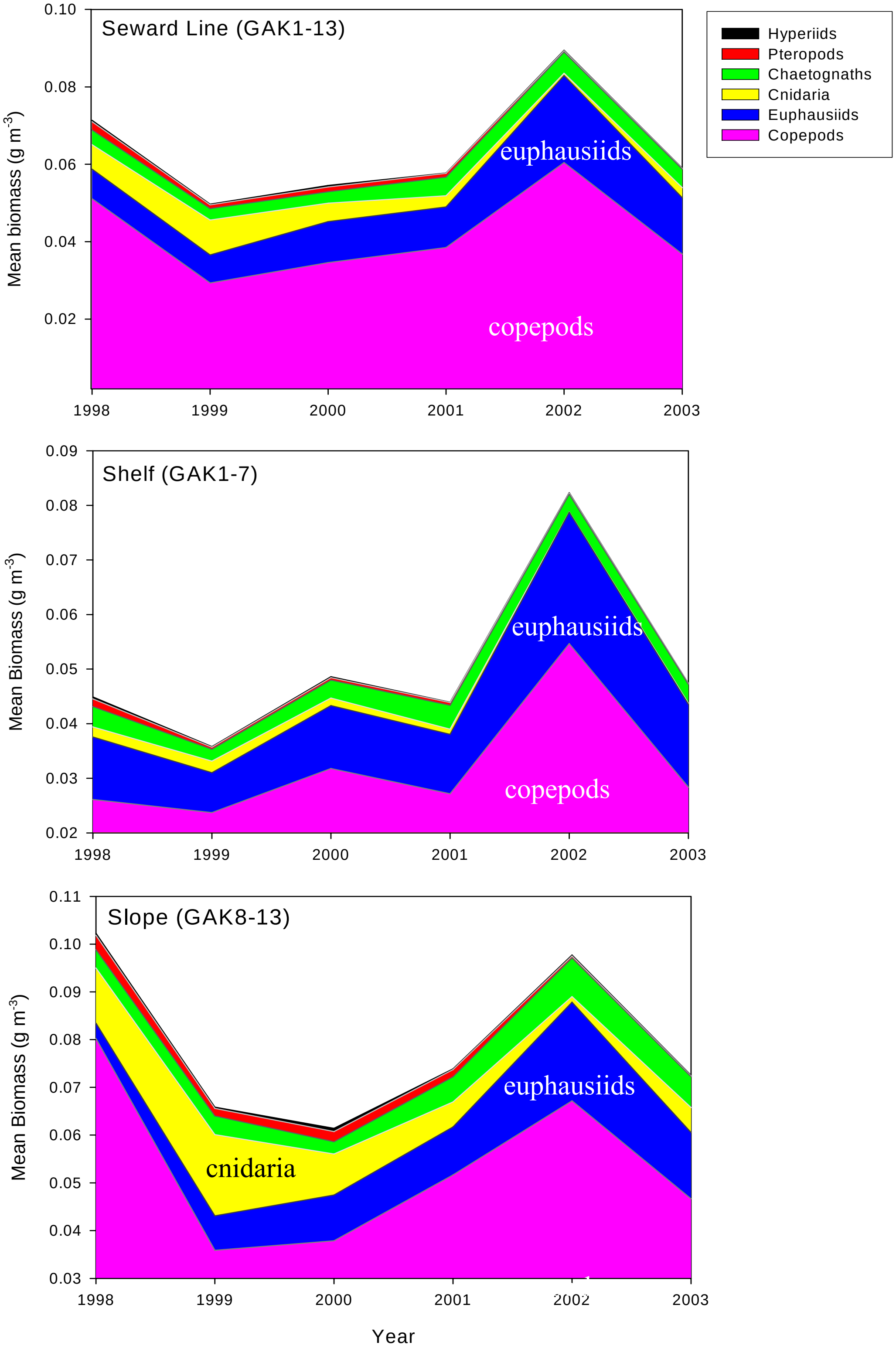

Figure 54. Interannual changes in biomass of major zooplankton taxa along the entire Seward Line, on the shelf and over the slope.

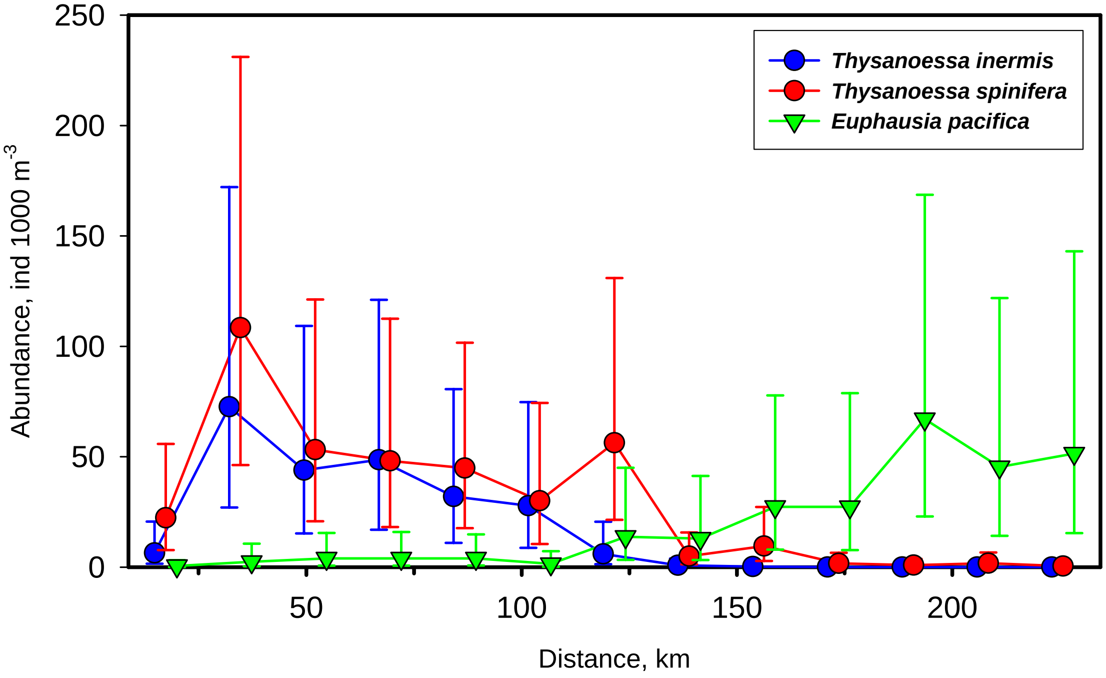

Figure 55. Cross-shelf distribution of major euphausiid species collected along the Seward Line in 1998-2003.

Bering Sea Zooplankton

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Last updated: September 2005

Summer zooplankton biomass data are collected in the eastern Bering Sea by the Hokkaido University research vessel T/S Oshoru Maru. The cruises began in 1954 and continue today. The time series (up to 1998) was re-analyzed by Hunt et al. (2002) and (Napp et al. 2002) who examined the data by oceanographic domain. The figure below updates the time series to 2004 and presents the data as biomass (wet weight) anomalies over the time period sampled. Up to 1998 there were no discernable trends in the time series for any of the four geographic domains (Napp et al. 2002). However, the updated time series depicts a strong decrease in biomass in the past 5 years (negative anomalies in these plots). What is remarkable is that the decrease occurred in all four domains (Figure 56). Part of the decrease in biomass over the middle shelf may be due to recent decreases in the abundance of *Calanus marshallae*, the only “large” copepod found in that area (Napp, in prep.). It is not clear what might be the cause of declines in other regions.

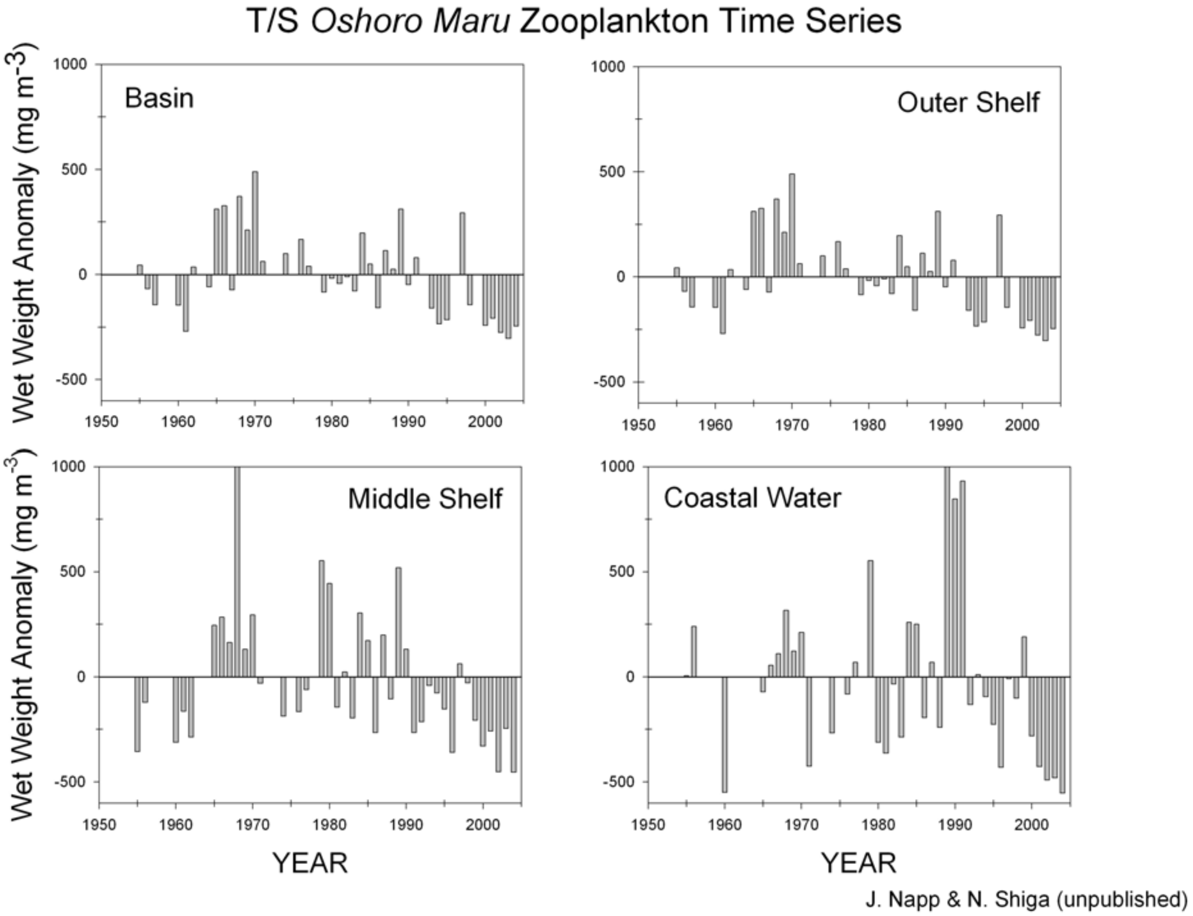

Figure 56. Zooplankton biomass anomalies at stations in regions of the deep basin of the Bering Sea and in the outer, middle and coastal domains of the southeastern Bering Sea shelf sampled during the T/S Oshoro Maru Summer Cruises. Data from 1977 to 1994 from Sugimoto and Tadokoro (1998). Data from 1995 to 2004 from Dr. N. Shiga.

Forage Fish

Exploring Links between Ichthyoplankton Dynamics and the Pelagic Environment in the Northwest Gulf of Alaska

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Last updated: August 2006

This particular contribution to the Ecosystem Considerations document represents the culmination of this study and the analyses and results have evolved since last year's contribution to the 2005 document.

The impact of climate on marine fisheries is highly variable, and year-to-year recruitment is subject to a complex interplay of influences. Potentially, much of this complexity stems from the impact of environmental conditions during the early life history of marine fish species. The present study focuses on a 21-year time-series of larval fish abundance in late-spring surveys from 1981 through 2003 (no data for 1984 and 1986) in the northwest Gulf of Alaska. In combination with basin and local-scale measures of the state of the atmosphere and ocean in the Gulf of Alaska during these years, links between fish early life history dynamics and the physical environment are explored.

Ichthyoplankton data were selected from an area and time (May 16-June 6) that had the highest sampling density and the most consistent sampling over the years. Numerically dominant species were used in the analysis (Table 8). The environmental data time-series includes climate indices, and atmospheric and oceanographic variables representative of both the broader basin of the Gulf of Alaska and northeast Pacific Ocean, and the local study area (Table 9). The influence of environmental conditions on the abundance and survival of various species of fish larvae is likely to be significant from the initial production of the eggs (predominantly winter to early spring in the Gulf of Alaska) through the period of late larval development, weeks to months later. Consequently, both time-lagged and survey time values of the environmental time-series were included in the analysis (Table 9). Relationships between larval fish abundance and environmental factors were examined using Generalized Additive Modeling (GAM). GAM is a form of non-parametric multiple regression that models a response variable as a function of several predictor variables. For each group of environmental variables (basin and local-scale), GAMs were run for individual species with every possible combination and subset of variables. Best-fit models were selected using generalized cross validation methods (Green and Silverman, 1994).

Interannual patterns in abundance of the larval fish species are presented in Figure 57 and a summary of the GAM analyses by species, variables and months is given in Table 10. The emergent associations between larval species and physical variables indicate that larval abundance in late spring is linked to species-specific combinations of environmental variables, with seasonal variation in linkages apparent (Table 10), and that the nature of the connections between larval abundance and physical variables reflects details of individual species early life history strategies. For instance, in the case of Pacific sandlance the strongest model to emerge from the analysis was the connection between late May larval abundance and local conditions in March (all local scale variables contributing to the model), the period of peak emergence of larvae from eggs incubated in coastal sediments over winter months. The implication in terms of recruitment success, or at least survival to the early juvenile stage, is that the primary period of vulnerability for this species during its early life history is the period of hatching and early exposure of yolk-sac larvae to the pelagic environment. Conversely, the overall connections between starry flounder larvae and the environmental variables were very weak reflecting the limited planktonic stage of this species (transformation to the juvenile stage and settlement occurs at 8-10.5 mm length). The latter observation suggests an early life history strategy of resilience to the pelagic environment, with limited environmental control of recruitment occurring during the larval phase. In Figure 58, species are ranked according to the total significant contributions of the two groups of physical variables to all monthly best-fit GAM models. We would like to propose this ordering of species as a gradient of early life history vulnerability to the physical environment with Pacific cod as the species displaying the strongest links, and therefore vulnerability, to the physical environment and starry flounder showing the weakest connections, implying the greatest resilience.

Summarizing the results across species, the relative influence of the different environmental variables on larval fish abundance in late spring is implied (Tables 11 and 12). For both the basin-scale and the local-scale variables, the combined contributions of the variables to the 12 best-fit species models is strongest for the April values relative to the other months. Seasonal variation in influence of the variables seems most pronounced for the EP-NP Index and the

Alongshore Wind Index both with strong connections between spring values and species abundance, and for the Freshwater Index that is primarily connected by the winter values. Ranking the variables according to their overall level of contributions to the species best-fit models (Table 11), it seems that basin-scale atmospheric circulation during spring (EP-NP Index) and the related local-scale spring wind conditions (Alongshore Wind Index) impart the strongest influence on the prevalence of various larval fish species in the favorable productive coastal waters of Shelikof Strait in late May. Influence of larval transport by atmospheric forcing of Alaska Coastal Current dynamics during April and May seems the most likely mechanism of environmental control of spring larval abundance in this instance. River discharge (Freshwater Index) during winter months and Sea Surface Temperature for winter and spring months also rank highly in terms of their potential influence on larval abundance in late May. The former is most likely to affect larval abundance and survival by flushing eggs and larvae from coastal waters during winter and also by influencing Alaska Coastal Current dynamics and subsequent larval transport. The persistent seasonal link with Sea Surface Temperature reflects a negative association with winter water temperature for certain species (walleye pollock, Pacific cod and northern rock sole), a link with spring water temperature for some (northern lampfish and negative link for Pacific halibut), and a positive association with spring water temperature for others (rockfish and southern rock sole) (Table 10). In this instance, likely mechanisms of control on larval abundance in late spring are the potential influence of temperature on the timing of egg and larval production and the physiology of egg and larval development.

Although individual species display unique patterns of periodicity and amplitude of variation in the time-series of late spring larval abundance, there are also common patterns that emerge (Figure 57) and it is interesting to investigate these similar patterns with respect to shared variable connections and early life history strategies among species (Tables 10 and 13). The degree of within group similarities in variable connections and early life history traits among the four species groups identified (Figure 57 and Table 13) suggest common mechanisms of environmental control on prevalence of larvae in late May for the constituent species. A more detailed discussion of these observations will be included in the manuscript that is presently being prepared for publication.

This type of ichthyoplankton time-series study is valuable in two major respects. It has good potential for assessing the degree of vulnerability or resilience of individual species early life history patterns to fluctuating climate and oceanographic conditions. It also provides crucial information to help identify “environmental indicators” that may have a broad-spectrum effect on multiple species early life history stages as well as those that may be more species-specific in exerting control on early life history survival.

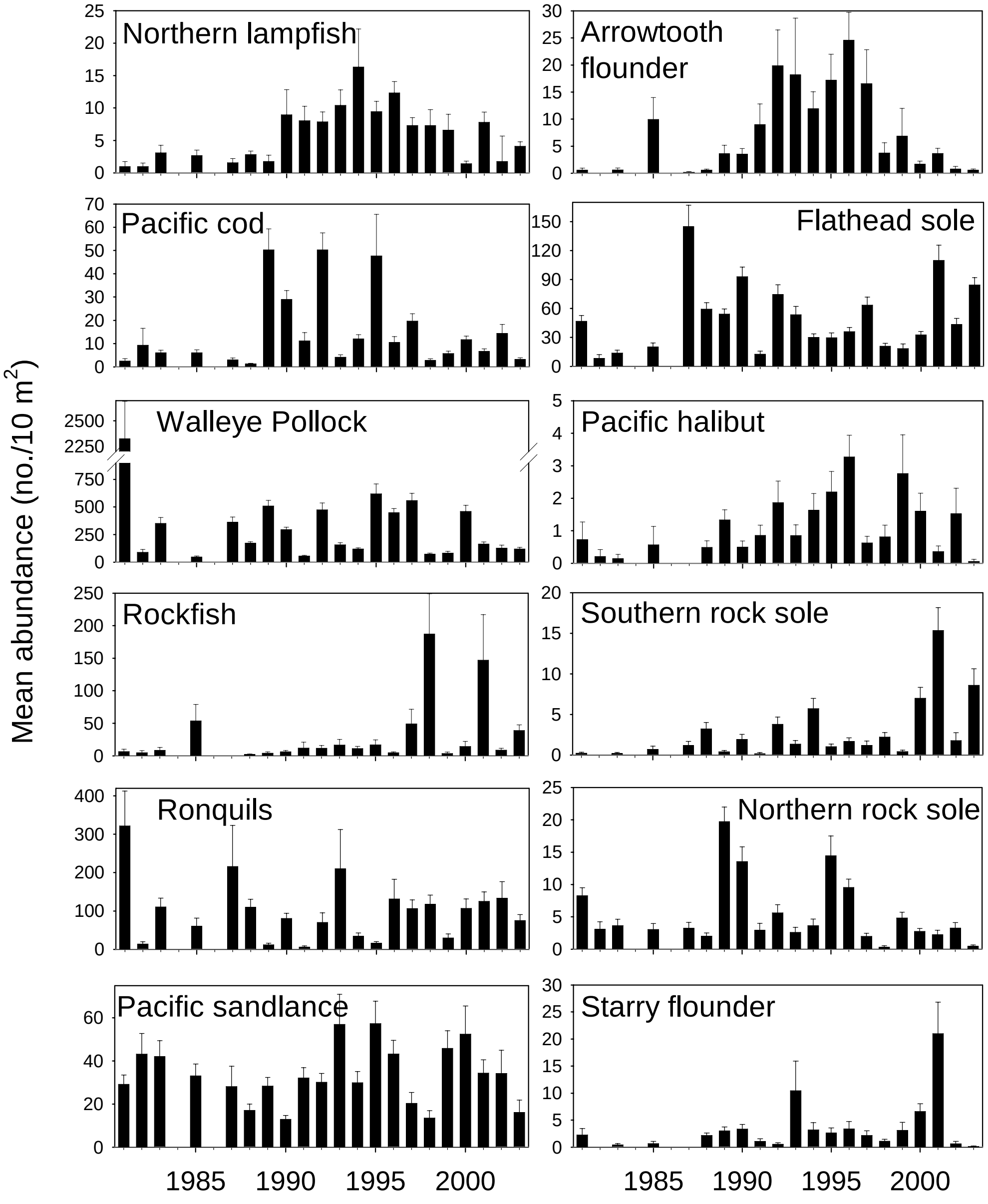

Figure 57. Interannual time-series of larval abundance based on ichthyoplankton collections in the vicinity of Shelikof Strait, Gulf of Alaska, May 16-June 6. No data for 1984 and 1986.

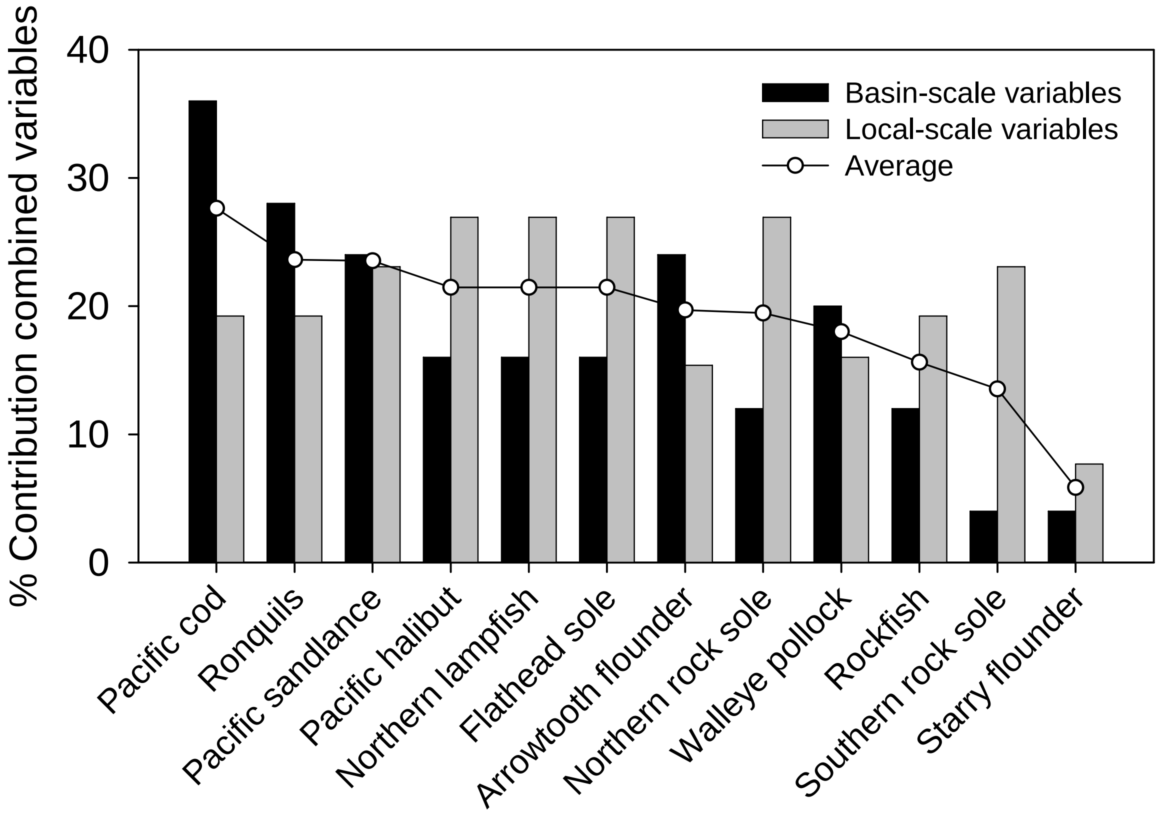

Figure 58. Gradient of vulnerability of species early life history patterns to the Gulf of Alaska physical environment based on the Generalized Additive Modeling results.

Table 8. Numerically dominant species of fish larvae included in the study, ranked according to percentage occurrence in the study area during late spring for all years combined.

Species	Common name	% Occurrence	Mean abundance (no./10m^2)
Theragra chalcogramma	Walleye pollock	90.18	362.11
Hippoglossoides elassodon	Flathead sole	76.57	50.01
Ammodytes hexapterus	Pacific sandlance	75.15	33.38
Bathymaster spp.	Ronquils (genus *Bathymaster*)	66.43	99.42
Gadus macrocephalus	Pacific cod	49.78	14.65
Lepidopsetta polyxystra	Northern rock sole	35.05	5.29
Stenobrachius leucopsarus	Northern lampfish	33.03	5.88
Sebastes spp.	Rockfishes	30.99	29.03
Lepidopsetta bilineata	Southern rock sole	20.55	2.77
Atheresthes stomias	Arrowtooth flounder	18.79	7.32
Platichthys stellatus	Starry flounder	18.56	3.24
Hippoglossus stenolepis	Pacific halibut	10.00	1.07

Table 9. Environmental variables included in GAM analysis (abbreviation on left), source of data and associated reference. Monthly mean values for January through May were used in all instances except for FLOWKL8 and RI. SPEM model output is unavailable prior to March so the latter variables are represented by March through May means.

Variable name		Source	Reference
1. Basin Scale Variables			
PDO	Pacific Decadal Oscillation (Leading pattern of North Pacific SST)	Joint Institute for the Study of the Atmosphere and Ocean, University of Washington.	Mantua et al., 1997.
NP	North Pacific Index (Intensity of the mean winter Aleutian Low pressure cell)	NOAA - National Center for Atmospheric Research	Trenberth and Hurrell, 1994.
AO	Arctic Oscillation Index (See-saw pattern of polar-middle latitude atmospheric pressure)	NOAA - Climate Prediction Center	Thompson and Wallace, 1998.
EP-NP	East Pacific - North Pacific Index (Leading mode of North Pacific atmospheric variability in spring)	NOAA - Climate Prediction Center	Barnston and Livezey, 1987.
MEI	Multivariate ENSO Index (See-saw pattern of tropical sea level pressure, East-West Pacific.)	NOAA - Climate Diagnostics Center	Wolter and Timlin, 1998.
2. Local Scale Variables			
FRESH	GOA River Discharge	Tom Royer	Royer et al., 2001
ALONG	Alongshore Wind Index, 59°N, 150°W	Calculated from coastal wind data at Gore Point	Stabeno et al., 2004.
MIXING	Wind Mixing Index (wind speed cubed)		
SST	Sea Surface Temperature (SST) 57.5°N,155.5°W	NOAA - Climate Prediction Center	Reynolds and Smith, 1994.
FLOWKL8	Flow through Line 8, Kodiak side (Proxy for transport up the sea valley)	Computed from the SPEM circulation model	Hermann and Stabeno, 1996.
RI	Retention Index (Percent particles released in study area not lost to advection in 15 days)		

Table 10. Results of GAM analysis for late spring larval species abundance versus monthly mean basin-scale variables (top half of list), and local-scale variables (bottom half of list). R2 values and levels of variable significance are for best-fit GAM models for each species and month combination. Blank columns indicate weak best-fit models with insignificant level of contribution (at P>0.05) from constituent variables.

Northern lampfish

Variables	Jan	Feb	Mar	Apr	May
PDO					
NP			■	Neg	Pos
AO			▨		▨
EP-NP			■		
MEI					
R^2(adj)	0.05	0.15	0.41	0.22	0.26
SST				▨	■
ALONG	▨			Pos	■
MIXING	Neg				■
FRESH					■
FLOWKL8	⧄	⧄		Pos	
RI	⧄	⧄			▨
R^2(adj)	0.38	0.05	0.09	0.34	0.70

Ronquils

Variables	Jan	Feb	Mar	Apr	May
PDO	Pos	■		Pos	
NP	■		Neg		
AO	▨			Pos	
EP-NP	■			▨	
MEI					
R^2(adj)	0.49	0.17	0.26	0.45	0.17
SST			▨	■	■
ALONG			■		
MIXING					
FRESH			Pos		
FLOWKL8	⧄	⧄		Neg	
RI	⧄	⧄			
R^2(adj)	0.13	0.19	0.81	0.52	0.53

Starry flounder

Variables	Jan	Feb	Mar	Apr	May
PDO					
NP			▨		
AO					
EP-NP			■		
MEI					
R^2(adj)	0.07	0.04	0.27	-0.01	0.04
SST					
ALONG					■
MIXING					
FRESH		Pos			
FLOWKL8	⧄	⧄			
RI	⧄	⧄			▨
R^2(adj)	0.18	0.45	0.03	0.05	0.33

Pacific cod

Variables	Jan	Feb	Mar	Apr	May
PDO		Neg			
NP		■		Pos	
AO		Pos	Pos	Neg	▨
EP-NP				Pos	Pos
MEI		Pos			
R^2(adj)	0.16	0.66	0.19	0.70	0.33
SST		Neg			
ALONG			■	■	
MIXING					
FRESH			■		
FLOWKL8	⧄	⧄			
RI	⧄	⧄		■	
R^2(adj)	0.04	0.17	0.50	0.48	0.05

Pacific sandlance

Variables	Jan	Feb	Mar	Apr	May
PDO		■	■		Neg
NP		▨	■		
AO			▨		Neg
EP-NP					■
MEI					
R^2(adj)	0.16	0.28	0.35	0.21	0.42
SST	▨		▨		
ALONG			■		
MIXING			■		
FRESH	Neg		Neg		
FLOWKL8	⧄	⧄	■		
RI	⧄	⧄	Neg		
R^2(adj)	0.37	0.21	0.65	0.03	0.27

Pacific halibut

Variables	Jan	Feb	Mar	Apr	May
PDO			▨		▨
NP					
AO				Neg	
EP-NP			■		Pos
MEI				Neg	
R^2(adj)	0.11	0.21	0.37	0.40	0.17
SST				Neg	
ALONG				Pos	
MIXING			▨	■	
FRESH		Neg	Neg	■	
FLOWKL8	⧄	⧄		■	
RI	⧄	⧄		▨	
R^2(adj)	0.15	0.16	0.33	0.82	0.03

Walleye pollock

Variables	Jan	Feb	Mar	Apr	May
PDO					
NP		■			
AO		Pos		Neg	
EP-NP				Pos	Pos
MEI					
R^2(adj)	0.07	0.50	0.02	0.50	0.40
SST	Neg				
ALONG	▨		■	■	
MIXING	▨				
FRESH					
FLOWKL8	⧄	⧄			
RI	⧄	⧄		■	
R^2(adj)	0.31	0.23	0.23	0.42	0.04

Arrowtooth flounder

Variables	Jan	Feb	Mar	Apr	May
PDO		■		Neg	
NP				Neg	▨
AO				Neg	▨
EP-NP				■	Pos
MEI					
R^2(adj)	0.01	0.31	0.23	0.69	0.34
SST					
ALONG	Pos			Pos	
MIXING	Neg				
FRESH	Neg				
FLOWKL8	⧄	⧄			
RI	⧄	⧄			
R^2(adj)	0.58	0.06	0.15	0.66	0.03

Southern rock sole

Variables	Jan	Feb	Mar	Apr	May
PDO					
NP			▨		
AO					
EP-NP			■		
MEI					
R^2(adj)	0.02	-0.03	0.26	0.02	0.09
SST			Pos	Pos	
ALONG		▨			■
MIXING				▨	
FRESH	Pos	Pos			
FLOWKL8	⧄	⧄		Pos	
RI	⧄	⧄			▨
R^2(adj)	0.20	0.60	0.16	0.47	0.45

Rockfish

Variables	Jan	Feb	Mar	Apr	May
PDO					
NP					Pos
AO	Neg				
EP-NP					■
MEI					▨
R^2(adj)	0.22	0.05	0.03	0.00	0.55
SST		Pos	Pos	Pos	▨
ALONG	▨				■
MIXING	▨				
FRESH	■				
FLOWKL8	⧄	⧄			
RI	⧄	⧄			
R^2(adj)	0.44	0.38	0.62	0.37	0.50

Flathead sole

Variables	Jan	Feb	Mar	Apr	May
PDO	Pos				
NP	▨				
AO	■				
EP-NP	Neg				
MEI	■				
R^2(adj)	0.79	0.01	0.22	0.19	0.13
SST				▨	
ALONG		■			
MIXING		Pos	▨		
FRESH	■	Pos	Pos		
FLOWKL8	⧄	⧄		■	
RI	⧄	⧄			■
R^2(adj)	0.22	0.58	0.26	0.45	0.31

Northern rock sole

Variables	Jan	Feb	Mar	Apr	May
PDO					
NP					
AO		Pos			
EP-NP				Pos	■
MEI				▨	▨
R^2(adj)	0.11	0.46	0.15	0.32	0.41
SST		Neg	Neg	■	Neg
ALONG				Pos	
MIXING			■	■	
FRESH					
FLOWKL8	⧄	⧄			
RI	⧄	⧄			
R^2(adj)	0.00	0.26	0.66	0.56	0.20

■ variable contribution to model significant at P<0.05
Pos variable effect positive
☐ variable absent from model
▨ variable contribution to model insignificanr at P$\geq$0.05
Neg variable effect negative
⧄ data unavailable

Table 11. Total significant contributions (at P<0.05) of variables by month to 12 best-fit species models.

Variables	Months **Jan**	**Feb**	**Mar**	**Apr**	**May**	% Contribution Months combined
Basin-scale						
EP-NP	2	0	4	4	7	28.33
AO	2	3	1	5	1	20.00
NP	1	2	3	3	2	18.33
PDO	2	4	1	2	1	16.67
MEI	1	1	0	1	0	5.00
% Contribution Total variables	13.33	16.67	15.00	25.00	18.34	17.67
Local-scale						
ALONG	1	1	4	6	4	26.67
FRESH	5	4	5	1	1	26.67
SST	1	3	3	5	3	25.00
FLOWKL8	no data	no data	1	5	0	16.67
MIXING	2	1	2	2	1	13.33
RI	no data	no data	1	2	1	11.11
% Contribution Total variables	18.75	18.75	22.22	29.17	13.89	20.83

Table 12. Ranking of variables in terms of overall level of contribution (at P<0.05) to best-fit GAM models, and number of species to which the variable was linked.

Variable	% Contribution	No. of Species
EP-NP	28.33	12
ALONG	26.67	12
FRESH	26.67	10
SST	25.00	8
AO	20.00	9
NP	18.33	7
PDO	16.67	5
FLOWKL8	16.67	6
MIXING	13.33	6
RI	11.11	4
MEI	5.00	3

Table 13. Common linkages with physical variables relative to interannual patterns in species abundance, and exploration of potential mechanisms of environmental forcing on late spring larval abundance in the vicinity of Shelikof Strait, Gulf of Alaska.

Species	Interannual Trend Group	Variable Connections in Common	Shared Early Life History Strategy Traits for GOA Populations	Likely Primary Vulnerability during Early Life History
Northern lampfish Arrowtooth flounder Pacific halibut	Decadal pattern of highest levels of abundance during 1990s.	Primarily positive with spring EP-NP and ALONG. Negative with winter FRESH (A. flounder, P. halibut). Spring SST (N. lampfish and negative for P. halibut.)	Winter-spring spawning deep water. Mesopelagic eggs. Shoreward and along-shelf larval drift.	Shoreward transport variability (A. flounder and P. halibut). Limited food availability winter-early spring.
Pacific cod Walleye pollock Northern rock sole	Occasional anomalous years of high levels of abundance, late 80s to mid 90s.	Positive with spring EP-NP. Mar-Apr ALONG. Negative with winter SSTs. Positive with Feb AO.	Late winter-early spring spawning in shelf waters on or close to bottom. April peak in larval abundance. Larval size range and duration similar. Along-shelf larval drift.	Spring larval transport variability. Anomalous high winter temps. Limited food availability winter-early spring.
Rockfish Southern rock sole Starry flounder	Trend of increasing abundance towards the end of the time-series.	March or May EP-NP, May ALONG. Positive with Mar-Apr SST (Rockfish, S. rock sole). Positive winter FRESH (S. rock sole, Starry flounder).	Late spring-summer spawning (Rockfish, Southern rock sole). Dispersal from shallow water (S. rock sole, S. flounder), shoreward from slope (rockfish). Along-shelf larval drift.	Spring larval transport variability. Diminished winter river discharge (S. rock sole, Starry flounder). Anomalous low early spring temps (Rockfish, Southern rock sole).
Ronquils Flathead sole	Greatest amplitude of variation in abundance 1980 through early 1990s. Moderately abundant mid-90s through 2003.	Strongest connections with Jan basin-scale variables including positive with PDO. Positive with late winter FRESH. April FLOWKL8.	Late winter-summer spawning with peak larval abundance May-June and larvae present in plankton through October. Along-shelf larval drift.	Winter atmospheric variability and negative PDO anomalies prior to spawning. Diminished winter river discharge.

Variations in distribution, abundance, diet, and energy density of age-0 walleye pollock, *Theragra chalcogramma*, in the eastern Bering Sea

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Last updated: November 2006

Over the past 30 years, a considerable amount of research has been conducted on larval and juvenile walleye pollock, *Theragra chalcogramma*, in the Bering Sea and Gulf of Alaska. Much of the work in the Bering Sea has focused on habitat, prey abundance, bioenergetics, and oceanographic conditions in areas surrounding the Pribilof Islands, an area known for high abundance of age-0 pollock (Ciannelli et al. 1998, Napp et al. 2000, Brodeur et al. 2000, Ciannelli et al. 2002, Swartzman et al. 2002). The few large-scale studies in the Bering Sea have mainly focused on distribution and abundance of juvenile pollock in relation to oceanographic conditions such as sea ice (Wyllie-Echeverria 1996), and growth and distribution of adult pollock (Akira et al. 2001). Because pollock are important both commercially and ecologically, there is a need for a better understanding of physical and biological processes that may affect the early marine survival of pollock throughout their range. This study examines annual changes in abundance, energy density and diet of age-0 pollock in the eastern Bering Sea.

The distribution and abundance of age-0 pollock was studied in the eastern Bering Sea during annual fall trawl surveys aboard the F/V Sea Storm, August - October, 2000-2005. Sampling stations were located between 54ºN and 68ºN spaced 15 to 30 km apart; however, spatial coverage varied between years. Fish were captured using a surface trawl towed for 30 minutes. On board, fish were identified, counted, measured, and the diet of a sub-sample of 10 fish per station was determined. In the lab, whole body energy density (J/g wet weight) was determined from fish collected at similar locations during 2003-2005 survey years using bomb calorimetry. Average annual abundance was estimated by dividing the average number of age-0 pollock caught by the average volume of water swept for all trawls during the 2000-2005 surveys. One-way analysis of variance (ANOVA) was used to test the effects of survey year on energy density. Bonferroni's test was used for pairwise comparisons between years when significant differences were found. Stomach content data (% wet weight) were also compared between years and size class for 2003-2005 survey years.

Age-0 pollock were distributed throughout the eastern Bering Sea, with the highest concentration occurring in frontal regions and in Bristol Bay. In 2005, more fish appeared to be distributed further offshore relative to 2004 (Figure 59). Average abundance increased annually from 2000-2004 and declined slightly in 2005; however, sampling areas were different among years and, therefore, no definitive abundance estimates can be made until differences in survey area are accounted for (Table 14). There was a significant difference in energy density of juvenile pollock between survey years ($P<0.001$). Pairwise tests indicated that pollock from 2003 and 2004 survey years had significantly greater energy densities than pollock from 2005 (2003: 3858.52 J/g; 2004: 3887.01 J/g; 2005: 3626.36 J/g), and there was no difference in energy density between 2003 and 2004 survey years (Figure 60). Stomach content analysis indicated that age-0 pollock between 40-80 mm had a more diverse diet dominated by calanoid copepods and euphausiids, whereas pollock between 90-120 mm had a less varied diet dominated by age-0 pollock (Figure 61). This cannibalistic feeding behavior was most pronounced in 2003, with 88.1% of the diet being composed of age-0 conspecifics.

It is not yet understood what factors may have contributed to the lower energy density of age-0 pollock in 2005. Pollock were distributed west of the inner front in 2005 compared to previous years, which could have separated them from critical foraging areas. Frontal regions are known to be areas of higher productivity (Franks 1992). In 2003 and 2004, age-0 pollock were more closely associated with the productive inner front, where well mixed coastal domain water meets stratified middle domain water. The inner front is associated with the 50 meter isobath (Kachel et al. 2002). Additionally, 2003 and 2004 were warmer years compared to 2000-2002, and 2005. To understand the factors driving the observed differences in energy density, and whether these differences have an effect on early marine survival of pollock, variability in zooplankton biomass and oceanographic conditions of these geographical areas needs to be further investigated.

Table 14. Mean annual age-0 pollock abundance (#/ km3) with 95% confidence intervals from August-October 2000-2005 surveys.

Survey Year	Mean annual abundance (# /km3)	95% CI
2000	1007.56	±589.1641
2001	2257.73	±2799.965
2002	2229.84	±1530.452
2003	4809.05	±5838.243
2004	9941.51	±6677.238
2005	8375.91	±4805.685

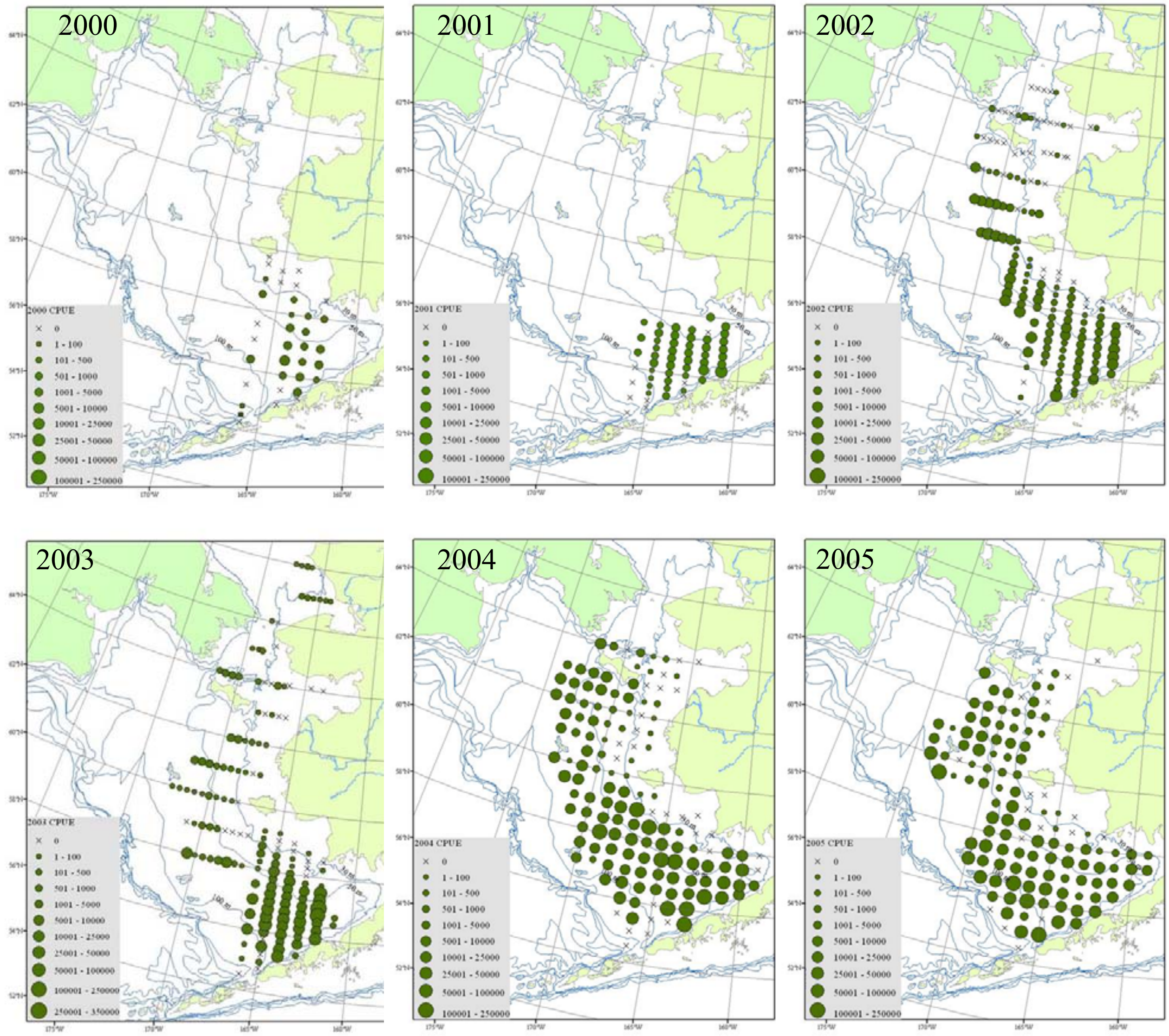

Figure 59. Age-0 pollock distribution from August-October, 2000-2005 surveys in catch per unit effort (CPUE) based on 30 minute surface trawl hauls.

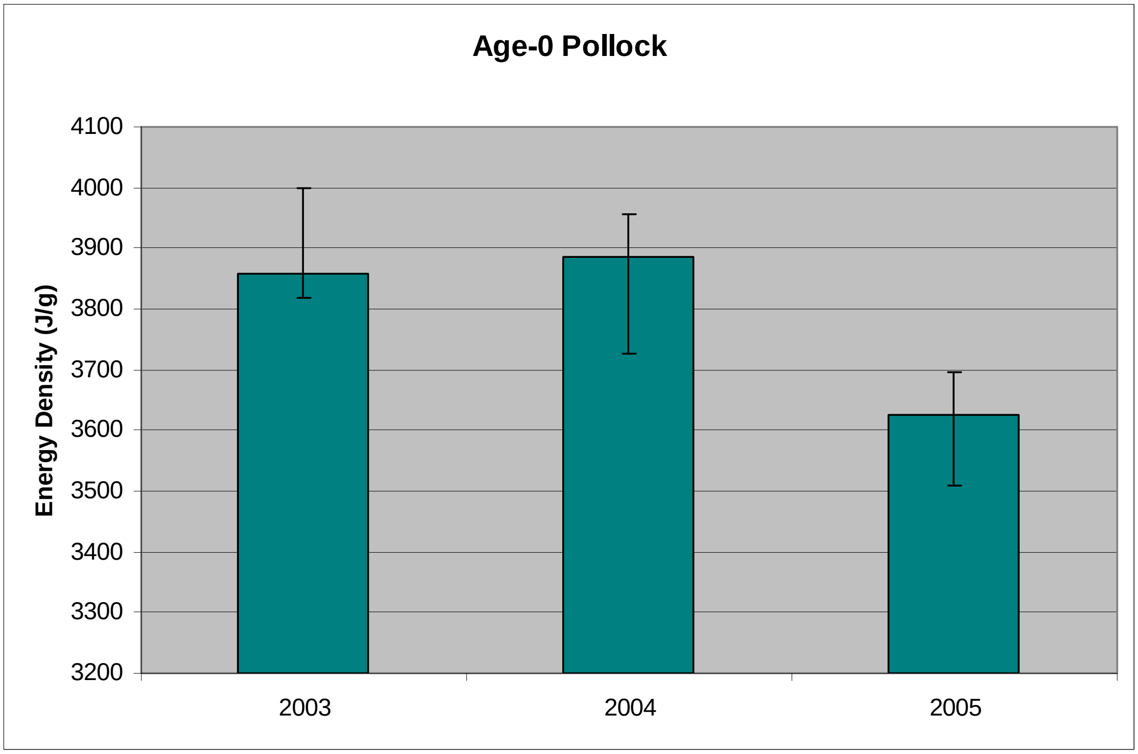

Figure 60. Average energy density (J/g wet weight) of age-0 pollock from August-October 2003-2005 surveys. Error bars represent 95% confidence intervals.

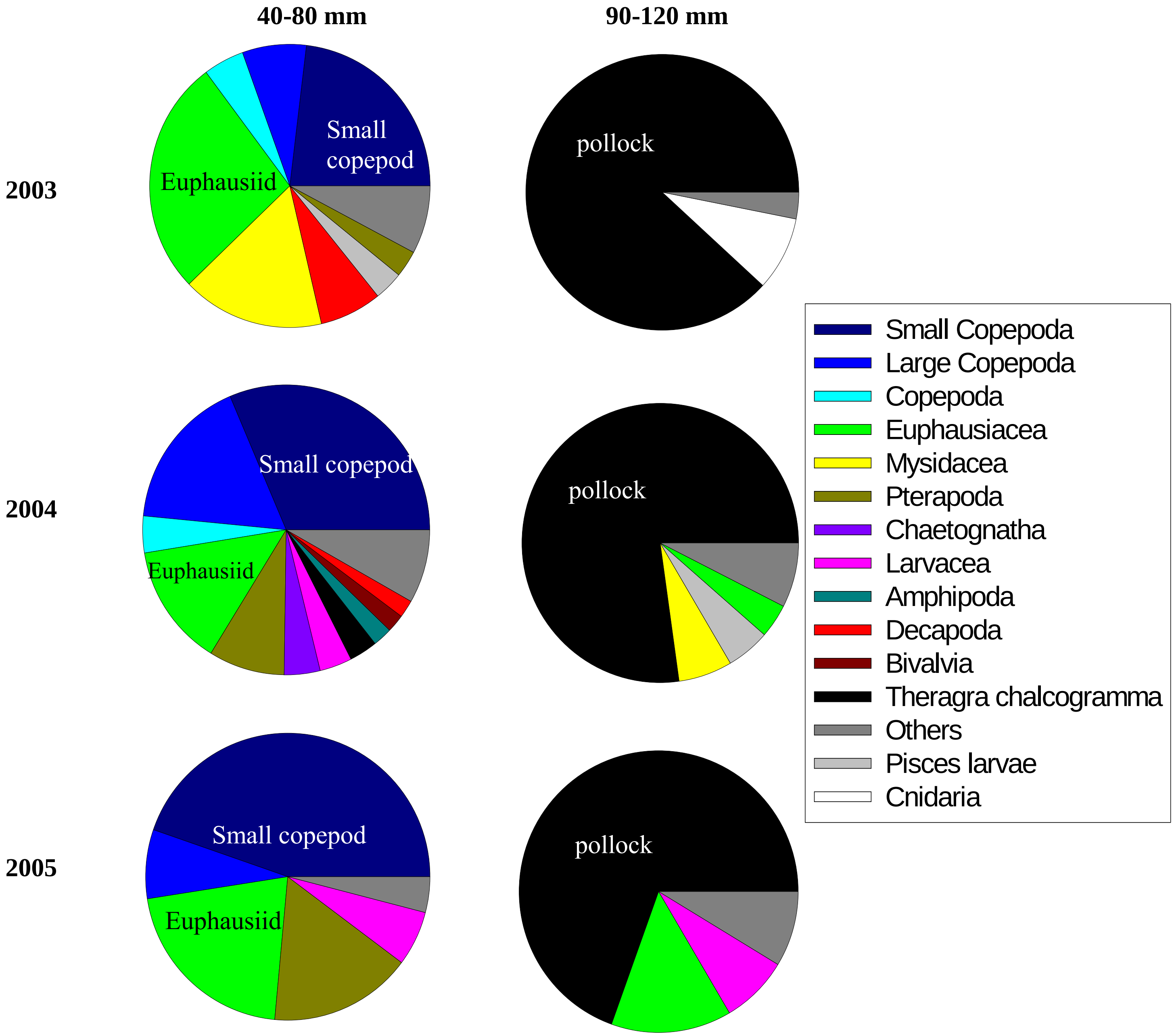

Figure 61. Diet composition by % weight for age-0 pollock from August- October 2003-2005 surveys. The left panel represents the diet composition of fish between 40-80 mm total length, and the right panel represents the diet composition of fish between 90-120 mm total length.

Variations in juvenile sockeye and age -0 pollock distribution during fall 2000-2005 in the eastern Bering Sea- BASIS

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Last updated: November 2006

Oceanographic and fisheries data have been collected in the Eastern Bering Sea (EBS) during fall 2000-2005 for the U.S. component of a multiyear international research program, Bering-Aleutian Salmon International Survey (BASIS). Stations were located between 54°N and 68°N, at 30-60 km resolution, although spatial coverage varied by region and by year. Bristol Bay stations were sampled from mid August to early September during all six years. While, stations in the central and northern EBS were generally sampled from mid September to early October. Oceanographic data were obtained from vertical conductivity-temperature-depth (CTD) profiles and laboratory analyses of discrete water samples at select depths (2003, 2004, and 2005). Oceanographic variables include temperature, salinity, nutrients, chlorophyll a, and phytoplankton taxonomic characteristics (based on phytoplankton species identification and chlorophyll a size fractionation). A long-term goal of this research is to characterize interannual variations in the abundance and distribution of lower and higher trophic level organisms in relation to oceanographic features in the EBS (see the *Physical Environment* and *Nutrients and Productivity* sections of this report).

Age-0 pollock and juvenile sockeye were more abundant in warmer years than cooler years (Figure 62 and see the *Physical Environment* section of this report). Juvenile sockeye distributions were bordered by the northern Inner Domain in Bristol Bay in 2002-2005 and were concentrated near the Alaska Peninsula in Bristol Bay in 2000 (data not shown) and 2001. The overlap of the two juvenile fish species distributions may improve the survival of juvenile sockeye salmon since age-0 pollock are an important prey species (age-0 pollock composed 40-60 % wet weight of juvenile sockeye salmon diets in 2003, 2004, and 2005). Additional data collection and analyses are required to further characterize the interannual variability in oceanography and fisheries distributions in the EBS.

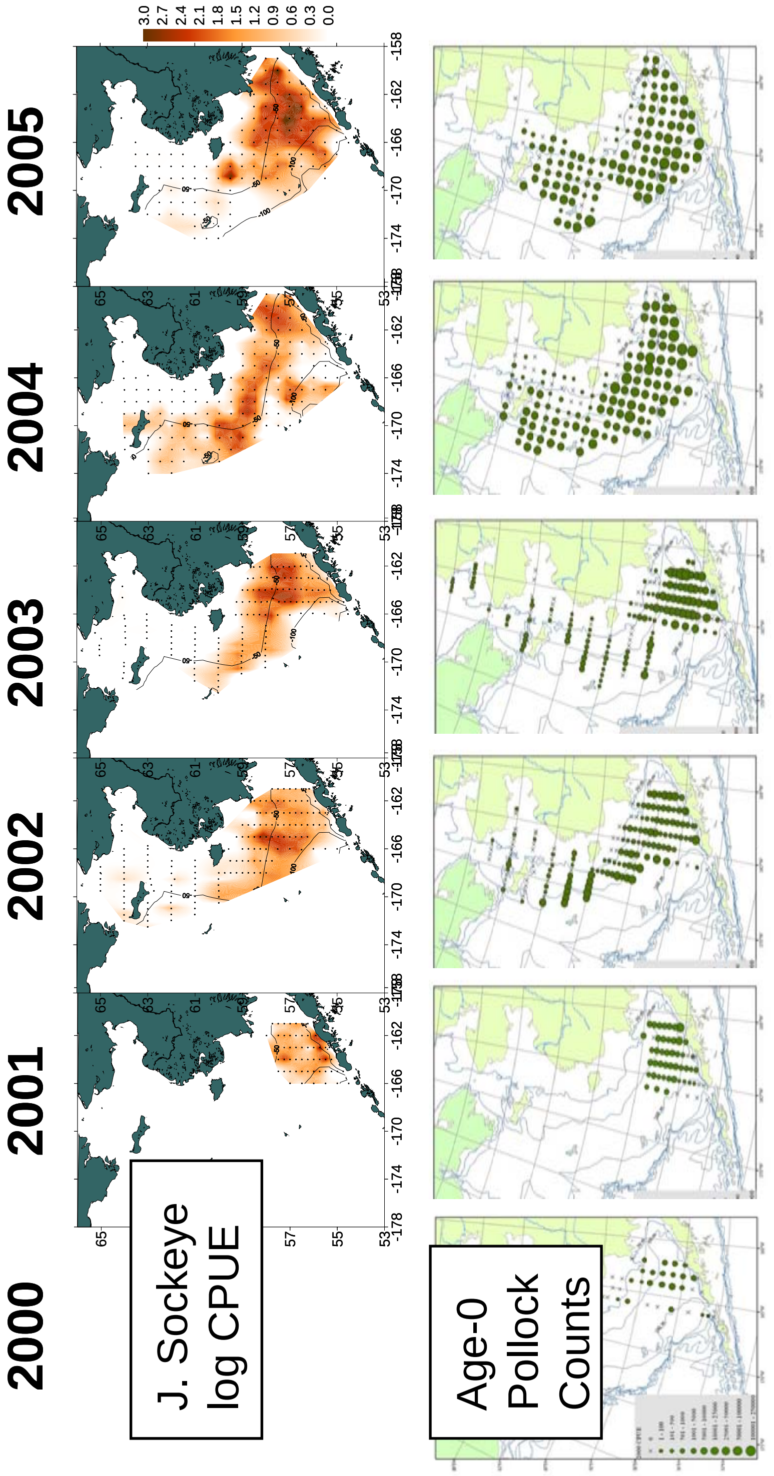

Figure 62. Juvenile sockeye and age-0 pollock abundance (CPUE) during fall in the EBS, 2000-2005.

Forage Species– Gulf of Alaska

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The North Pacific Fishery Management Council has defined several groups as forage species for management purposes in the Gulf of Alaska (GOA). These groups include gunnels, lanternfish, sandfish, sandlance, smelts, stichaeids, and euphausiids. Several of these groups are captured incidentally in the Gulf of Alaska biennial RACE bottom trawl survey. Since all of these species are quite small relative to the size of the mesh used in the survey gear, the capture efficiency for these species is quite low. Many of these species are rarely encountered during the survey and therefore trends in abundance are difficult to discern, due to the high variability of the resulting estimates. A possible exception to this generalization would appear to be eulachon (*Thaleichtys pacificus*). Eulachon are generally captured in a relatively large number of tows, and although they are not sampled well by the gear, it is possible that trends in abundance may be discernible from the survey data. There appears to be a general increase in the abundance of eulachon over the time series, particularly in the central GOA. The abundance seems to have reached a peak in 2003, however, before returning to 2001 levels in 2005 (Figure 63). It is also interesting to note that the frequency of occurrence generally increases from west to east, although the biomass seems to be highest in the central GOA. For each species group, the largest catch over the time series was arbitrarily scaled to a value of 100 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error.

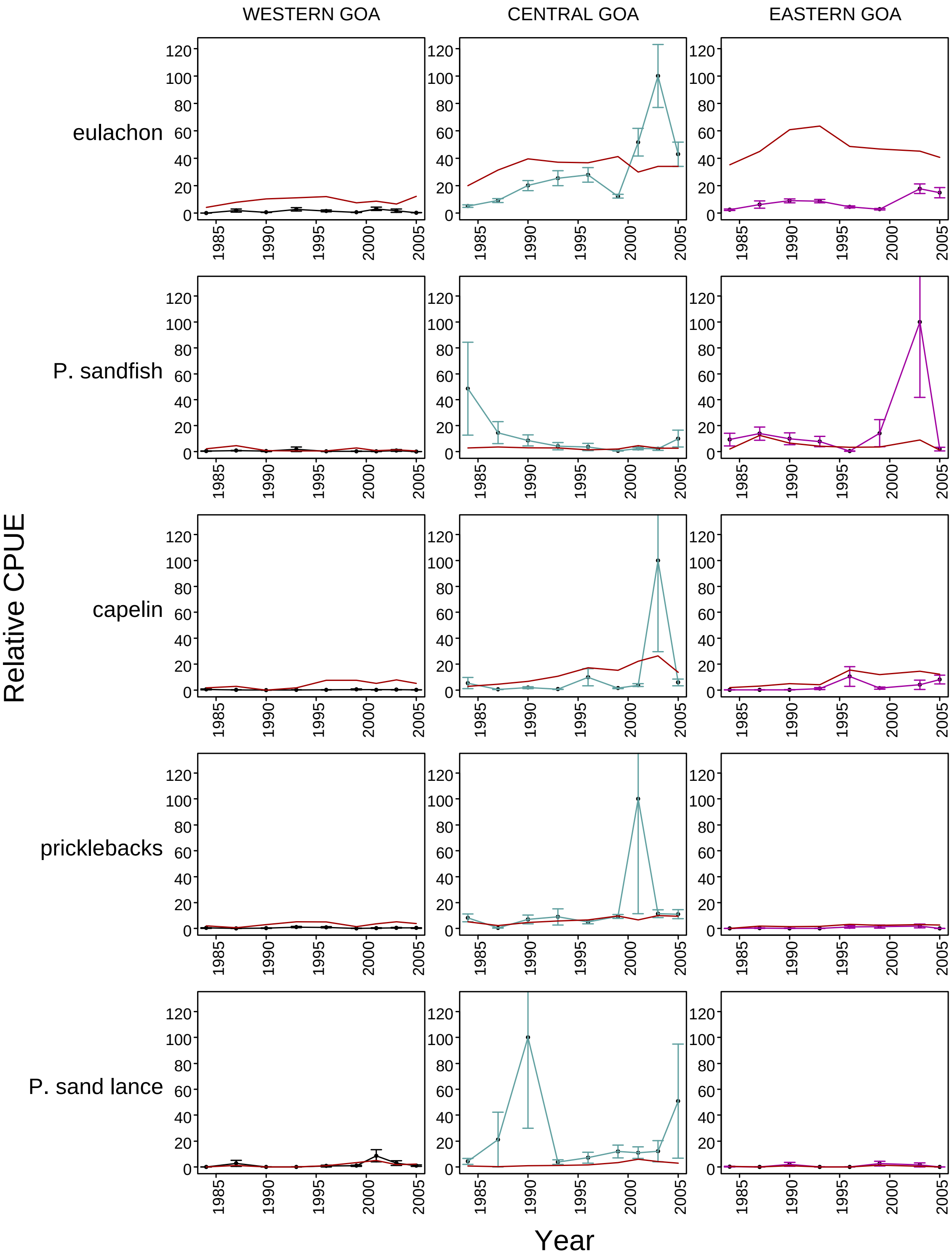

Figure 63. Relative mean CPUE of forage fish species by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2005. Error bars represent standard errors. The red lines represent the percentage of non-zero catches.

Forage – Eastern Bering Sea

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Last updated: November 2006

The North Pacific Fishery Management Council defined several groups as forage species for management purposes. These groups include: gunnels, lanternfish, sandfish, sandlance, smelts, stichaeids, and euphausiids. Some of these groups are captured incidentally in the RACE bottom trawl survey of the shelf, which may provide an index of abundance (Figure 64). For each species group, the largest catch over the time series was arbitrarily scaled to a value of 1 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error. Sandfish are generally in low abundance in the trawl surveys and are usually caught in high abundance in only a few hauls in the shallower stations (Figure 64). Stichaeids, which include the longsnout prickleback (*Lumpenella longirostris*), daubed shanny (*Lumpenus maculatus*) and snake prickleback (*Lumpenus sagitta*), are small benthic-dwelling fish. Their relative abundance in trawl survey catches was generally higher in trawl survey catches prior to 1999. Similar to stichaeids, the Relative CPUE's of sandlance were generally higher prior to 1999. Eulachon Relative CPUE is relatively low compared to the 90's and first half of the new millennium. Capelin catches in the survey have been relatively low and even with the exception of one year (1993) when CPUE was very high (Figure 64).

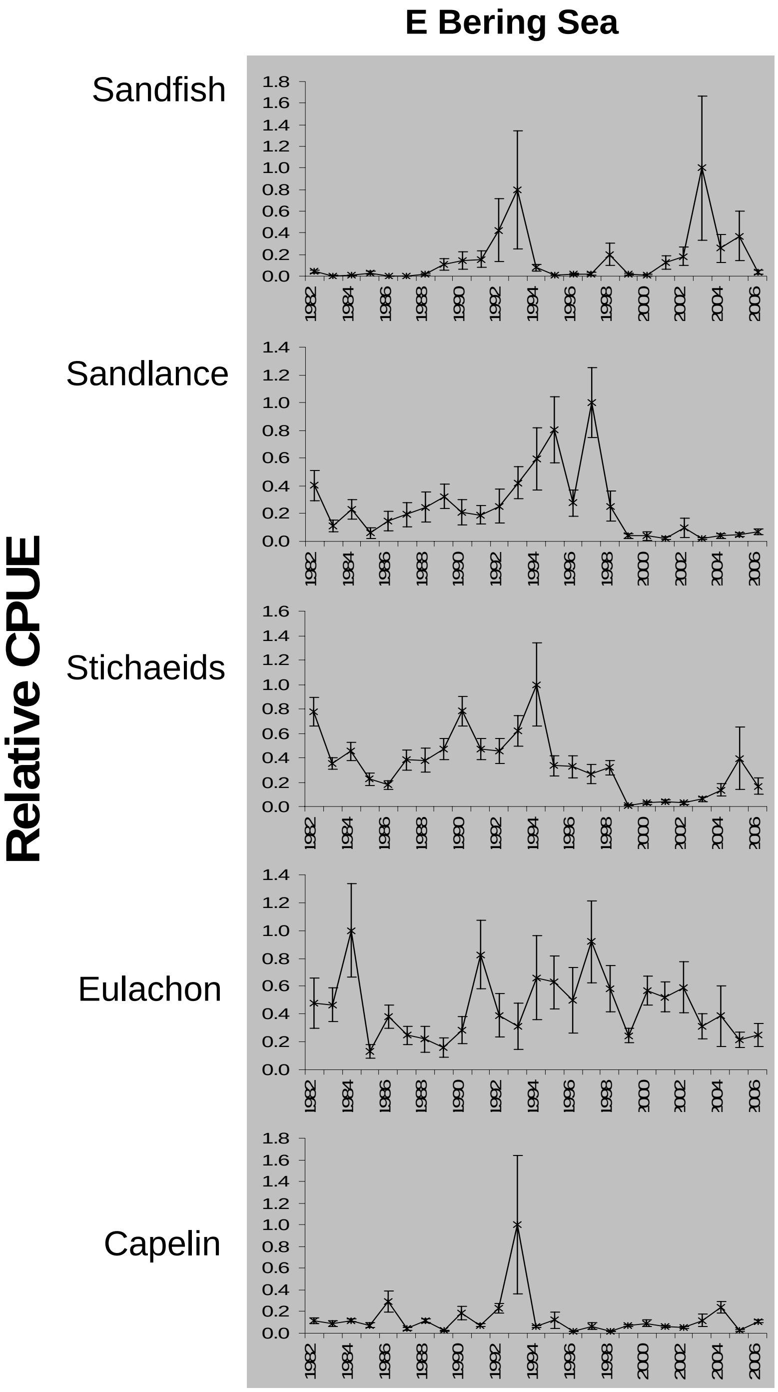

Figure 64. Relative CPUE of several forage fish groups from the eastern Bering Sea summer bottom trawl survey, 1982-2006. Data points are shown with standard error bars.

Forage – Aleutian Islands

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The North Pacific Fishery Management Council has defined several groups as forage species for management purposes in the Aleutian Islands (AI). These groups include gunnels, lanternfish, sandfish, sandlance, smelts, stichaeids, and euphausiids. Some of these groups are captured occasionally in the RACE bottom trawl survey of the Aleutian Islands (Figure 65). The survey is not designed to assess these species and the percentage of catches containing these species is very low, indicating that the survey probably does not provide a reliable index of abundance. For example, the apparent large increase of Pacific sandfish catch per unit effort (CPUE) seen in the western Aleutian Islands in 1986 is a result of only 4 individuals appearing in one catch, the only year that this species has been captured in the western Aleutians. Similarly, the highest catch rates for pricklebacks, eulachon and capelin are attributable to two to three catches. The large increase in pricklebacks seen in the western Aleutians in 1991 was attributable to only three catches, the largest being less than 8 kg. The high abundance of eulachon in the western Aleutians in 1994 was due to only two unusually large catches of 431 kg and 63 kg while the high CPUE of capelin in the southern Bering Sea in 2000 was the result of one very unusually large catch of 221 kg. For each species group, the largest catch over the time series was arbitrarily scaled to a value of 100 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error.

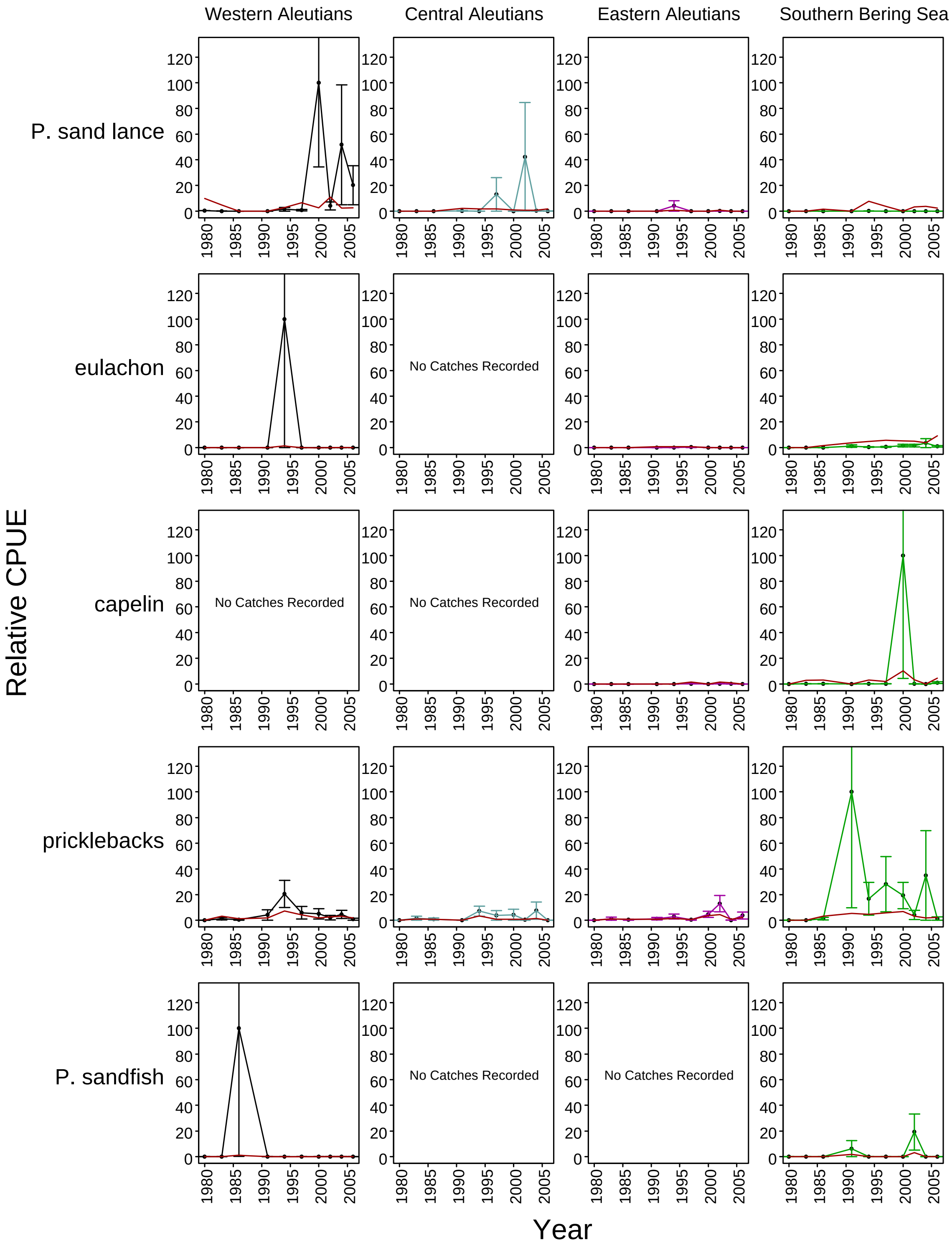

Figure 65. Relative mean CPUE of forage fish species by area from RACE bottom trawl surveys in the Aleutian Islands from 1980 through 2006. Error bars represent standard errors. The red lines represent the percentage of non-zero catches.

Herring

Prince William Sound Pacific herring

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Last updated: November 2006

The Alaska Department of Fish and Game (ADF&G) has completed Pacific herring stock assessments in Prince William Sound (PWS) since ~1973. Population trends were initially monitored with aerial surveys to estimate biomass and the linear extent of beach used for spawning (Brady 1987), and have continued almost without interruption. Age, sex, and size data has been collected from most fisheries and spawning aggregations since 1973 (e.g., Baker et al. 1991). Dive surveys to estimate spawning biomass began with feasibility studies in 1983 and 1984 and continued in 1988-1992 (Brown and Baker 1998) and 1994-1997 (Willette et al. 1999). In 1993, ADF&G in cooperation with the Prince William Sound Science Center began fall acoustics surveys (e.g., Thomas and Thorne 2003). Spring (March/April) acoustics surveys have been conducted during 1995-2005. Age structured models have been used since 1993 to estimate historical population parameters and project future biomass, recruitment, and abundance (Funk 1994).

In the 1980s a strong recruitment occurred approximately every four years (Figure 66). The recruitment as age-3 fish from the 1984 and 1988 year classes were particularly large (~ 1 billion fish from 1984). The prefishery run biomass estimate peaked in 1988 and 1989 at >100,000 metric tons (mt; Figure 66). The 1993 biomass projection was >100,000 mt; however, the 1993 observed biomass was < 30,000 mt (Marty et al. 2003). The stock collapsed and the biomass has remained (1993 – 2006) at levels less than half of the 1980-1992 average of 84,000 mt. The causes of the decline have been hypothesized to be related to effects of the 1989 *T/V Exxon Valdez* oil spill, commercial harvesting, or environmental effects (Carls et al. 2002, Pearson et al. 1999, Thomas and Thorne 2003).

The Prince William Sound Pacific herring fishery is managed to allow harvest of from 0-20% of the biomass above a spawning biomass threshold of 22,000 tons (20,020 mt). Since the stock collapse in 1993, purse seine sac roe harvest has only occurred in 1997 and 1998 (2 of 14 years). The fishery is also closed for the fall 2006 and spring 2007 fisheries because the projected biomass is below the threshold spawning biomass.

The variability of recruitment in Prince William Sound herring is probably at least related to large-scale environmental factors (Williams and Quinn 2000), smaller-scale environmental factors (Norcross et al. 2001) and disease (Marty et al. 2003, 2004). Disease assessments (1993-2002) indicate viral hemorrhagic septicemia virus (VHSV) and associated ulcers were related to population declines in 1993/1994 and 1998; and *Ichthyophonus hoferi* was related to a population decline in 2001 (Marty et al. 2004). The prevalence of *I. hoferi* increased significantly between 2002 (14%) and 2005 (25%) and remained high in 2006 (25%); this may cause increased mortality in the older age classes. The 2007 forecast model is a modified version of the 2006 model (Marty et al. 2004) and integrates disease assessment and spring acoustics survey data directly into the model (Hulson et al. *in prep*).

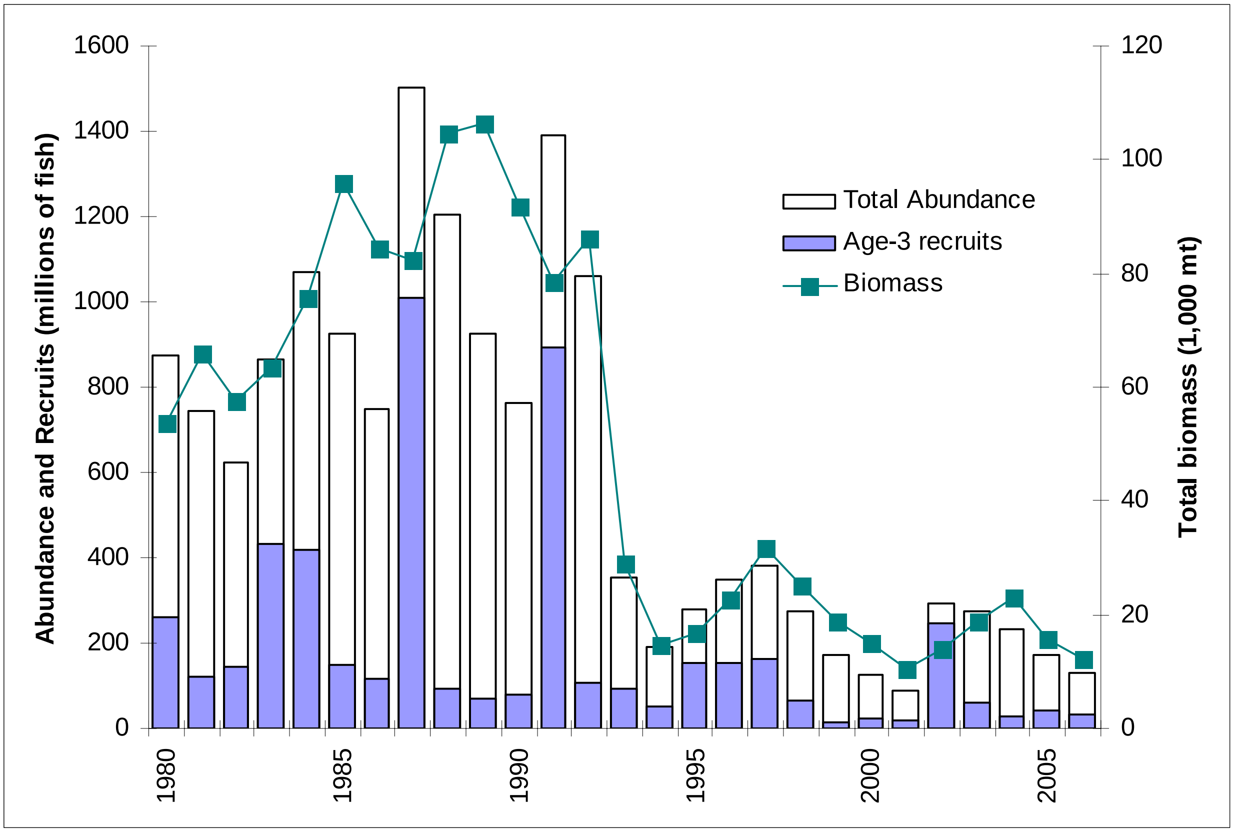

Figure 66. Age-3 recruitment, total prefishery abundance and run biomass (metric tons) of Pacific herring in Prince William Sound, 1980-2006. The abundance values and biomass are outputs of the age-structured model used to produce the 2007 projections.

Southeastern Alaska herring

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Last updated: November 2006

Herring *(Clupea pallasii)* stock assessments have been conducted each fall by the Alaska Department of Fish and Game at nine spawning areas in southeastern Alaska for most years since 1980. Recurrent, annual spawning and biomass levels have warranted yearly stock assessment surveys, and potential commercial harvests, at these locations during most of the last 25 years. More limited spawning occurs at other locales throughout southeastern Alaska. However, other than aerial surveys to document shoreline miles of spawning activity, little stock assessment activity occurs at these locations. Spawning at the nine primary sites for which regular assessments are conducted have probably accounted for 95-98% of the spawning biomass in southeastern Alaska in any given year.

Herring spawning biomass estimates in southeastern Alaska often change markedly from year to year, rarely exhibiting consistent, monotonic trends (Figures 67 and 68). Since 1980, three of the nine primary locations (Sitka Sound, Hoonah Sound, and Seymour Canal) have exhibited long term trends of increasing biomass and one area (Kah Shakes/Cat Island) has had a pronounced downward trend (Figure 68). Other areas have shown fluctuations in spawning biomass without a pronounced long term trend. Since 1997, the southeastern Alaska spawning herring biomass estimate has been above the long-term median of 81,120 tons (1980-2005; Figure 67). The 2004 and 2005 estimates of spawning biomass were the two highest in the 25-year time series. Since 1980, herring biomass at Sitka has contributed 37 to 68% (median: 54%) of the total estimated annual biomass among the nine spawning locations. Excluding the Sitka biomass from a combined estimate, southeastern Alaska herring biomass has been above the 25-year median of 40,029 tons in every year since 1997, except for 2000 (Figure 67).

Estimated abundance of age-3 herring recruits has varied greatly among and within stocks over time (Figure 69). The number of age-3 recruits has been estimated for Kah Shakes-Cat Island, Seymour Canal, Sitka, and Tenakee Inlet for most years since 1980; for Craig in every year since 1988; and for West Behm Canal, Ernest Sound, Hobart Bay-Port Houghton, and Hoonah Sound for most years since 1995. An oscillating recruitment pattern with strong recruit classes every three to five years is apparent for Kah Shakes/Cat Island, Craig, and Sitka Sound stocks prior to 1997. For Sitka Sound, the stock with the greatest annual recruit abundance, oscillating years of extremely high and low recruit abundance in the 1980s and early 1990s has changed to more consistent, intermediate recruit abundances in the mid-1990s to early 2000s. Every stock except Seymour Canal exhibited low recruitment in 2004 and 2005 in relation to other years. Therefore, decreasing population biomass can be expected for most stocks unless recruitment increases substantially in upcoming years.

There has been some speculation and debate about the extent to which commercial harvests may have contributed to marked declines in estimated abundance and/or localized changes in herring spawning sites in a few areas in southeastern Alaska, notably Revillagigedo Channel (Kah Shakes/Cat Island) and Lynn Canal. Some spawning areas are sufficiently close to one another so interannual movement between areas may also contribute to year-to-year fluctuations in local abundance. In the Revillagigedo Channel area, significant spawning and a fishery occur at Annette Island, a site outside the management jurisdiction of the State and from which limited data are gathered by the department. Although spawning activity at the Kah Shakes and Cat Island sites in Revillagigedo Channel has declined in recent years, this decline may be at least partially attributable to a shift in spawning grounds to Annette Island, bordering Revillagigedo Channel.

A threshold management policy in southeastern Alaska allows for harvests ranging from 10 to 20% of forecast spawning biomass when the forecast biomass is above a minimum threshold biomass. The rate of harvest depends upon how much the forecast exceeds the threshold. Consequently, catch, at most areas, has varied roughly in proportion to forecast biomass (Figures 67 and 68).

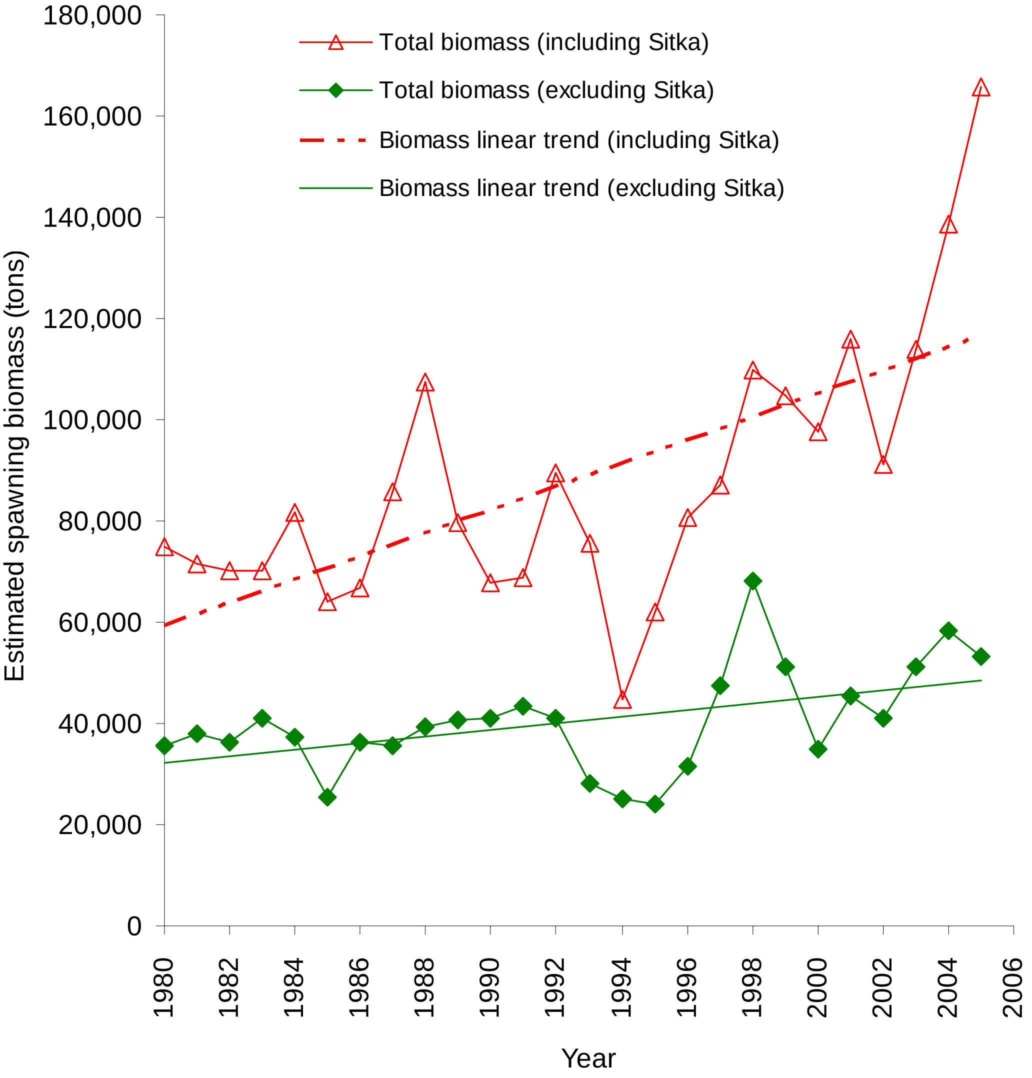

Figure 67. Estimated combined annual mature herring biomass (including and excluding Sitka) at major southeastern Alaska spawning areas, 1980-2005.

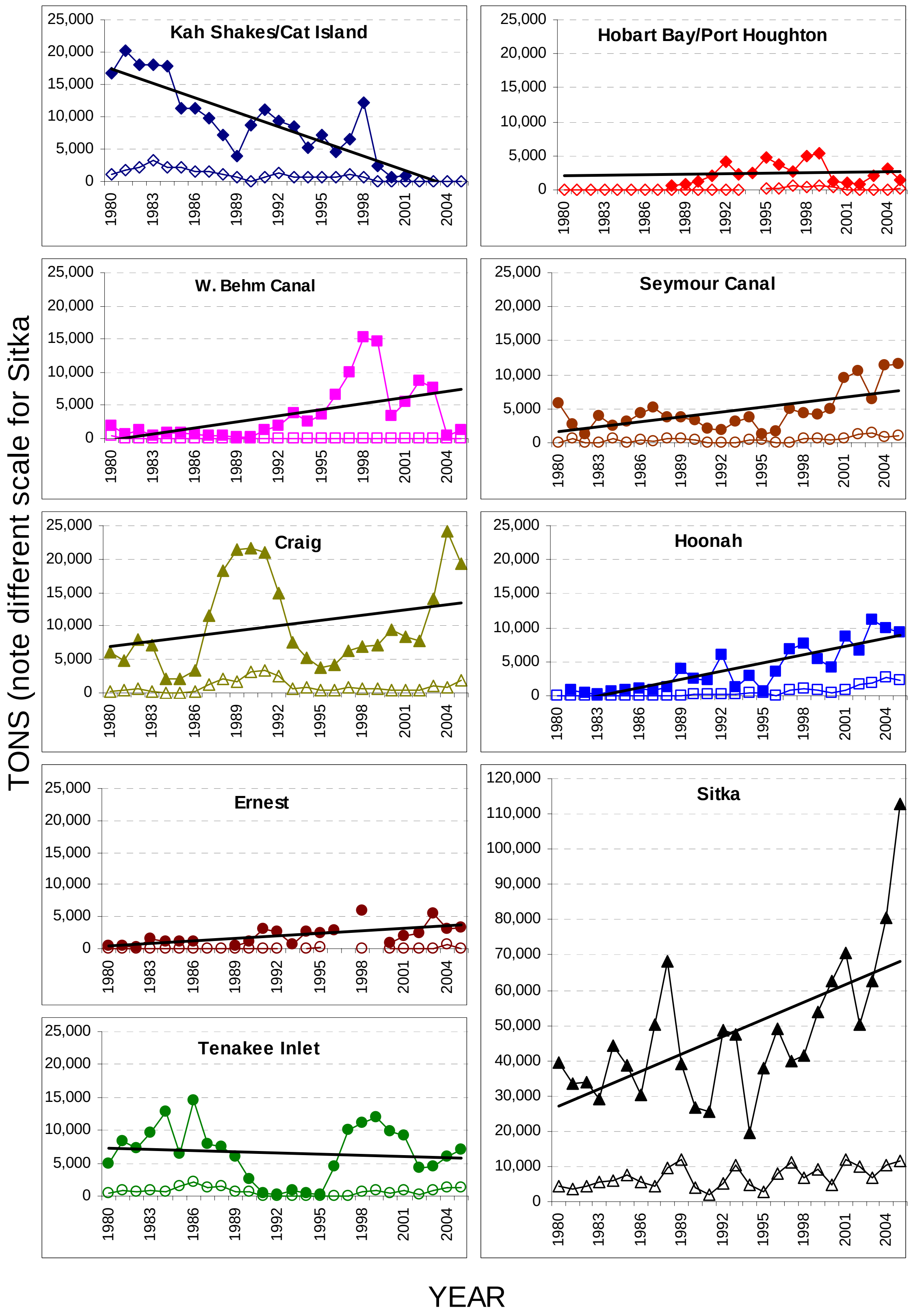

Figure 68. Estimated mature herring biomass (tons), catch (tons) and biomass linear trend at nine major spawning locations in southeastern Alaska, 1980-2005. Open symbols represent catch, solid symbols represent biomass, solid lines represent the biomass linear trend.

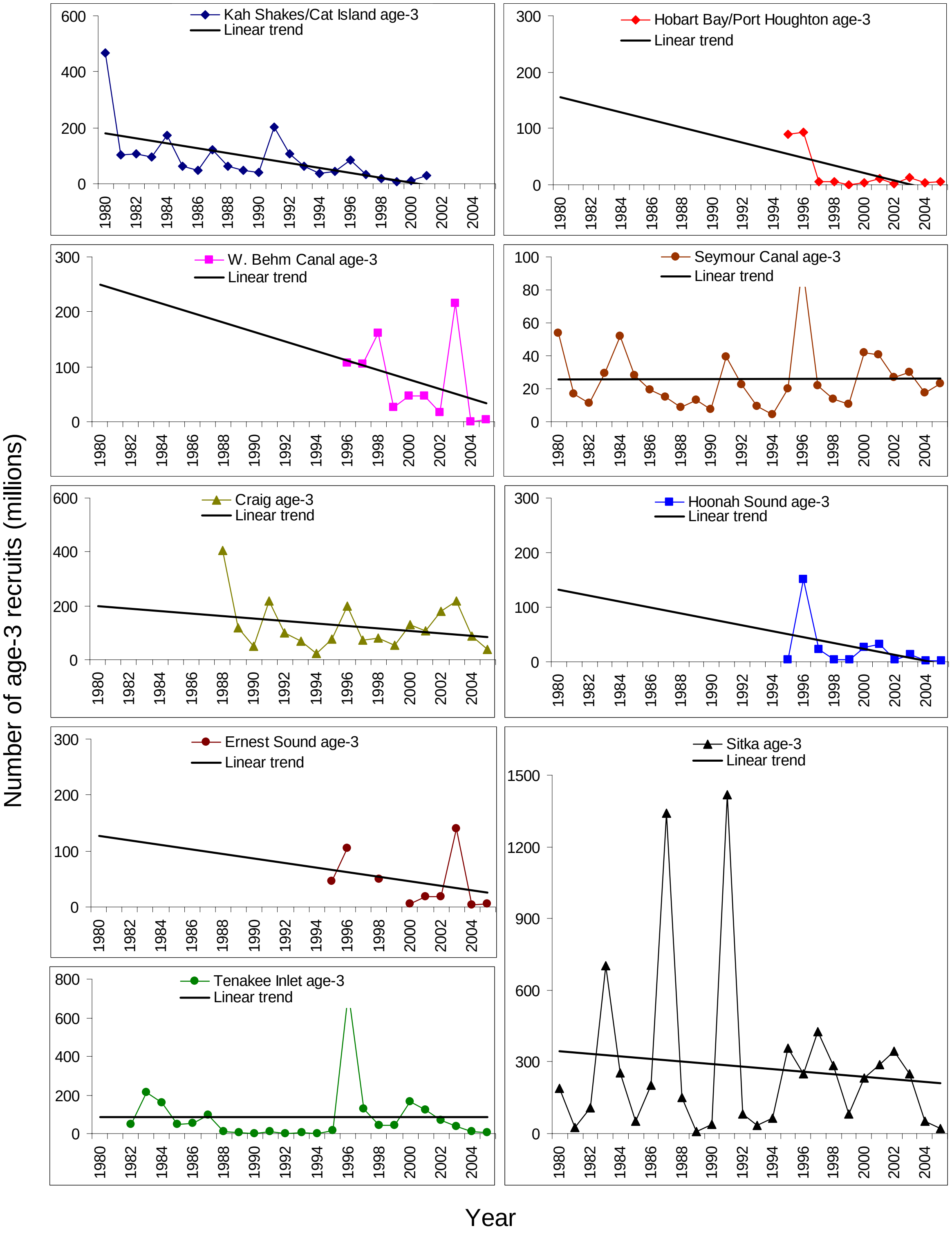

Figure 69. Estimated number of age-3 herring recruits (millions of fish) and linear trend at nine major spawning locations in southeastern Alaska, 1980-2005.

Togiak Herring Population Trends

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Last updated: December 2005

An age-structured analysis model developed by Fritz Funk was used to assess Pacific herring population trends in the Togiak District of Bristol Bay (Funk et al. 1992). Abundance peaked in the early 1980's with approximately 2.5 billion fish when herring from the 1977 and 1978 year classes recruited into the fishery as age-4 fish in 1981 and 1982 (Figure 70). Beginning in 1983, total abundance steadily declined until modest recruitment events occurred in 1991 and 1992 from the 1987 and 1988 year classes. Temporal trends in Togiak herring abundance show that total abundance in much of the 1980s was above the 1978 - 2003 average but fell below in 1989 and has remained below average since, with the exception of slightly above average values in 1991 and 1992 (Figure 70).

The high abundance estimates in the early 1980s may be a result of projecting backwards from the ASA model which was used beginning in 1993. The aerial survey data for the same time period conflicts with those estimates yielding much lower biomass estimates. We continue to work on resolving this; the aerial survey data is currently being used to "ground truth" the ASA estimates. With the 1996 and 1997 recruitment entering the fishery in strength now, and the outlook that recent mild years should also provide substantial recruitment to the stock, the status of the Togiak herring stock has been changed from "nominal decline" to "stable".

Pacific herring recruitment trends are highly variable, with large year classes occurring occasionally at regular intervals of approximately every 9-10 years (Figure 70). These large recruitment events drive the Togiak herring population. Environmental conditions may be the critical factor that influences strength of herring recruitment. Williams and Quinn (2000) have demonstrated that Pacific herring populations in the North Pacific are closely linked to environmental conditions with temperature having the strongest correlation. A general consensus in fisheries points towards the larval stage of herring life history as being the most important factor for determining year class strength (Cushing 1975, Iles and Sinclair 1982). Ocean conditions relative to spawn run timing would greatly influence the strength of each year class. Closer examination of trends in sea surface temperature, air temperature, and Bering Sea ice cover specific to the Bristol Bay area may find a specific correlate for Togiak herring recruitment.

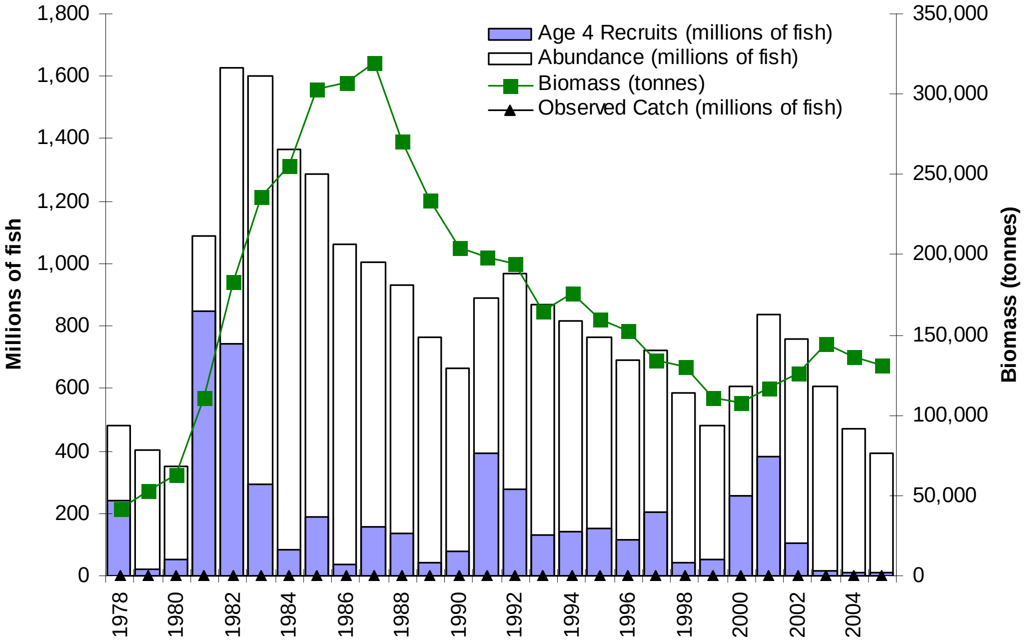

Figure 70. Total abundance, age-4 recruits, mature biomass, and total harvest of Pacific herring in the Togiak District of Bristol Bay, 1978 – 2005.

Salmon

Historical trends in Alaskan salmon

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With contributions from Lowell Fair (ADFG; lowell_fair@fishgame.state.ak.us), Tom Kline (PWSSC), and Jennifer Boldt (University of Washington).
Last updated: November 2006

Overall Catch Trends

Pacific salmon rear in the Gulf of Alaska (GOA) and Central Bering Sea (BS) and are managed in four regions based on freshwater drainage areas, Southeast, Central (Cook Inlet, Prince William Sound, Bristol Bay), Westward (Alaska Peninsula, Chignik, Kodiak), and Arctic-Yukon-Kuskokwim (Figure 71). Salmon distribution throughout the GOA and BS varies by species and stock, some of which migrate between the two areas (K.W. Myers, University of Washington, personal communication). All salmon, except chinook, generally spend the majority of their ocean life in offshore pelagic waters, bounded by brief periods of migration through coastal areas as juveniles and returning adults. Chinook salmon migrate through coastal areas as juveniles and returning adults; however, immature chinook salmon undergo extensive migrations and can be found inshore and offshore throughout the North Pacific and Bering Sea (Morrow 1980). In summer, chinook salmon concentrate around the Aleutian Islands and in the western GOA (Morrow 1980).

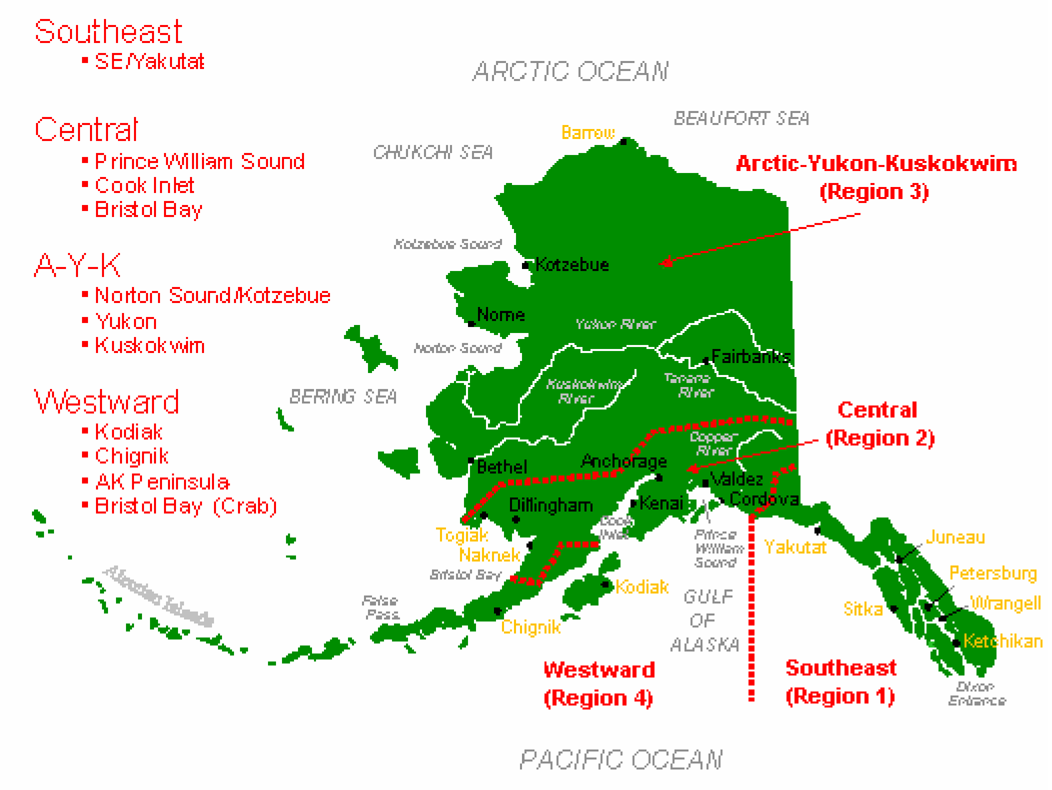

Figure 71. Four fishery management regions of the Alaska Department of Fish and Game, Division of Commercial Fisheries (adapted from http://www.cf.adfg.state.ak.us/regnmap.php, accessed October 5, 2006).

Generally, Alaskan salmon stocks have been at high levels of abundance in the last 20 years (Figures 72-78). Asian stocks have shown similar trends as Alaskan salmon. Salmon stocks in the Pacific Northwest and British Columbia were at lower levels in the 1980s and 1990s. Trends in salmon production have been attributed to PDO scale variability (Hare and Francis 1995), ocean temperature (Downton and Miller 1998), and regional-scale sea surface temperatures (Mueter et al. 2002). A simple and comprehensive summary of stock status is not possible because long term assessments of stock specific catch and escapements by age are not available for some important salmon stocks (eg. Kuskokwim River, Noatak River, and important components of the Yukon River). The Alaska Department of Fish and Game is developing comprehensive stock assessment documents that will be available in the future.

Catch Trends by Species

Catch of salmon species by management area during 1900-2003 was provided by Doug Eggers (Alaska Department of Fish and Game). A full report (Plotnick and Eggers 2004) of run forecasts and a review of the 2003 season is available on the web under "Forecasts" at:
http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/salmhome.php
Bristol Bay sockeye salmon catch and escapement data was provided by Lowell Fair (Alaska Department of Fish and Game). Catch data for 2004 and 2005 were acquired from the ADFG website (http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/salmon_catch.php; accessed October 2, 2006) which lists catches rounded to the nearest 1000th fish. For cases where 2004 or 2005 catches were listed as "<1,000", a value of 500 was assigned. The values presented for 2004 and 2005 in this contribution may, therefore, be different from official ADFG estimates by as much as 500 fish.

SOCKEYE

Abundance of sockeye salmon in all areas increased from the mid 1970s to the 1980s (Figure 72). Since then catches peaked in the early 1990s and have since decreased and have varied around catch levels observed in the 1980s. Recruitment for most Bristol Bay sockeye salmon stocks other than Kvichak was moderate to strong in the 1980s to the mid-1990s (Figure 73). The levels of recruitment observed for weak stocks during the recent period are not unprecedented. Similar levels of returns per spawner were observed for Bristol Bay sockeye during the 1960 to early 1970s. Beginning with the 1973 brood year (>1979 return year) of Bristol Bay sockeye salmon, the number of returning adults produced from each spawner showed a dramatic increase across most stocks (Fair 2003). Poor returns in 1996-98, however, suggested a return to a level of productivity similar to the pre-1978 period (Fair 2003). Fish from the 1996-98 return years reared in the ocean when temperatures were above average, whereas, cooler than average ocean temperatures characterized the pre-1978 period.

PINK

Pink salmon catches increased in the late 1970s to the mid-1990s and have generally remained high in all regions in the last decade (Figure 74). Marine survival of Prince William Sound hatchery pink salmon appeared to increase after 1977, but does not appear to have shifted after the 1988/89 or the 1998/99 climate regime shifts (Figure 75). Hatchery pink salmon marine survival in 2003 was the second highest recorded during the 1977-2004 time period, and was below average in 2004 (2002 brood year) (Figure 75).

CHUM

Chum salmon are generally caught incidental to other species and catches may not be good indicators of abundance. In recent years chum salmon catch in many areas has been depressed by low prices (Figure 76). Directed chum salmon fisheries occur in AYK and on hatchery runs in Prince William Sound and Southeast Alaska. Chum salmon runs to AYK rivers have been declining in recent years (Figure 76). Chum salmon in the Yukon River and in some areas of Norton Sound have been classified as stocks of concern (Eggers 2003).

COHO

Coho catches have been moderate to high in all regions. Coho fisheries in Central and Western Alaska are not fully developed due to the late run and lack of processor interest. The coho catch in AYK from 1998 to 2003 was lower than the previous decade, but still above catches in the 1960s and 1970s (Figure 77).

CHINOOK

Directed commercial chinook salmon fisheries occur in the Yukon River, Nushagak District, Copper River, and the Southeast Alaska troll fishery. In all other areas chinook are taken incidentally and mainly in the early portions of the sockeye salmon fisheries. Catches in the Southeast Alaska troll fishery declined in the late 1990s due to U.S./Canada treaty restrictions and declining abundance of chinook salmon in British Columbia and the Pacific Northwest. Chinook salmon catches have been moderate to high in most regions over the last 20 years (Figure 78). Chinook salmon production for many stocks in the Yukon River has been declining in recent years. These stocks have been classified as stocks of concern (Eggers 2003).

Average Weight of Returns

A period of high Alaskan salmon production from the mid-1970s to the late 1990s has been attributed to changes in ocean and atmospheric conditions that increased survival, as well as enhanced hatchery releases (Beamish and Bouillon 1993, Coronado and Hilborn 1998, Mantua et al. 1997). The increased production was accompanied by a decrease in average salmon weight at maturity, 1975-1993, which has been attributed to density dependence (Bigler et al. 1996, Ishida et al. 1993), sea surface temperature (Pyper and Peterman 1999, Hinch et al. 1995, Ishida et al. 1995), and sea surface salinity (Morita et al. 2001). Exceptions to this decreasing trend include AYK sockeye, pink, and chum salmon (Figure 79). The decreasing trend observed in other species and areas generally appears to have leveled off within the last decade (Figure 79).

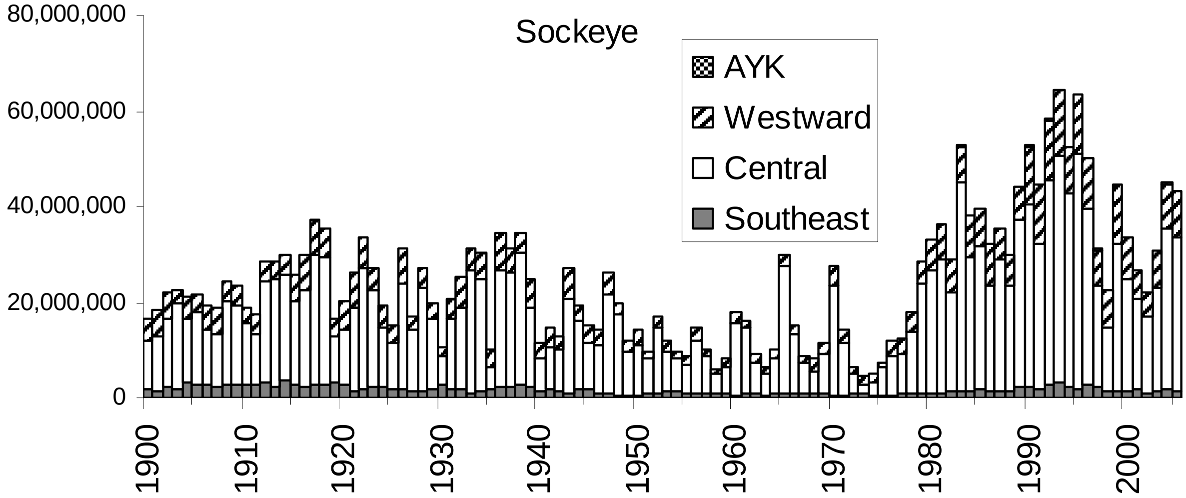

Figure 72. Historical catch of sockeye salmon by area in Alaska, 1900-2005.

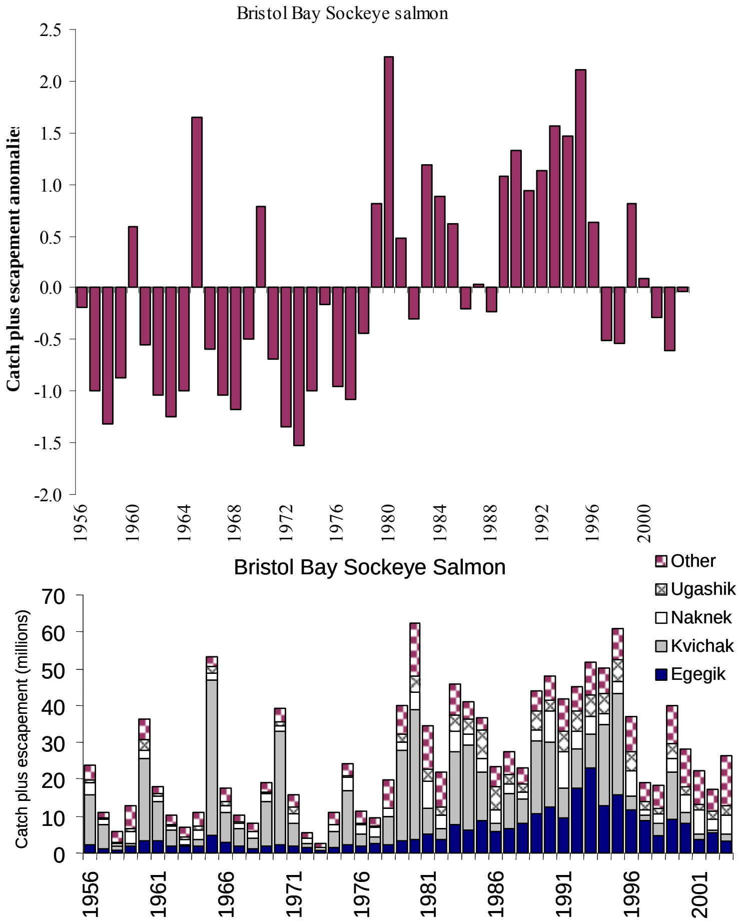

Figure 73. Historical catch plus escapement anomalies of Bristol Bay sockeye salmon, 1900-2003 (top panel). Bristol Bay sockeye salmon catch plus escapement by stock, 1900-2003 (bottom panel). Data provided by Lowell Fair (Alaska Department of Fish and Game).

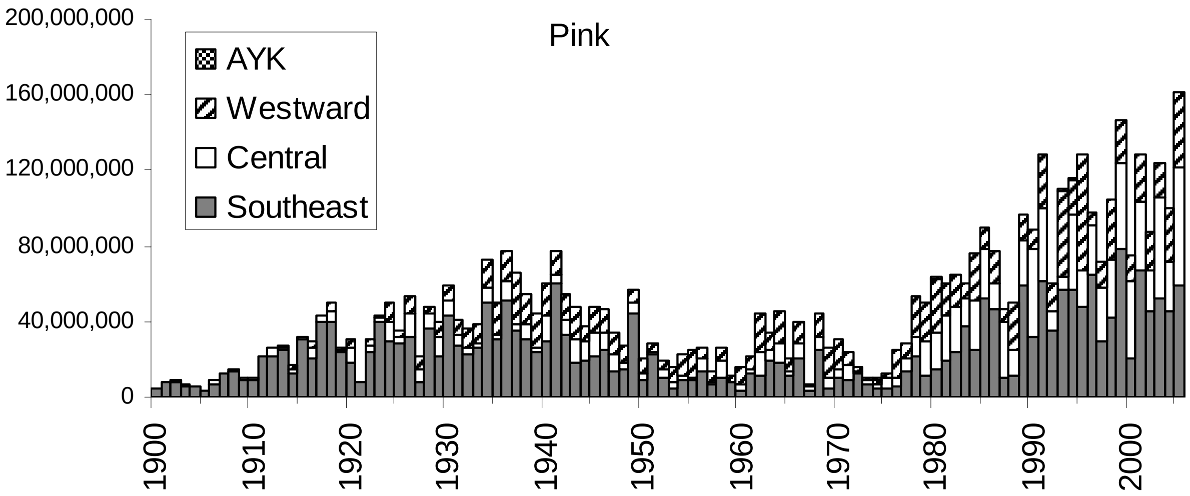

Figure 74. Historical catch of pink salmon by area in Alaska, 1900-2005.

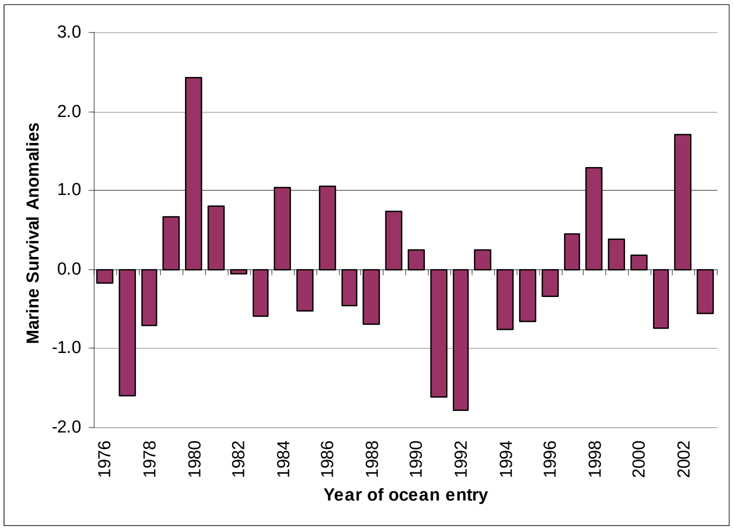

Figure 75. Marine survival of Prince William Sound hatchery pink salmon by year of ocean entry (release year), 1977-2003. Data from 1977-2002 taken from Gray et al. (2002); 2003 data from Gray (Alaska Department of Fish and Game, personal communication) and from Tom Kline (Prince William Sound Science Center, personal communication).

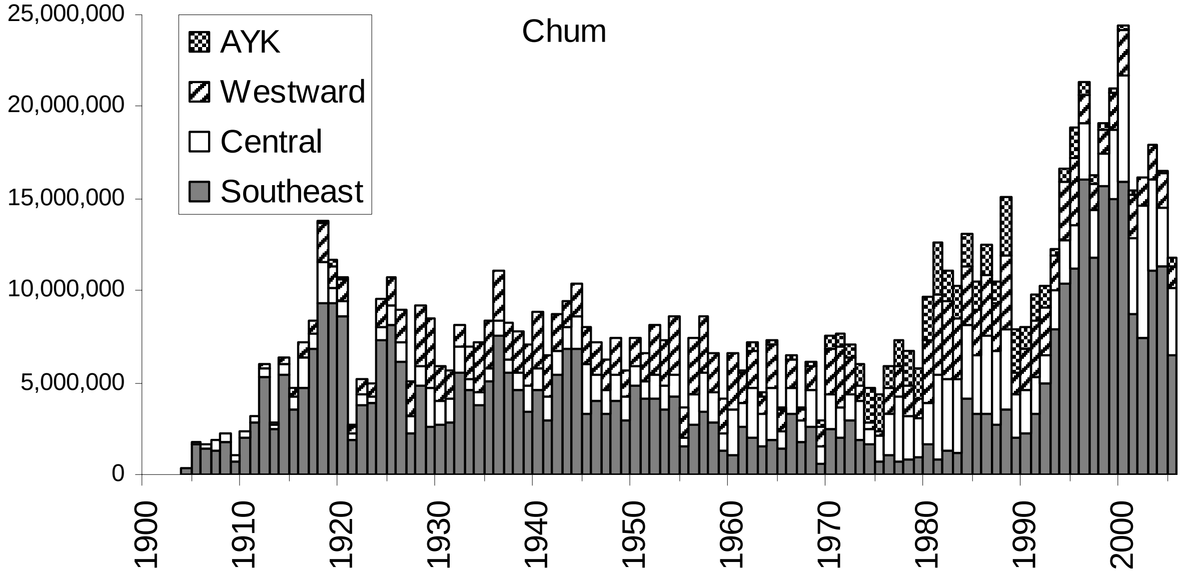

Figure 76. Historical catch of chum salmon by area in Alaska, 1900-2005.

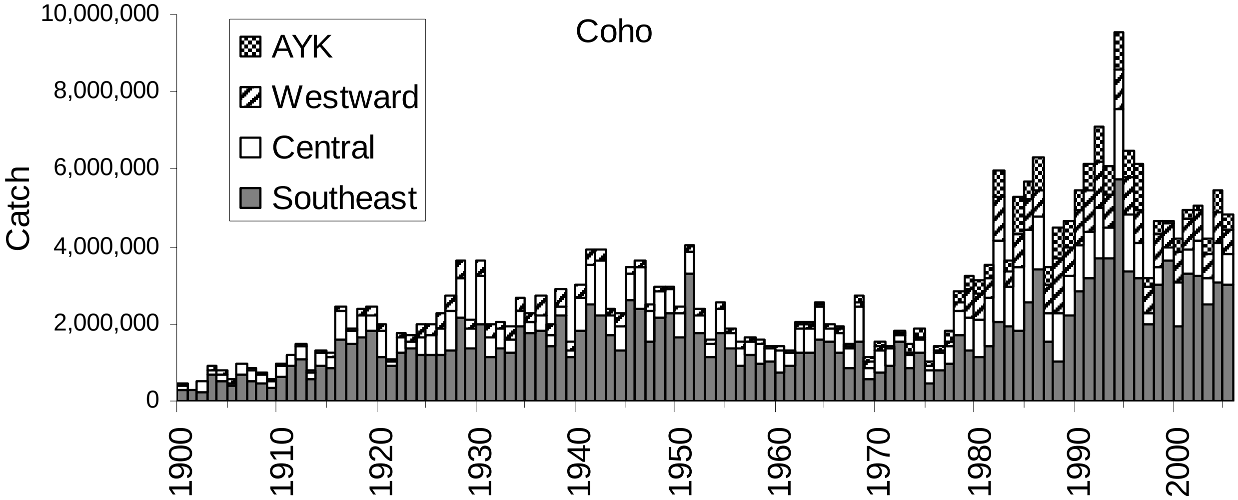

Figure 77. Historical catch of coho salmon by area in Alaska, 1900-2005.

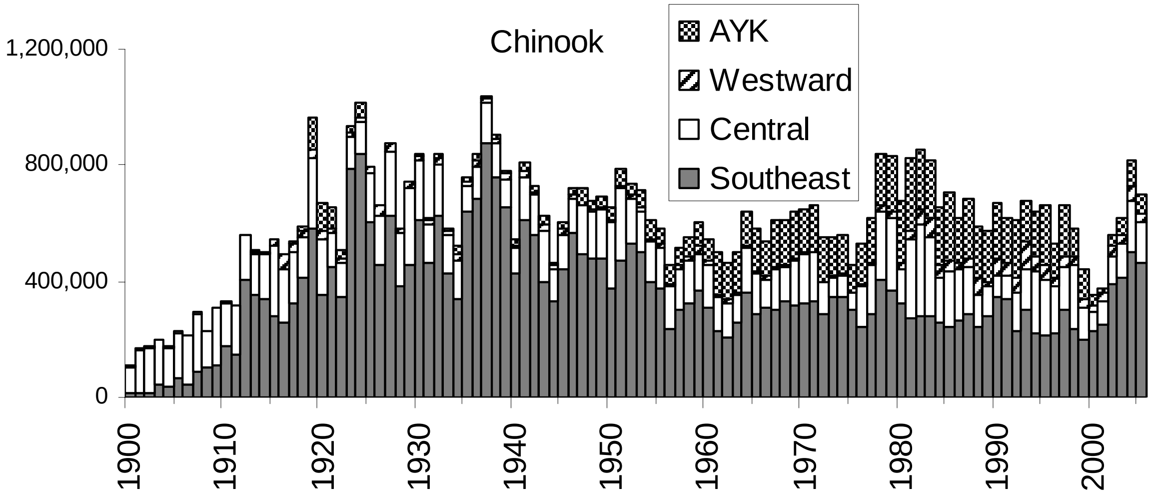

Figure 78. Historical catch of chinook salmon by area in Alaska, 1900-2005.

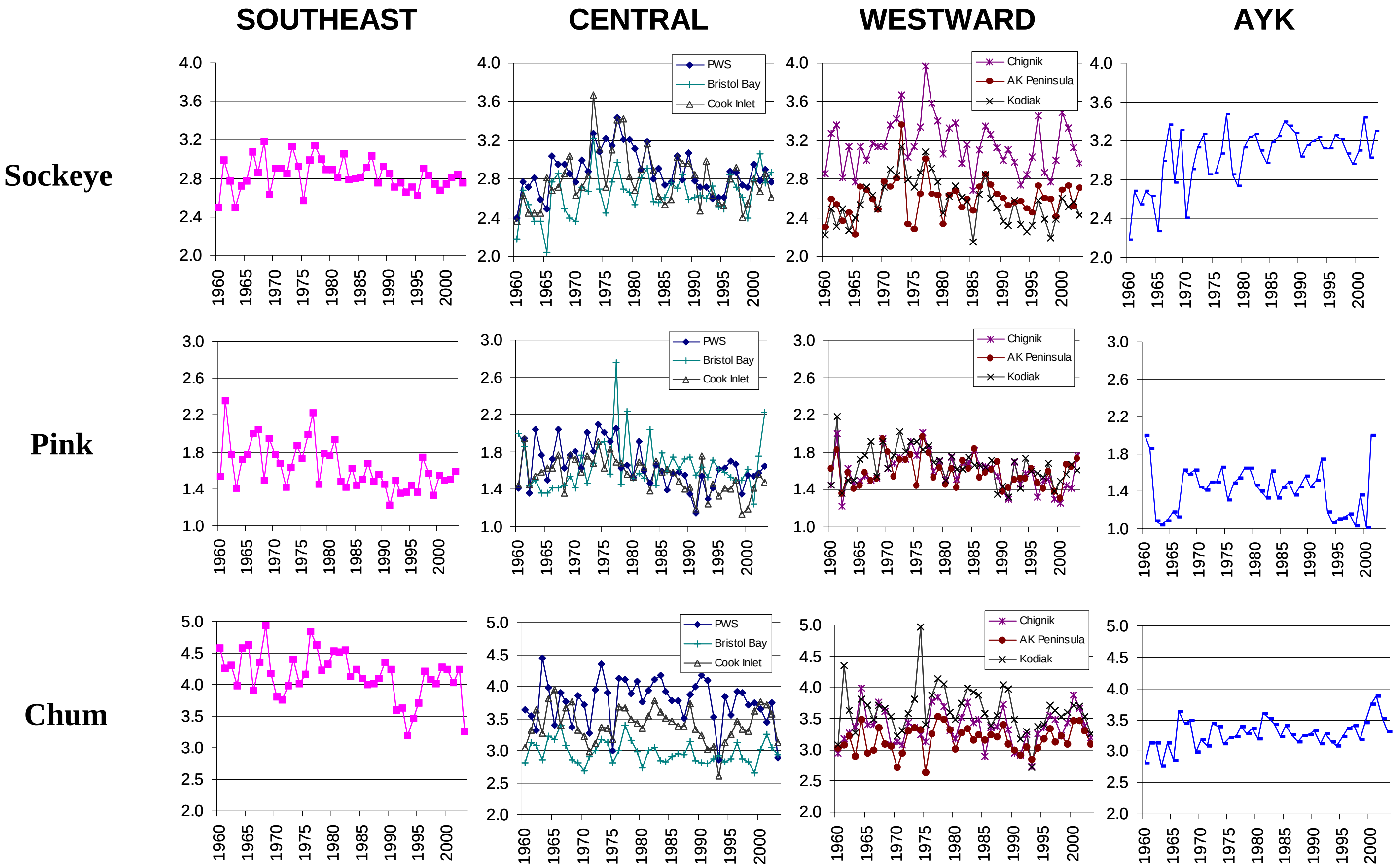

Figure 79. Average weight (kg) of sockeye, pink, and chum salmon in commercial fishery catch by management area, 1960-2003. Data for years 1960-1976 from INPFC (1979). Data for later years from the ADF&G fish ticket system.

Western Alaska juvenile salmon ecology along the eastern Bering Sea shelf.

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Last updated: April 2005

Data from annual BASIS (Bering-Aleutian Salmon International Survey) surveys are being used to address how changing ocean conditions impact the distribution, growth, and survival of North Pacific salmon. The BASIS research program is an international effort among members of the North Pacific Anadromous Fish Commission (Canada, Japan, Republic of South Korea, Russia, and United States). The U.S. BASIS surveys have occurred along the eastern Bering Sea shelf during August–September of 2000–2001 and during August–October of 2002–2004, and have gathered information on the distribution, growth, and condition of western Alaska salmon and on the pelagic ecosystem of the eastern Bering Sea shelf. Physical and biological data including information on frontal boundaries, water column structure, nutrients, phytoplankton, and zooplankton populations are also collected during the surveys.

Results indicate that there are geographical differences in distribution and migration pathways of western Alaska juvenile salmon during this time period (Figure 80). Yukon River salmon stocks are distributed along the western Alaska coast from the Yukon River to latitude 60ºN. Kuskokwim River salmon stocks are generally distributed south of latitude 60ºN from the Kuskokwim River to longitude 175ºW. Bristol Bay stocks are generally distributed within the middle domain between the Alaska Peninsula and latitude 60ºN and from Bristol Bay to longitude 175ºW. The seaward migration from natal freshwater river systems is south and east away from the Yukon River for Yukon River chum salmon, to the east and south away from the Kuskokwim River for Kuskokwim River chum, chinook, and coho salmon, and east away from Bristol Bay river systems for Bristol Bay sockeye salmon stocks. The size and relative abundance of juvenile Bristol Bay sockeye salmon was lowest during 2001 and highest during 2002 and 2003 (Figures 81 and 82). Relative survival of juvenile Bristol Bay sockeye salmon was lowest during 2001 and highest during 2002 (Table 15). It is hypothesized that survival of western Alaska sockeye salmon is linked to their early marine growth and that their growth is related to ocean conditions that influence the offshore distribution of juvenile salmon into areas of higher forage opportunities.

Table 15. The number of returning adult sockeye salmon, average brood year escapements (BYESC), and estimated relative survival for early marine growth years (EMG Yr) 2000 – 2002.

EMG Year	Brood Years	Avg. BYESC (Millions)	Return Years	Returns (Millions)	Relative Survival
2000	1997/1998	7.1	2002/2003	27.1	3.8
2001	1998/1999	10.9	2003/2004	20.4	1.88
2002	1999/2000	10.6	2004/2005	56.6*	5.33

*The 3-ocean sockeye salmon return for 2005 is based on the estimate of the 3-ocean returns from the 2005 Alaska Department of Fish and Game Bristol, Bay sockeye salmon forecast.

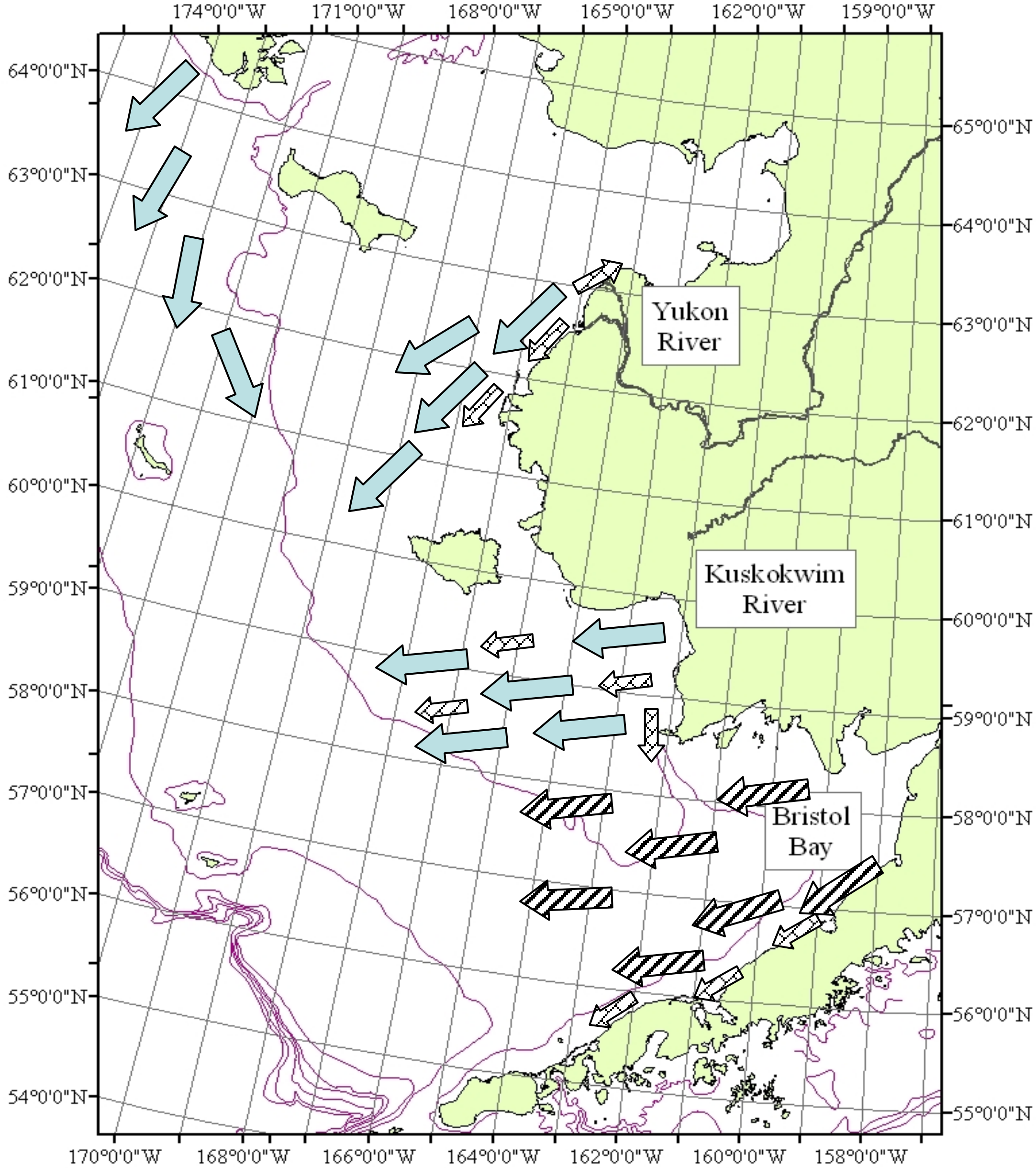

Figure 80. Seaward migration pathways for juvenile chum (solid arrow), sockeye (slashed line arrow), coho, and chinook (boxed line arrow) salmon along the eastern Bering Sea shelf, August through October.

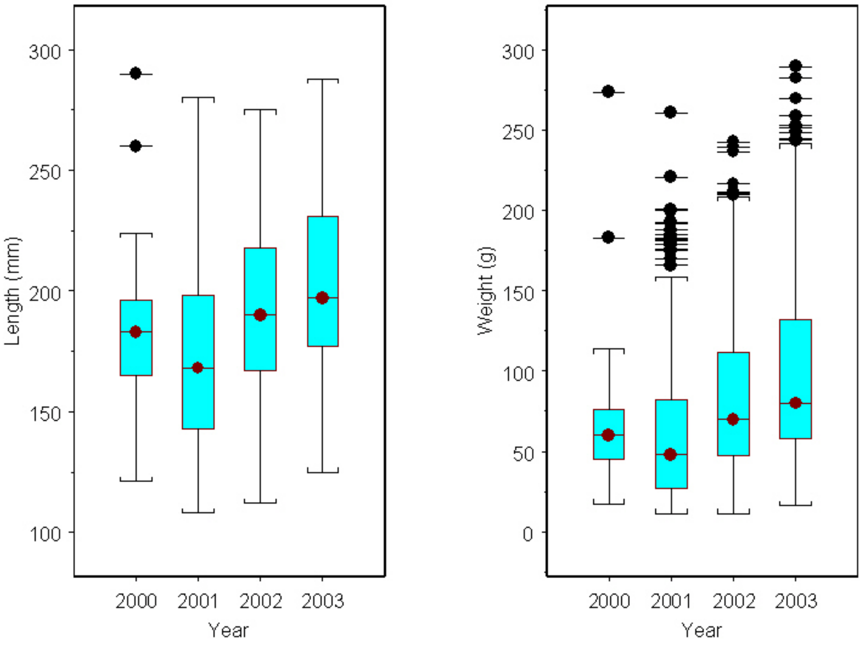

Figure 81. Box plots of juvenile Bristol Bay sockeye salmon fork length (mm) and weight (g) collected along the eastern Bering Sea shelf, August–September of 2000–2003.

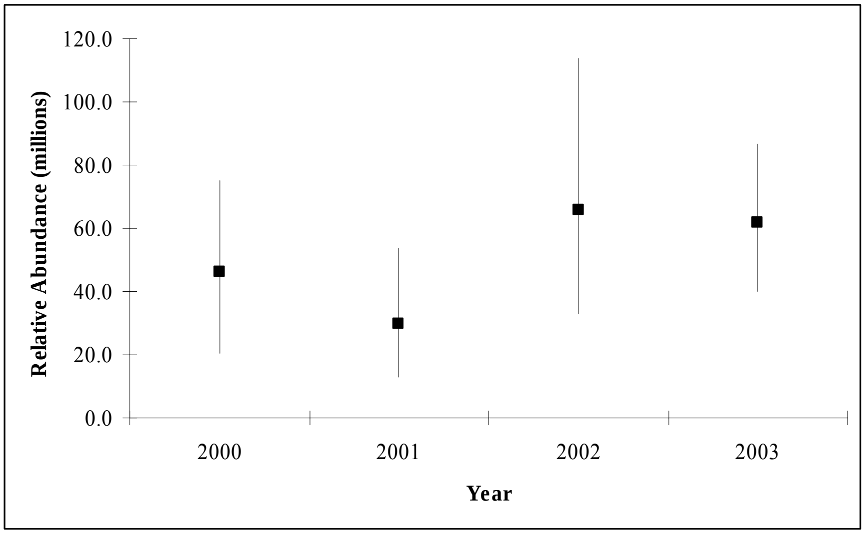

Figure 82. Relative abundance (millions) and 95% confidence intervals of juvenile Bristol Bay sockeye salmon collected along the eastern Bering Sea shelf, August–September of 2000–2003.

Groundfish

Trends in Groundfish Biomass and Recruits per Spawning Biomass

By Jennifer Boldt, Julie Pearce, Steven Hare, and the Alaska Fisheries Science Center Stock Assessment Staff
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Last updated: August 2006

Groundfish that are assessed with age- or size-structured models in the Bering Sea/Aleutian Islands (BSAI) and the Gulf of Alaska (GOA) show different trends. The assessment information is available in the NPFMC stock assessment and fishery evaluation reports (2005 a, b) and on the web at: http://www.afsc.noaa.gov/refm/stocks/assessments.htm. Halibut information was provided by the International Pacific Halibut Commission (IPHC, S. Hare, personal communication).

BIOMASS

Total biomass of BSAI groundfish was apparently low in the late 1970s but increased in the early 1980s to around 20 million metric tons. Some fluctuations in the total biomass have occurred, with biomass below the 1978 to present average occurring in 1978-82 and 1990-91 (Figure 83). Walleye pollock is the dominant species throughout the time series and has influenced observed fluctuations in total biomass.

Gulf of Alaska groundfish biomass trends (Figure 83) are different from those in the BSAI. Although biomass increased in the early 1980s, as also seen in the BSAI, GOA biomass declined after peaking in 1982 at over 6 million metric tons. Total biomass has been fairly stable since 1985 however the species composition has changed. Pollock were the dominant groundfish species prior to 1986 but arrowtooth flounder has increased in biomass and is now dominant. The 2005 IPHC stock assessment of halibut, ages 6 and older, for the GOA (areas 2C, and 3A) indicates halibut biomass increased from 1978 to 1996 and declined slightly during 1997-2005. Biomass levels in 2005 were still above the 1978-present average.

RECRUIT PER SPAWNING BIOMASS

Methods

Median recruit per spawning biomass (log(R/S)) anomalies were calculated for each species to provide an index of survival (Figures 84-87). In stocks that are abundant, the relationship between recruits and spawners will not be linear and density dependent factors may limit recruitment. Under these circumstances, the pattern of recruits per spawner will appear as an inverse of the pattern of spawning biomass as annual rates of production have leveled off. For this reason, it is important to also consider recruitment, as well as recruits per spawning biomass. Abundance of recruits for each species was lagged by the appropriate number of years to match the spawning biomass that produced them. For graphical display, the median of each time series was subtracted from the log-transformed recruit per spawning biomass ratios and expressed as a proportion of the median (Figures 84-87). A sequential t-test analysis of regime shifts (STARS; Rodionov 2005, Rodionov and Overland 2005) was used to determine if there were significant shifts in the logged recruit per spawning biomass ratios. The STARS method sequentially tests whether each data point in a time series is significantly different from the mean of the data points representing the latest regime (Rodionov and Overland 2005). The last data point in a time series may be identified as the beginning of a new regime; and, as more data is added to the time series, this is confirmed or rejected. Two variables are needed for the STARS method: the cutoff value (minimum length of regimes) and the p-value (probability level). For this analysis, a cutoff value of 10 years and a p-value of 0.10 were chosen. A description of STARS and software is available at: http://www.beringclimate.noaa.gov/index.html. An analysis of recruitment is not included in this section; however, Mueter (see contribution in this report) examined combined standardized indices of groundfish recruitment and survival rate. Mueter's indices of survival rate are calculated as residuals from stock-recruit relationships, thereby, accounting for density dependence and providing an alternative examination of groundfish survival.

Results

Regime shift indices averaged across stocks within the BSAI indicated that several stocks experience negative step-changes in log(R/S) in the late 1980s; however, in general, there was no indication of uniform step changes in all stocks in the late 1970s (BSAI or GOA) or in the late 1980s (in the GOA; Figure 88). When groundfish time series are combined (see Mueter, this report) there does appear to be a system-wide shift in groundfish survival and recruitment within the BSAI and GOA in the late 1980s.

Roundfish (gadids, Atka mackerel, and sablefish) typically did not show a shift in 1976-77 or 1988-89 in the BSAI or GOA (Figures 84-87). Instead, shifts were observed in the early to mid-1980s and potential shifts were identified in 1998-2001.

Several BSAI flatfish had high survival prior to the late 1980s and low survival in the 1990s, including Greenland turbot, arrowtooth flounder, yellowfin sole, northern rock sole and flathead sole (Figures 84-87). This was not the case for GOA flatfish, which tended to show shifts in the late 1990s.

Pacific ocean perch generally showed positive shifts in the late 1970s and negative shifts in the late 1980s to the early 1990s, in both the BSAI and GOA (Figures 84-87). Other rockfish showed shifts in other years or no shifts at all. GOA northern rockfish had a period of anomalously low survival between 1986 and 1994.

Conclusions

The survival of roundfish generally did not appear to be affected by the 1976-77 or the 1988-89 climate regime shifts. Examination of the average recruit per spawning biomass anomalies, however, indicates roundfish experience similar trends in survival within ecosystems. For example, pollock and cod have similar recruit per spawner trends within both the BSAI and GOA (Figure 88). Aleutian Island pollock and Atka mackerel (not included in this analysis) also show similar patterns in recruitment (Barbeaux et al. 2003). This may be an indication that roundfish respond in similar ways to large-scale climate changes.

Flatfish survival did appear to be related to known climate regime shifts, especially the late 1980s shift. In particular, the BSAI winter spawning flatfish (rock sole, flathead sole and arrowtooth flounder) showed a negative shift in survival in the late 1980s. Examination of the recruitment of winter-spawning flatfish in the Bering Sea in relation to decadal atmospheric forcing indicates favorable recruitment may be linked to wind direction during spring (Wilderbuer et al. 2002; Wilderbuer and Ingraham, this report). Years of consecutive strong recruitment for these species in the 1980s corresponds to years when wind-driven advection of larvae to favorable inshore nursery grounds in Bristol Bay prevailed. The pattern of springtime wind changed to an off-shore direction during the 1990s which coincided with below-average recruitment.

Pacific ocean perch survival also appears to be related to decadal-scale variability since it responded positively to the late 1970s shift and negatively to the late 1980s shift. The mechanism causing these shifts in survival is unknown. Recruit per spawning biomass ratios are autocorrelated in long-lived species, such as rockfish.

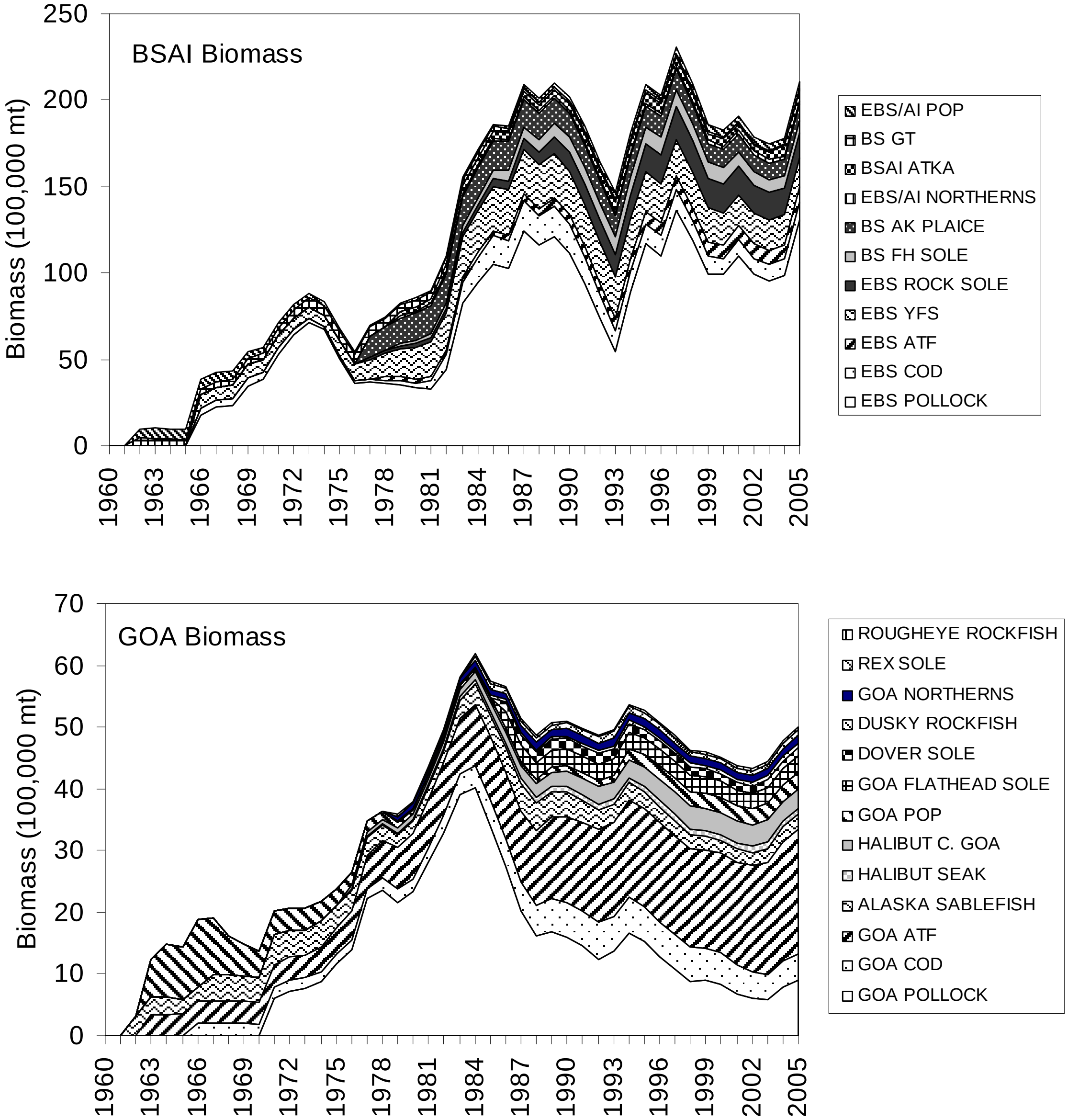

Figure 83. Groundfish biomass trends (100,000 metric tons) in the BSAI and GOA from 1960-2005, as determined from age-structured models of the Alaska Fisheries Science Center reported by NPFMC (2005 a, b). Halibut data provided by the IPHC (S. Hare, personal communication).

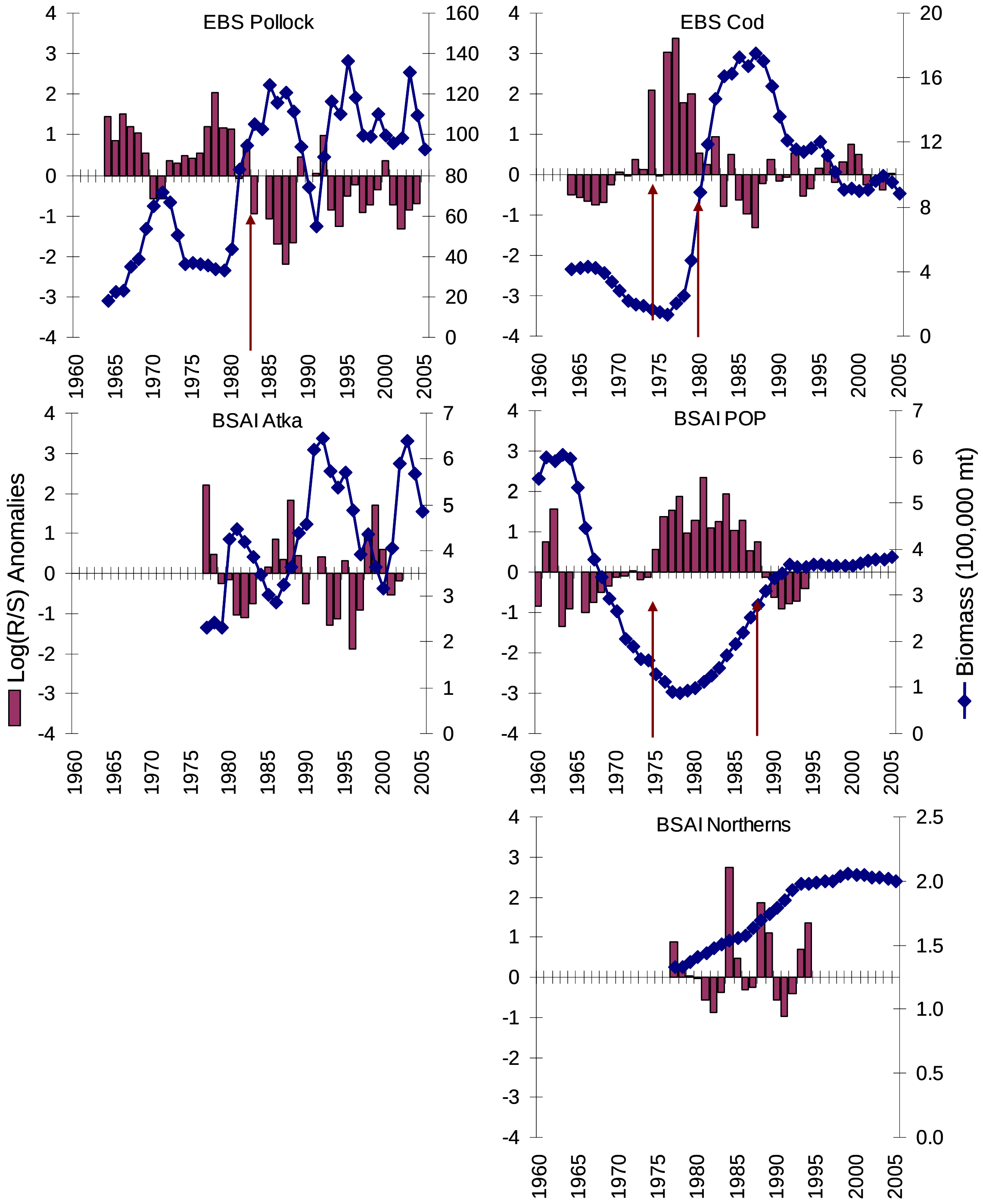

Figure 84. Median recruit per spawning biomass anomalies and biomasss for BSAI groundfish species assessed with age- or size-structured models, 1960-2005. EBS = Eastern Bering Sea, BS = Bering Sea, AI = Aleutian Islands, POP = Pacific ocean perch, GT = Greenland turbot, Atka = Atka mackerel.

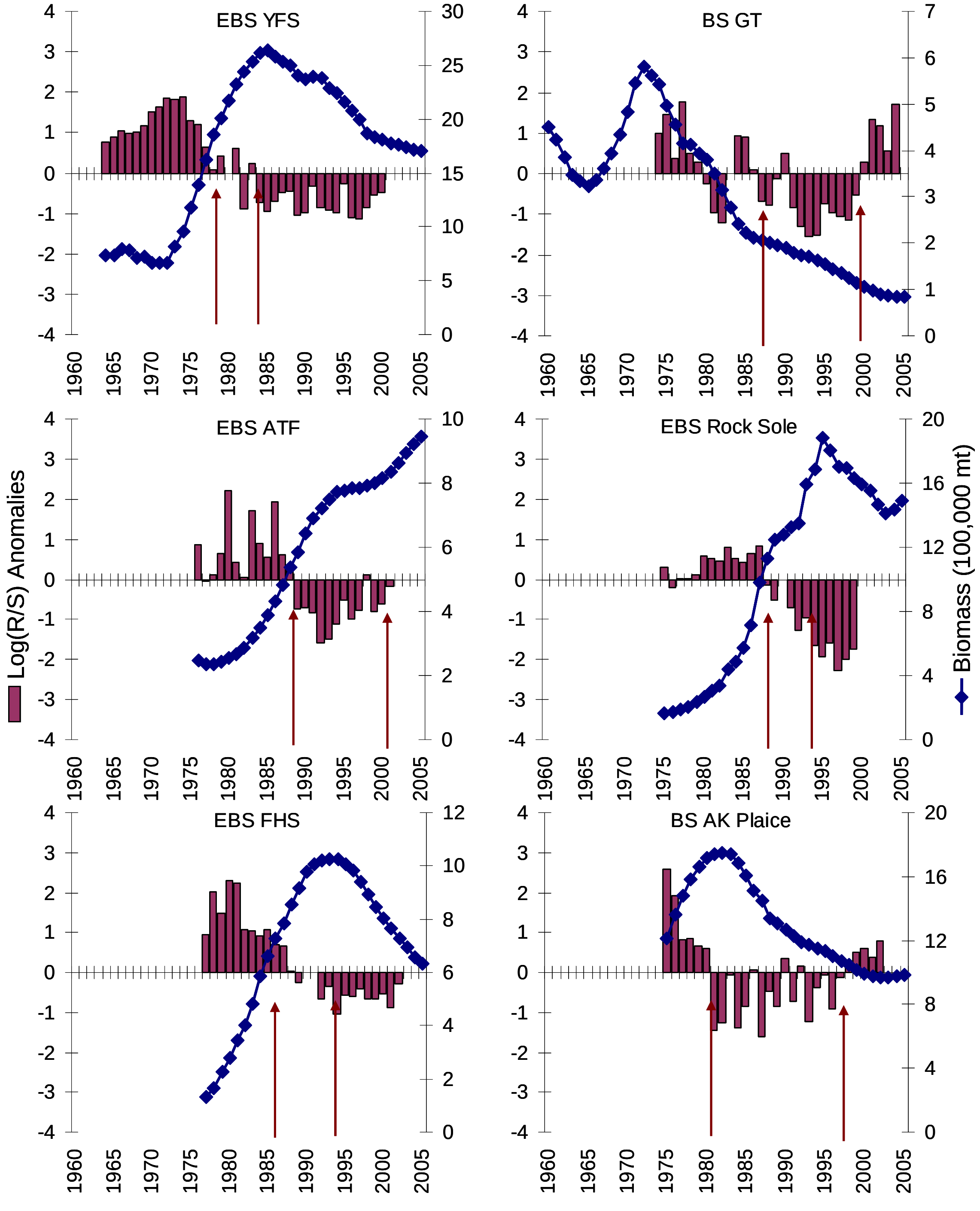

Figure 85. Median recruit per spawning biomass anomalies and biomasss for BSAI groundfish species assessed with age- or size-structured models, 1960-2005. EBS = Eastern Bering Sea, BS = Bering Sea, AK= Alaska, YFS = yellowfin sole, ATF = arrowtooth flounder, FHS= flathead sole, GT = Greenland turbot.

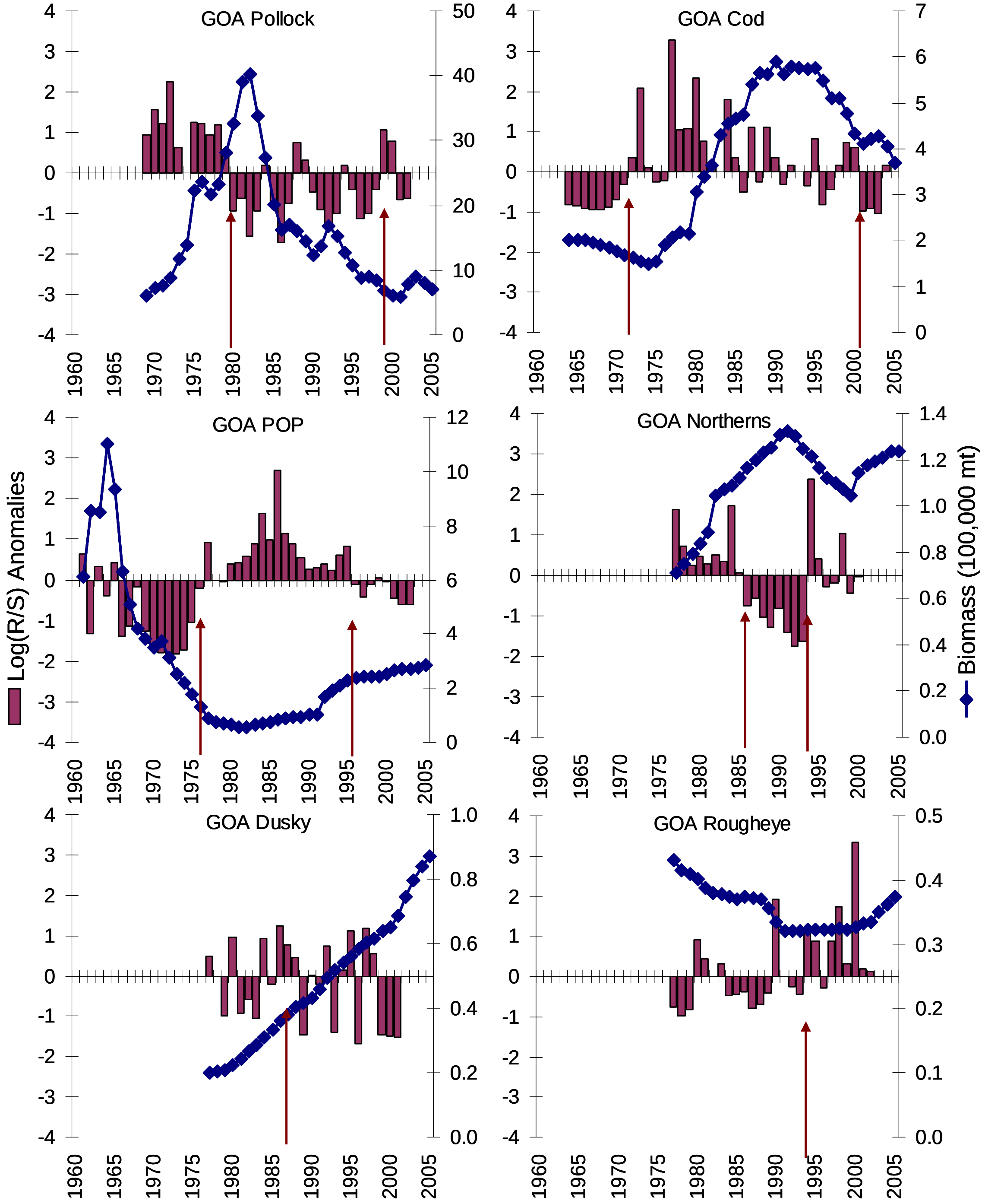

Figure 86. Median recruit per spawning biomass anomalies for GOA groundfish species assessed with age- or size-structured models, 1960-2003. GOA = Gulf of Alaska, POP = Pacific Ocean perch, Dusky = Dusky rockfish.

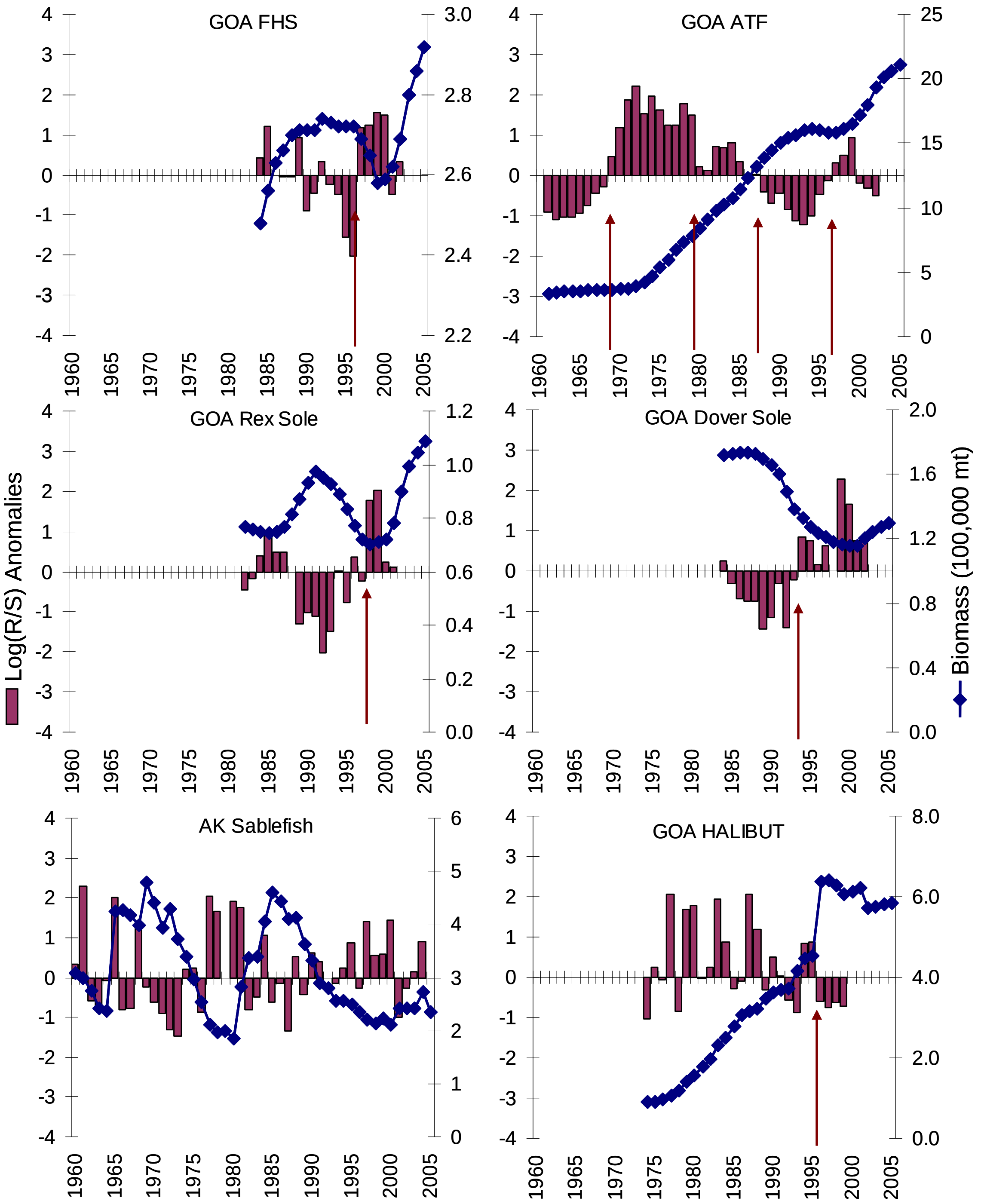

Figure 87. Median recruit per spawning biomass anomalies for GOA groundfish species assessed with age- or size-structured models, 1960-2003. GOA = Gulf of Alaska, ATF = arrowtooth flounder FHS = flathead sole.

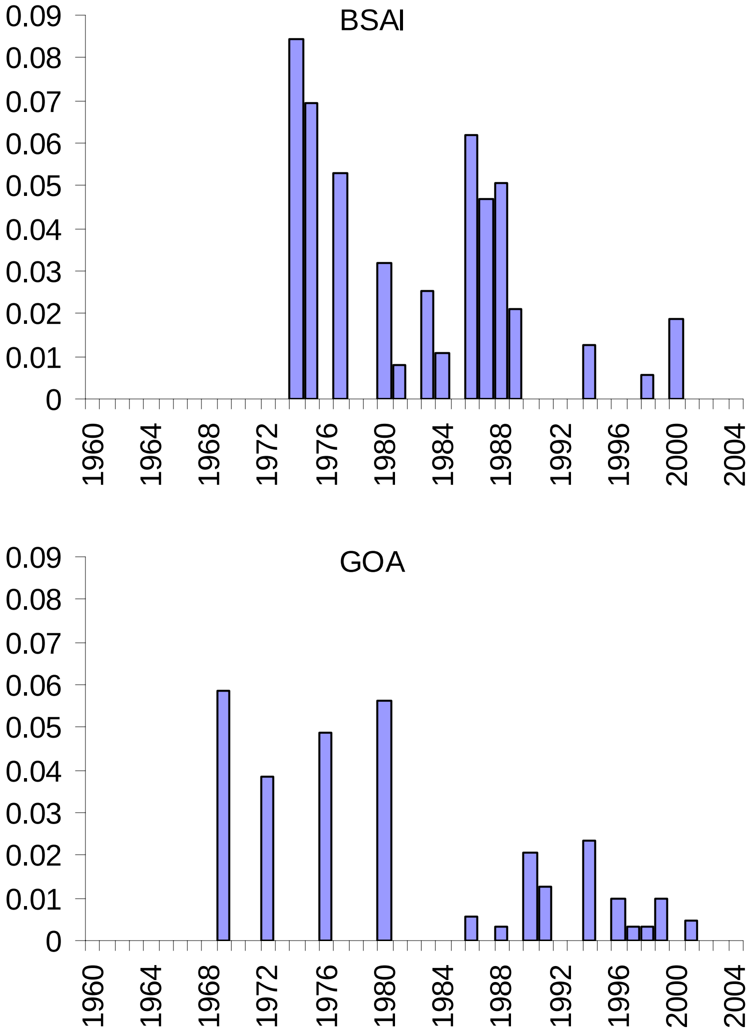

Figure 88. Average regime shift indices (RSI) values from the STARS (Rodionov 2005, Rodionov and Overland 2005) analysis (absolute values that indicate strength of step change) on log recruit per spawning biomass anomalies in each year for the BSAI and GOA.

Update on EBS winter spawning flatfish recruitment and wind forcing

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Last updated: August 2006

Wilderbuer et al. (2002) summarized a study examining the recruitment of winter-spawning flatfish in relation to decadal atmospheric forcing, linking favorable recruitment to the direction of wind forcing during spring. OSCURS model time series runs indicated in-shore advection to favorable nursery grounds in Bristol Bay during the 1980s. The pattern change to off-shore in the 1990- 97 time series coincided with below-average recruitment for northern rock sole, arrowtooth flounder and flathead sole, relative to the 1980s. The time series is updated (2001-2006; Figure 89) for the last 6 years.

Five out of six OSCURS runs for 2001-2006 were consistent with those which produced above-average recruitment in the original analysis, 2005 being the exception. The north-northeast drift pattern suggests that larvae may have been advected to favorable, near-shore areas of Bristol Bay by the time of their metamorphosis to a benthic form of juvenile flatfish. Preliminary estimates of rock sole recruitment in recent years are consistent with this larval drift hypothesis (Figure 89). For arrowtooth flounder and flathead sole, the correspondence between the springtime drift pattern from OSCURS and estimates of year class strength have weakened since the 1990s. Arrowtooth flounder produced year classes of average strength during some off-shore drift years, suggesting that this species may have different settlement preferences than northern rock role. In the case of flathead sole, weak recruitment has persisted since the 1990s with no apparent response to the surface wind advection pattern.

The end point of the drift trajectory in 2005 was the furthest offshore of any since 2000; therefore, recruitment strength for the 2005 year class of northern rock sole may be weak.

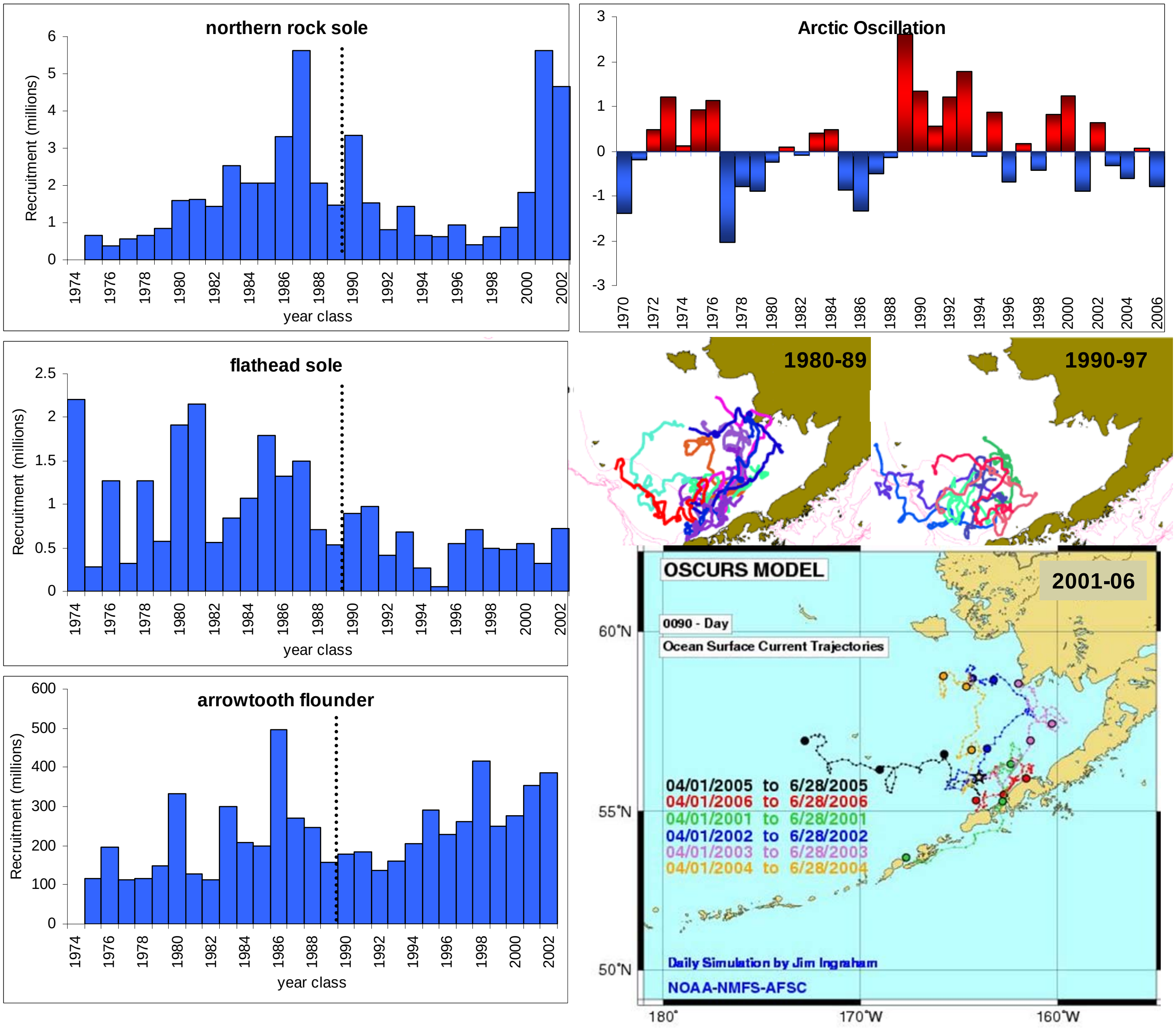

Figure 89. The left column shows recruitment of northern rock sole, flathead sole, and arrowtooth flounder in the Bering Sea (1974-2002). The right column shows the Arctic Oscillation index (1970-2006), along with OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56° N, 164° W from April 1-June 30 for three periods: 1980-89, 1990-97, and 2001-2006.

Relationships between EBS flatfish spatial distributions and environmental variability from 1982-2004

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Last updated: September 2005

Previous studies have noted that the relationship between habitat use of EBS flatfish (as measured by CPUE from summer trawl surveys) and temperature has generally remained constant over time (Swartzman et al. 1992), motivating the hypothesis that flatfish may shift distributions in order to maintain temperature preferences. Recent bottom temperatures in the EBS show considerable contrast and thus provide opportunity to examine the relationship of flatfish distributions to temperature variability. For example, 1999 was one of the coldest years on record and a warming trend has occurred since 2000 such that 2003 and 2004 were two of the warmest years observed. The average latitude and longitude, by year, of the EBS shelf survey stations within the "cold pool" (defined as water < 2˚C) was computed, as well as the annual centroids (average latitude and longitude of survey stations containing a particular species, weighted by EBS shelf survey CPUE). Ellipses of fish distributions were centered on the centroids and were computed as contour encompassing a probability of 50% for a bivariate normal distribution. Locations of the cold pool centers and the distribution ellipses were then contrasted between the years with the five lowest (1999, 1994, 1995, 1986, and 1992) and highest (2003, 1996, 2004, 1998, and 2002) mean temperatures since 1982.

For flathead sole and rock sole, the location of the distribution ellipses were related to environmental conditions (Figure 90a). The center of the cold pool was located further to the southeast during the cold years, and three of the five warmest years observed in the 1982-2004 time series have occurred since 2002, providing evidence of the recent warming trend. The locations of the distribution ellipses for flathead sole and rock sole are generally located further to the north or northwest during the warm years (shown in red) relative to cold years (shown in blue). In particular, the northern boundaries of the distribution ellipses for rock sole in each of the warm years are located farther north than the northern boundaries from each of the cold years. In contrast, although Alaska plaice distributional ellipses have moved slightly they do not show a correspondence with environmental conditions (Figure 90b).

Correlation analysis was used to assess the relationship between the proportion of the population distribution (based upon survey CPUE) located in the southeast EBS shelf survey strata (south of a line extending from approximately from the north end of Kuskokwim Bay to the Pribilof Islands) to the proportion of the cold pool located in the southeast survey strata. The time series were standardized by subtracting the mean and dividing by the standard deviation. Significant correlations with the cold pool location were found for rock sole and flathead sole, but non-significant relationships for other species (Figure 91). For flathead sole and rock sole, relatively small proportions of the population (low standardized values) are found in the southeast strata during warm years in which a relatively small portion of the cold pool is located in this area. This finding suggests that flatfish habitat selection is related not only to sea floor characteristics, but is also influenced by temporally varying environmental conditions.

The diet of flathead sole consists of a greater proportion of fish than other small flatfish, and one hypothesis is that flathead sole distributions may be linked to prey fish populations which in turn may be related to temperature. For rock sole, density-dependent changes in growth and population distribution have also been observed (Walters and Wilderbuer 2000), confounding the results observed here. Ongoing research is currently investigating models that simultaneously evaluate the effects of population density and environmental variability.

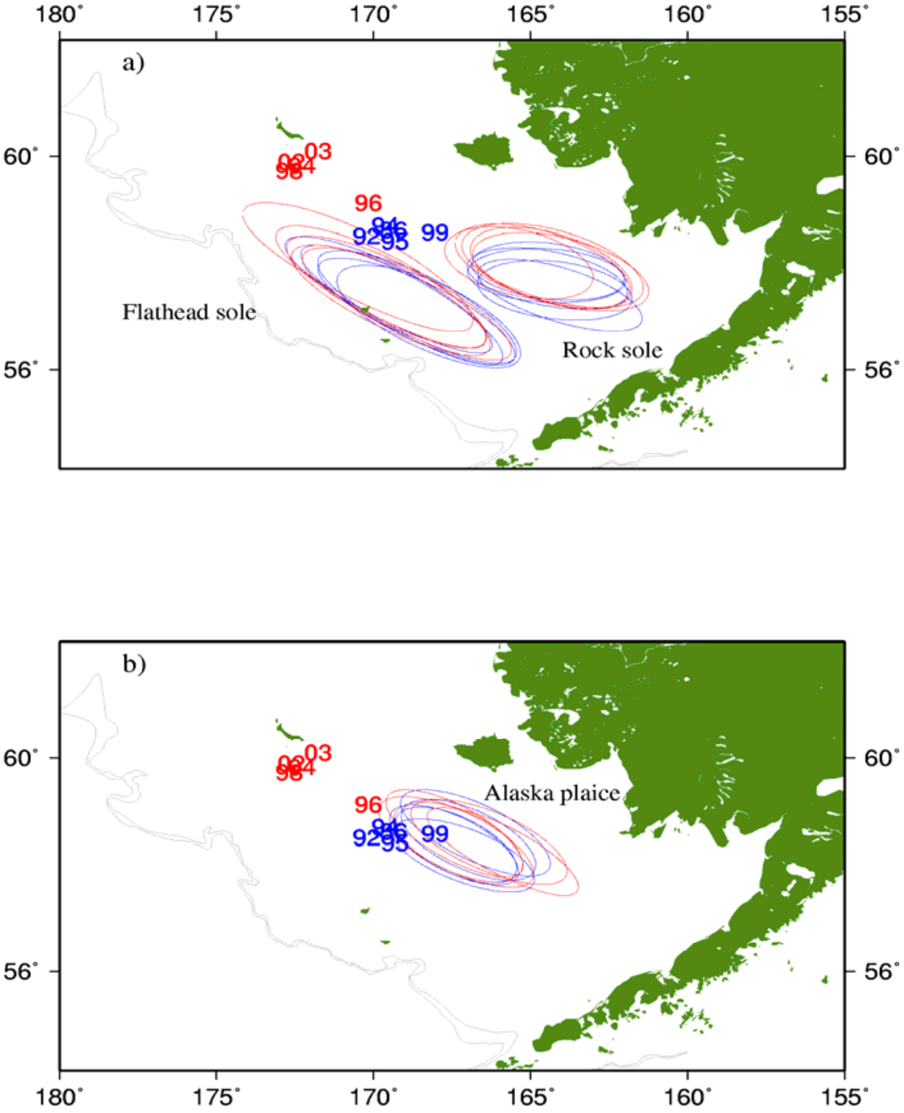

Figure 90. Centers of the cold pool, label by year, from the five warmest (red) and coldest (blue) years observed from 1982-2004, and the distributional ellipses encompassing a probability of 50% for a bivariate normal distribution (based upon EBS shelf survey CPUE data) for flathead sole and rock sole (a) and Alaska plaice (b).

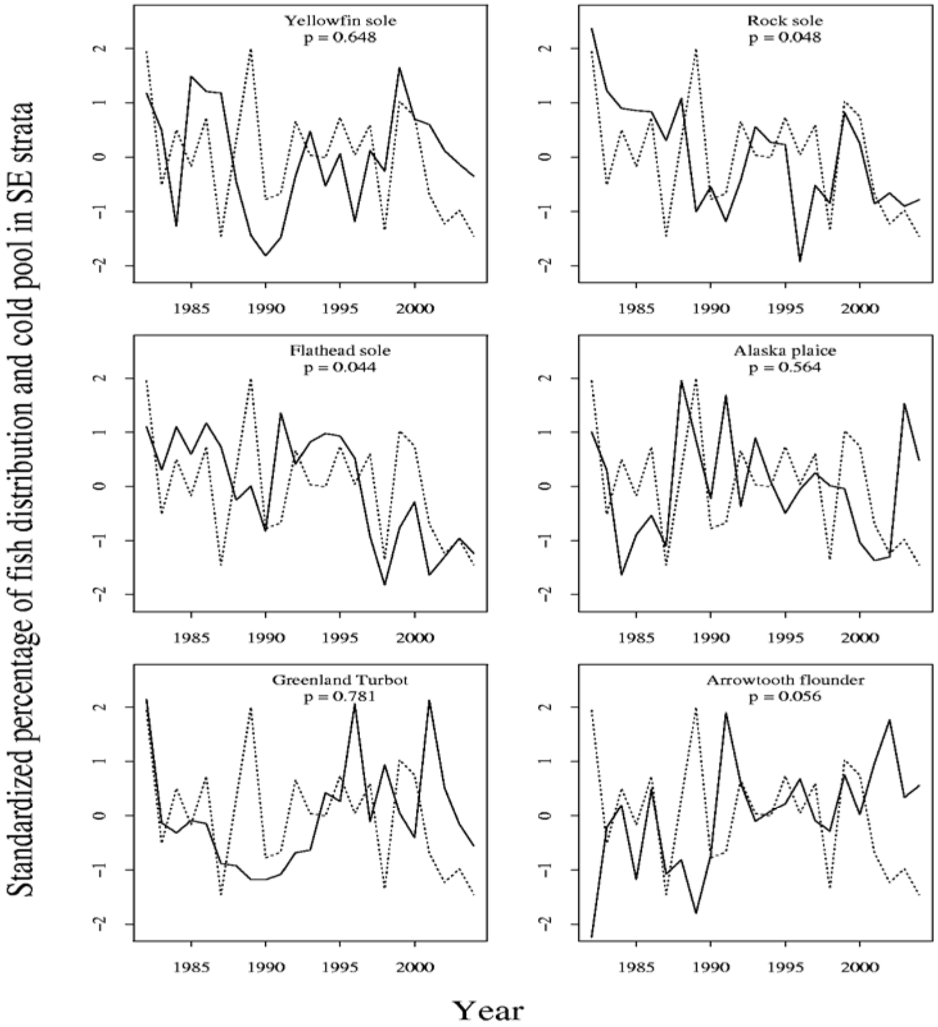

Figure 91. Time series of the standardized proportions of fish populations (solid lines) and proportion of the cold pool (dashed lines) located in the southeast EBS shelf survey strata. Data were standardized by subtracting the mean and dividing by the standard deviation; positive values indicate relatively higher percent with the SE survey strata.

Benthic Communities and Non-target Fish Species

ADF&G Gulf of Alaska Trawl Survey

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Last updated: November 2006

The Alaska Department of Fish and Game continued its trawl survey for crab and groundfish in 2006. The 400 Eastern trawl net is targeted on areas of soft substrate around Kodiak Island, the Alaska Peninsula, and the Eastern Aleutian Islands. While the survey covers a large portion of the central and western Gulf of Alaska, results from Kiliuda and Ugak Bays and the immediately contiguous Barnabas Gully (Figure 92) are broadly representative of the survey results across the region. These areas have been surveyed continuously since 1984, but the most consistent time series begins in 1988.

Ugak Bay was also the subject of an intensive seasonal trawl survey in 1976-1977 also using a 400 Eastern trawl net (Blackburn 1979). Ugak Bay is a very different place than it was in 1976. Red king crabs were a main component of the catch in 1976-1977, but now are nearly non-existent. Flathead sole, skate, and gadid catch rates have all increased roughly 10-fold. While Pacific cod made up 88% and walleye pollock 10% of the gadid catch in 1976-1977, the 2006 catch was a reverse of this composition with Pacific cod making up 13% of catch and walleye pollock 87%. The most striking result of the 2006 survey was the record number of Tanner crabs caught in some stations in Ugak Bay.

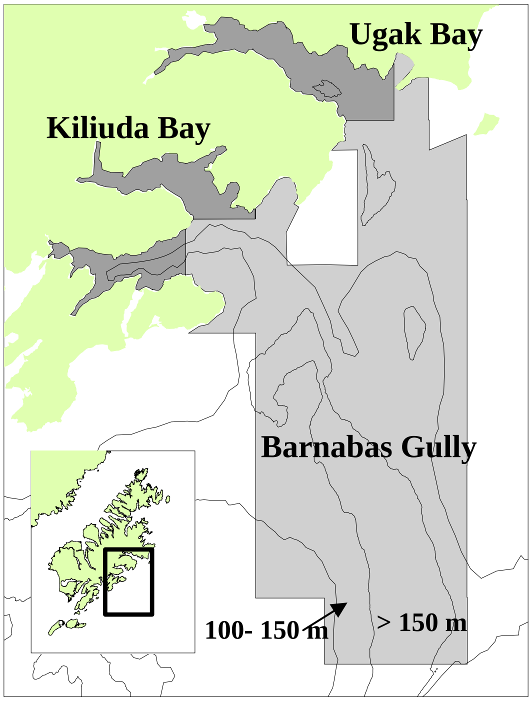

Figure 92. Adjoining survey areas on the east side of Kodiak Island used to characterize bay (dark gray, 14 stations) and ocean (light gray, 33 stations) trawl survey results. For two missing stations, the catch results from the 2005 survey were used.

Arrowtooth flounder are the main component of the offshore catches, while Tanner crab have replaced flathead sole as the largest catch in the bays (Figures 93-94). Overall catch rates have increased in recent years with the increase especially dramatic in the 2006 catches. It is not known if the increased catches are directly related to increased productivity in the area or if it is an artifact of slightly different gear configuration and towing practices.

Standardized anomalies for the 2006 survey were calculated and plotted by station for selected species (skates, arrowtooth flounder, flathead sole, and Tanner crab) using a similar method as Link et al. (2002) and DFO (2003) and using large mesh trawl survey data from 1988-2006. The increased catches have contributed to the wide distribution of positive values for the standardized anomalies plotted (Figure 94). Anomaly values greater than 3.0 were recorded in both inshore and offshore stations for each of the selected species (Figure 94).

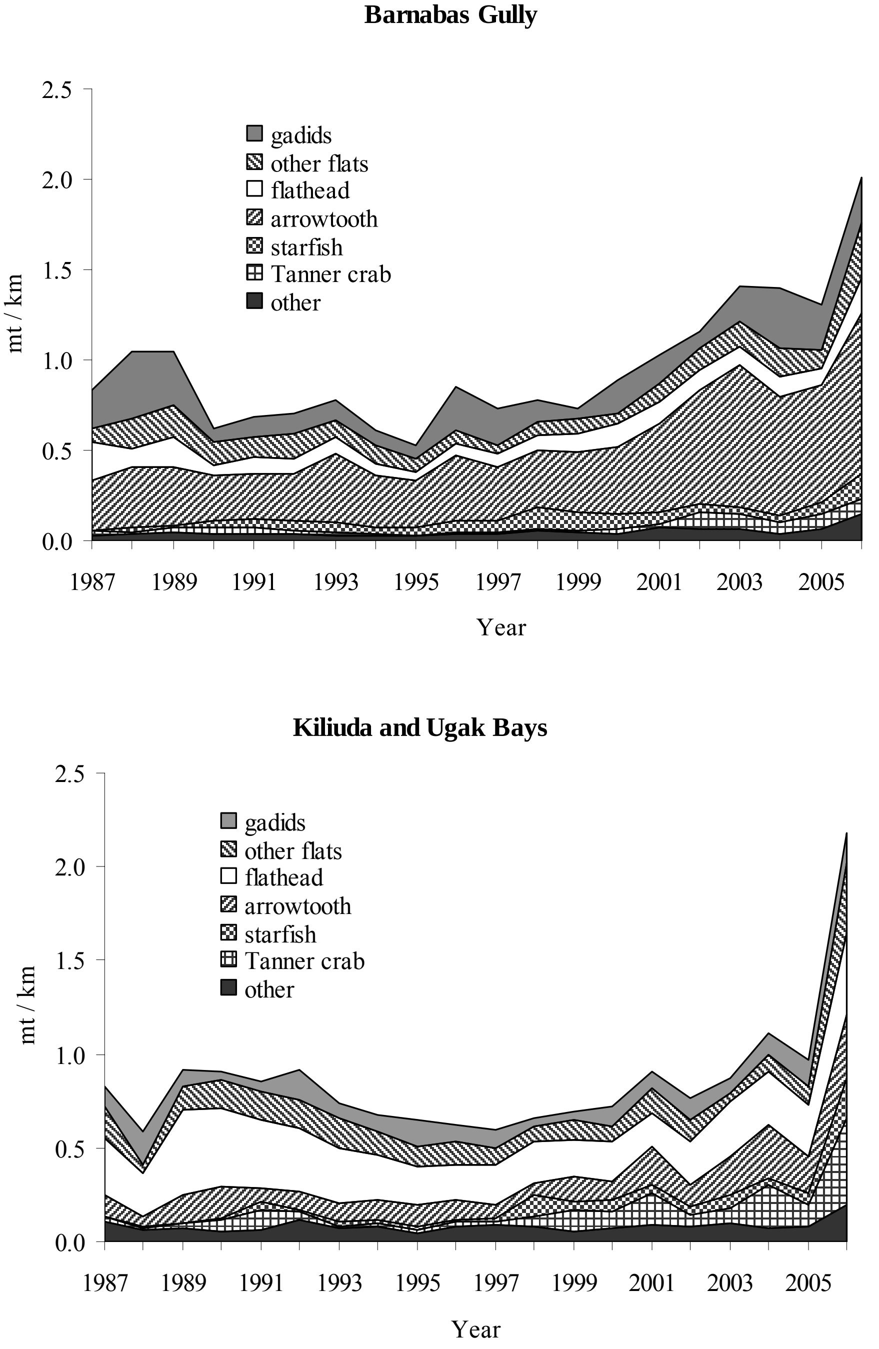

Figure 93. Metric tons per kilometer caught from 1987 to 2006 during the ADF&G large mesh trawl survey from adjacent areas off the east side of Kodiak Island.

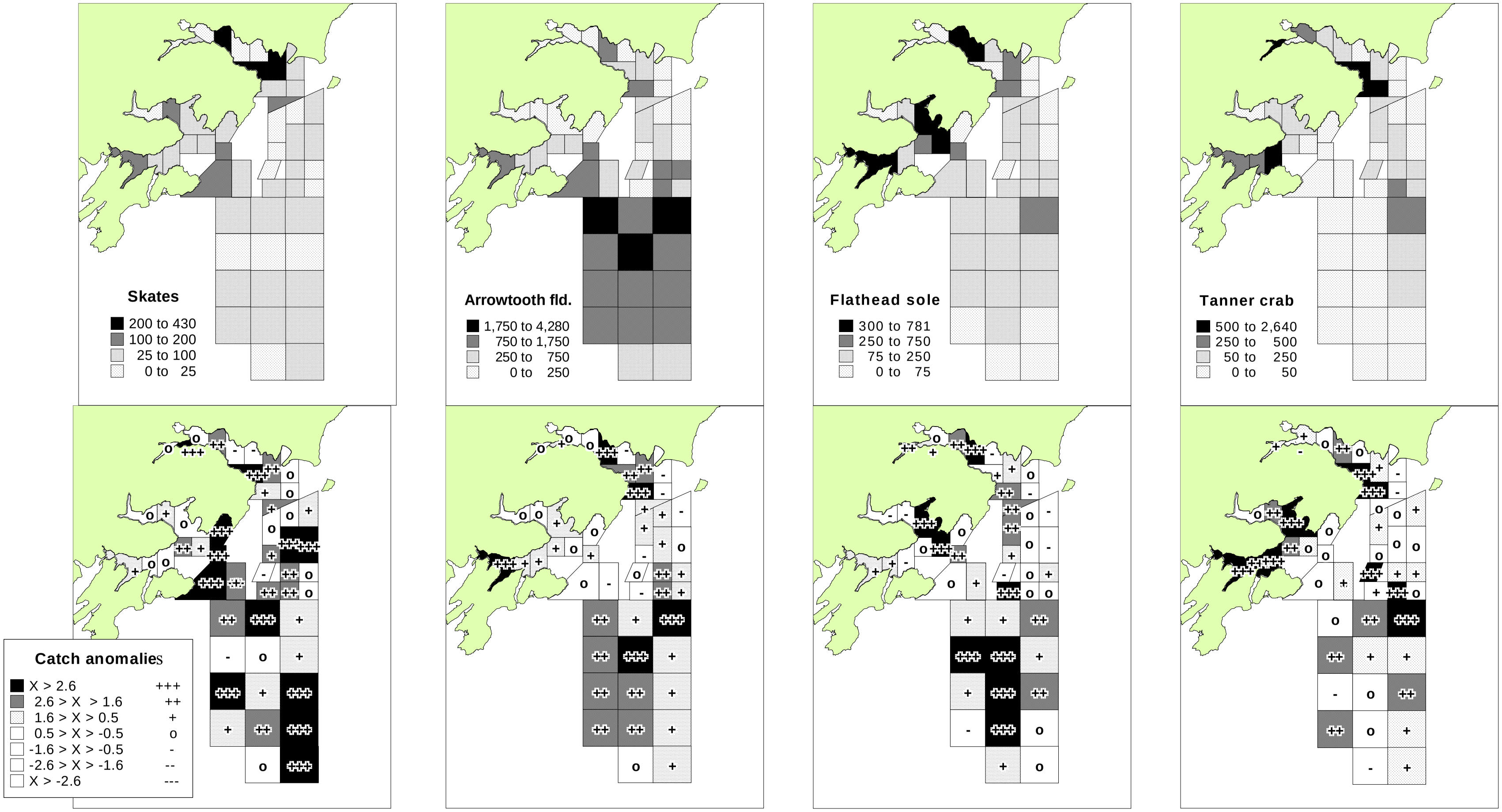

Figure 94. Catch mt/km (top map series) and standardized anomalies (lower maps) of the 2006 catch as compared to the 1988-2006 survey catches.

Gulf of Alaska Small Mesh Trawl Survey Trends

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Last updated: November 2006

Annual small-mesh trawl surveys of the nearshore Gulf of Alaska have been conducted by NMFS and ADF&G using standard methods since 1972 (n = 8,215 hauls). Sampling in 2005 occurred between 26 September and 30 October around Kodiak Island (Chiniak, Inner and Outer Marmot, Uyak, Uganik, Ugak, Kiliuda and Alitak Bays and Two-Headed Gully) and the Alaska Peninsula (Kukak, Puale, Wide and Pavlof Bays), and in Shelikof Strait (n = 132 hauls). This contribution describes trends in the abundance of some ecologically important taxa which may serve as indicators of community state. More detailed results for the 2005 survey can be found in Jackson (2006).

The small-mesh time series shows the transition from a community rich in shrimp and capelin to a community rich in groundfish following the 1976/1977 Pacific Decadal Oscillation (PDO) regime shift (Anderson and Piatt 1999). Catches through 2005 do not show any significant deviation from the groundfish-dominated community state (Litzow 2006). However, during 2001-2005 sea surface temperature in the sampled area has increased, while sea level pressure has decreased (Litzow 2006), which suggests an increased likelihood of climate-forced ecological change in the near future.

Here I present catch data for ecologically important taxa that were either responsive to the 1976/1977 PDO regime shift or that have shown recent changes in catch per unit effort (CPUE, kg km hauled^{-1}). These include taxa that showed declining CPUE following the regime shift (capelin *Mallotus villosus* and pink shrimp *Pandalus borealis*), taxa that showed CPUE increases after the regime shift (arrowtooth flounder *Atheresthes stomias*, Pacific cod *Gadus macrocephalus* and jellyfish [Scyphozoa]), and taxa with more recent increases in CPUE (spiny dogfish *Squalas acanthias* and eulachon *Thaleicthys pacificus*). Data come from the seven most consistently sampled bays (Inner Marmot, Kiliuda, Alitak, Two-Headed, Pavlof, Kuiukta and Chignik/Castle), five of which were sampled in 2005. CPUE is presented as the grand mean (± SD) of mean CPUE values from individual bays.

Capelin CPUE remained low in 2005 (0.025 ± 0.03 kg km^{-1}), one to two orders of magnitude lower than peak values observed in the 1970s and early 1980s (Figure 95a). Pink shrimp CPUE (10.58 ± 13.84 kg km^{-1}) also continued at low post-regime shift levels, more than an order of magnitude below 1970s values (Figure 95b). CPUE of arrowtooth flounder (26.69 ± 19.57 kg km^{-1}) and jellyfish (24.62 ± 19.38 kg km^{-1}) remained at the high levels observed since the mid 1980s (Figure 95c and d). Pacific cod CPUE (5.43 ± 1.53 kg km^{-1}) continued the recent trend of lower values, reduced nearly an order of magnitude from values observed during the 1980s and 1990s (Figure 95e). And the CPUE of spiny dogfish (1.81 ± 2.26 kg km^{-1}) and eulachon (1.98 ± 2.25 kg km^{-1}) continued the trend of recent high values (Figure 95 f and g).

Recent high eulachon CPUE values are generally within an order of magnitude of catches observed earlier in the time series. Spiny dogfish, on the other hand, were largely absent from small-mesh catches prior to 1998, with the exception of catches in Kiliuda Bay in the 1980s. The recent increase in spiny dogfish CPUE is apparently part of a general increase in spiny dogfish abundance throughout the central and eastern Gulf of Alaska (Wright and Hulbert 2000). Log-transformed CPUE of eulachon and spiny dogfish have been positively correlated in the eastern part of the survey area (Marmot, Kiliuda, and Alitak Bays and Two-headed Gully) during 2001-2005 (using the bay-year as sample unit, r = 0.59), suggesting a possible mechanistic link between recent increases in the two taxa (e.g., similar responses to thermal habitat or a predator-prey interaction resulting in bottom-up control of spiny dogfish distribution).

Also notable in 2005 was the appearance of smooth pink shrimp (*Pandalus jordani*) in two bays in the easternmost survey area (outer Marmot Bay, CPUE =1.48 ± 2.15 kg km^{-1} and Kiliuda Bay, CPUE = 0.01

± 0.02 kg km^{-1}). *P. jordani* was also detected in samples retained from the 2004 survey in outer Marmot Bay, although they were not recognized in the field that year (CPUE estimated from retained samples ~ 1.4 kg km^{-1}). *P. jordani* is a lower-latitude species that is commercially fished off British Columbia and the west coast of the U.S. This species was sporadically caught in the small-mesh survey during 1974-1983 (n = 14 total catches), although the close similarity with *P. borealis* casts some doubt on the validity of those records. The consistent catches in 2004 and 2005 in outer Marmot Bay (e.g., seven out of 11 hauls in 2005) are unprecedented in the time series. One possible explanation for these recent *P. jordani* catches is a northward distribution shift in response to recent warming of the Gulf of Alaska (Litzow 2006), although further years of observation will be needed to assess the persistence of *P. jordani* in the study area.

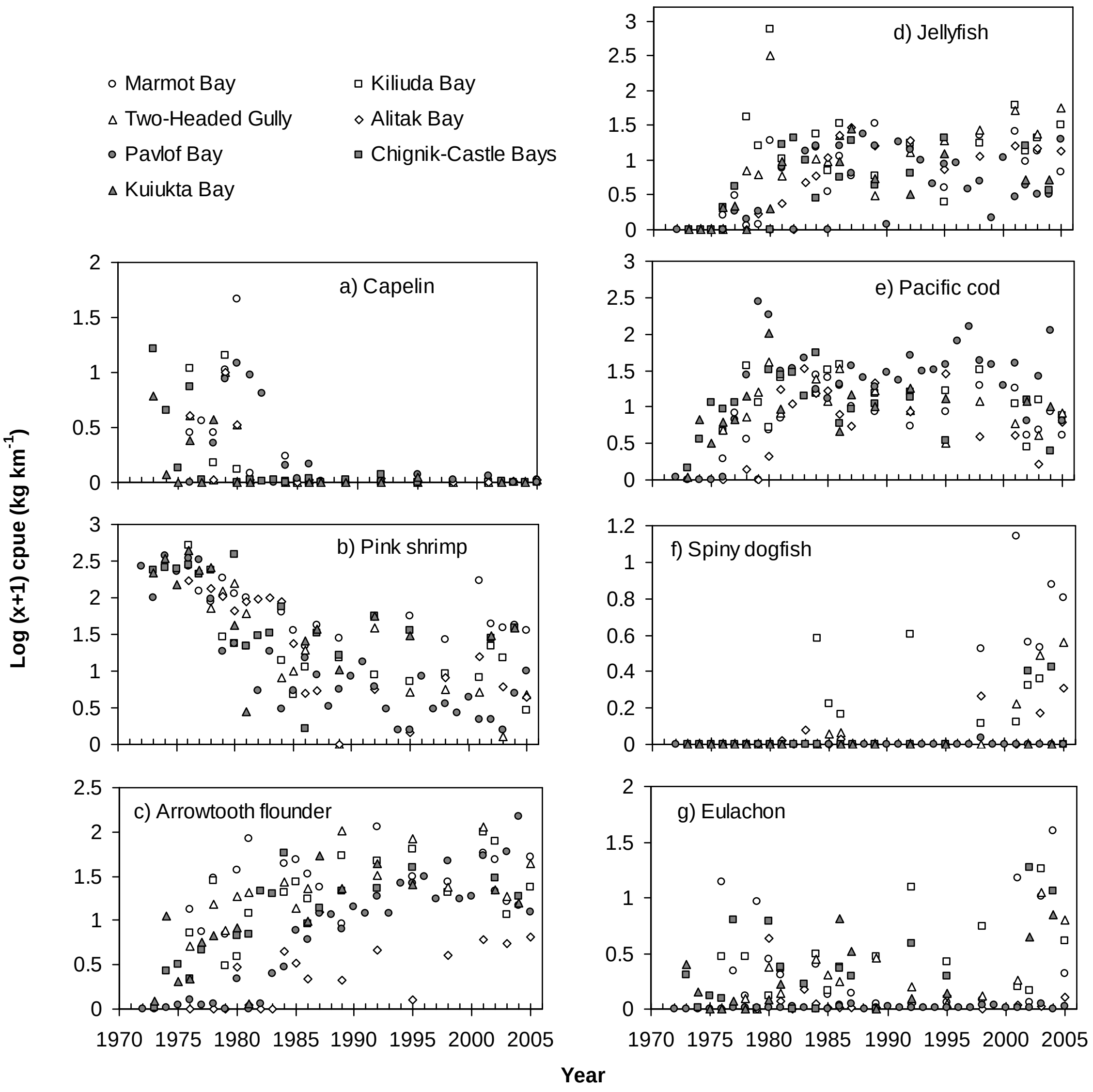

Figure 95. Catch per unit effort (CPUE) trends for selected taxa in small-mesh surveys of seven Kodiak Island and Alaska Peninsula Bays, 1972-2005.

Bering Sea Crabs

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Last updated: October 2006

An annual NMFS trawl survey is conducted in the Eastern Bering Sea to determine distribution and abundance of crabs and demersal fishes. Crab population abundance indices are determined using an 'area-swept' method in a stratified systematic sampling design. Current crab abundances are low relative to historic peaks, and at the time of writing this report, there are 2 stocks that are considered overfished, Pribilof Island blue king crab and St. Matthew Island blue king crab. Four stocks of crabs are under continuing rebuilding plans: BS snow crab, EBS tanner crab, Pribilof Island blue king crab, and St. Matthew Island blue king crab. Mature biomass estimates are being reviewed in the 2006 crab assessment. All crab biomass information presented below is based upon past estimates of crab biomass, and will be updated next year. For more up-to-date biomass estimates, please refer to the 2006 crab assessment (http://www.afsc.noaa.gov/race/shellfish/default_sf.htm).

BRISTOL BAY RED KING CRAB.

Based upon past estimates of crab biomass, the mature biomass of Bristol Bay red king crab was highest in 1980, declined and has remained relatively low since 1983. The total mature biomass of crabs has remained above 50% of the MSY biomass and, therefore, the stock is not considered overfished.

PRIBILOF ISLANDS RED KING CRAB.

Mature biomass of Pribilof Island red king crab was well below 50% MSY in the 1980s but has been higher than the 50% MSY since 1991 and is not considered overfished. Although not considered overfished, the fishery remains closed because of considerable uncertainty as to population abundance and due to concerns of unacceptable levels of incidental catch of the severely depressed blue king crab in the Pribilof District.

PRIBILOF ISLANDS BLUE KING CRAB.

Blue king crab in the Pribilof Islands area have been considered overfished since mature biomass fell below the 50% MSY in 2002. Little or no recruitment is apparent in the population which has been declining continuously since 1995.

ST. MATTHEW ISLAND BLUE KING CRAB.

Blue king crab in the area of St. Matthew Island are also considered overfished. The population has declined steeply since 1998. Indices of female crab abundances are not considered meaningful due to their preference for inshore, rocky, hence untrawlable habitat.

EASTERN BERING SEA TANNER CRAB.

The Eastern Bering Sea tanner crab population was high in the early 1980s and from 1988-1992. The population has been low since then and the 2005 survey indicated that recruitment is improving.

EASTERN BERING SEA SNOW CRAB.

Snow crab recruitment was higher during 1979-1987 than in other years (Figure 96). The two highest recruitment events occurred in 1980 and 1987, after which, recruitment was low. Low recruitment estimates during 1988-1998 could be due to fishing, climate, and/or a northward shift in snow crab distribution. A northward shift in distribution could result in a decrease in reproductive output, because snow crab may only spawn every other year (rather than annually) in colder temperatures, such as those found further north.

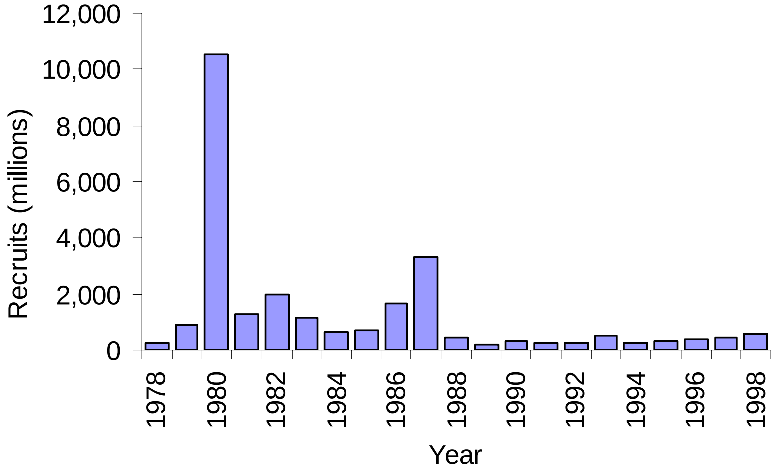

Figure 96. Snow crab recruitment from 1978 to 1998 in millions of crabs that are 25 mm to 50 mm in carapace width and lagged by 5 years (to fertilization year).

Stock-recruitment relationships for Bristol Bay red king crabs

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Last updated: November 2006

The results from the length-based model were used to develop S-R relationships for Bristol Bay red king crabs. Male reproductive potential is defined as the mature male abundance by carapace length multiplied by the maximum number of females with which a male of a particular length can mate (Zheng et al. 1995). If mature female abundance was less than male reproductive potential, then mature female abundance was used as female spawning abundance. Otherwise, female spawning abundance was set equal to the male reproductive potential. The female spawning abundance was converted to biomass, defined as the effective spawning biomass SP_t. The S–R relationships of Bristol Bay red king crabs were modeled using a general Ricker curve:

$$R_t = SP_{t-k}^{r1}\, e^{r2 - r3\, SP_{t-k} + v_t}, \qquad (1)$$

and an autocorrelated Ricker curve:

$$R_t = SP_{t-k}\; e^{r2 - r3\, SP_{t-k} + \upsilon_t}, \qquad (2)$$

where

$\upsilon_t = \delta_t + a1\ \upsilon_{t-1}$,

v_t, δ_t are environmental noises assumed to follow a normal distribution $N(0,\sigma^2)$, $r1$, $r2$, $r3$, and $a1$ are constants.

As a comparison, mature male biomass on February 15 was also used as an alternative spawning stock index for the S–R relationships. Population abundance at survey time was projected forward to February 15 after adjusting fishing and natural mortalities. February 15 is near the peak of the primiparous female mating, prior to the molting of mature males, and after the fishery. This is about the lowest mature male biomass in a given year and is a conservative spawning biomass index.

Generally, strong recruitment occurred with intermediate levels of effective spawning biomass, and very weak recruitment was associated with extremely low levels of effective spawning biomass (Figure 97). These features suggest a density-dependent S–R relationship. On the other hand, strong year classes occurred in the late 1960s and early 1970s, and weak year classes occurred in the 1980s and 1990s. Therefore recruitment is highly autocorrelated, so environmental factors may play an important role in recruitment success. The general Ricker curve (R^2=0.51, *df*=28) was used to describe the density-dependent relationship, and the autocorrelated Ricker curve (R^2=0.44, *df*=28) was used to depict the autocorrelation effects. Because the autocorrelated curve regards the strong recruitment during the late 1960s and early 1970s as a result of autocorrelation, the recruitment associated with intermediate effective spawning biomass is much lower for the autocorrelated curve than for the general curve. Likewise, because the autocorrelated curve is less density-dependent, it has much higher recruitment than the general curve when effective spawning biomass is very high. The autocorrelation parameter fit the residuals well only before the 1982 year class and then fit the residuals poorly. As expected, recruitment levels as a function of the spawning stock are lower from the S–R curve estimated with the data after 1976 than those estimated with all data.

The S–R curves estimated with mature male biomass on February 15 have overall lower recruitment levels than those estimated with effective spawning biomass (Figure 97). The S–R curves fit the data better with effective spawning biomass than with mature male biomass (R^2=0.39, *df*=28 for the general curve and R^2=0.38, *df*=28 for the autocorrelated curve).

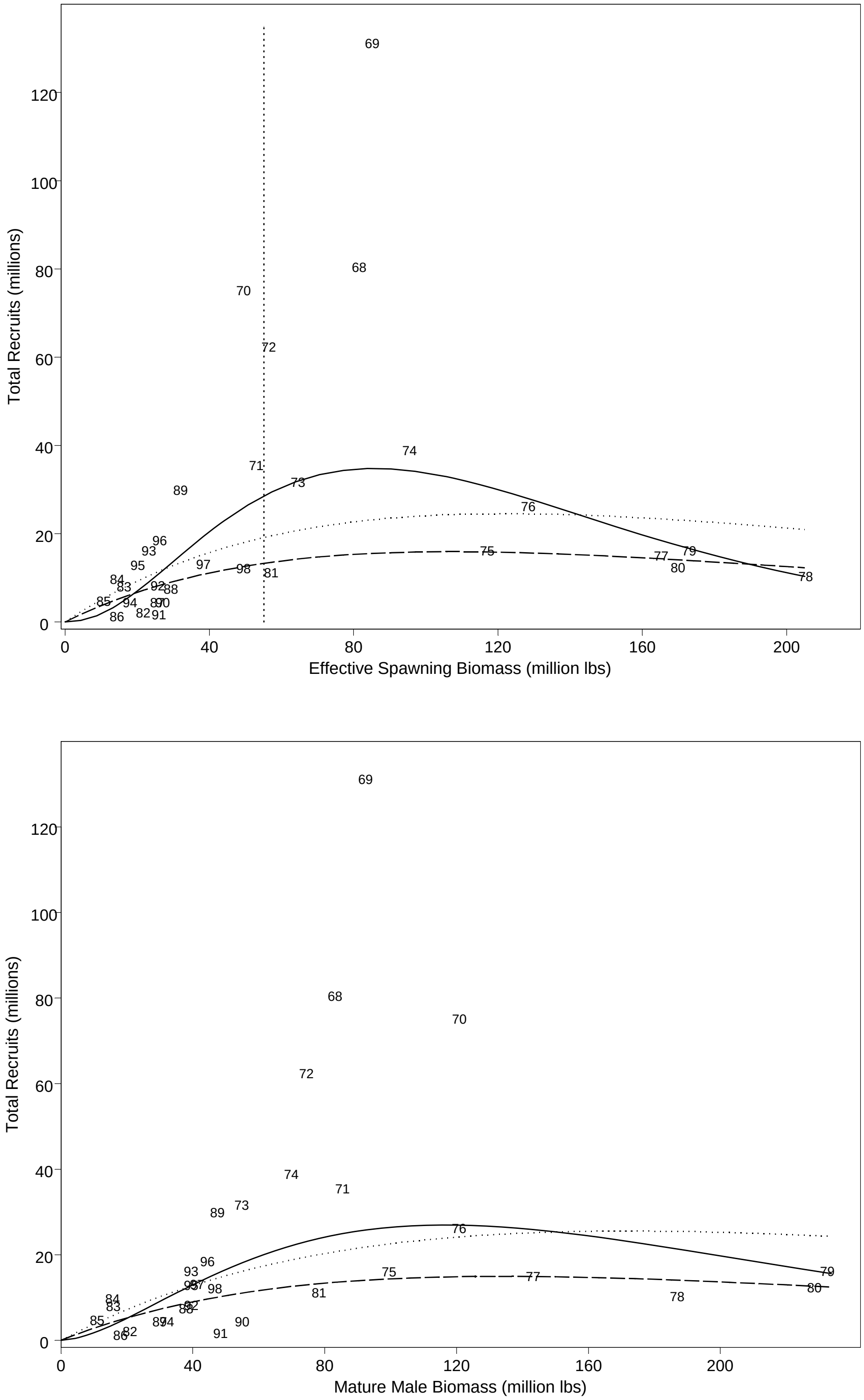

Figure 97. Relationships between effective spawning biomass and total recruits (upper panel) and between mature male biomass on Feb. 15 and total recruits at age 7 (i.e., 8-year time lag) (lower panel) for Bristol Bay red king crabs. Numerical labels are years of mating, the solid line is a general Ricker curve, the dotted line is an autocorrelated Ricker curve without υ_t values (equation 2), and the dashed line is a Ricker curve fit to recruitment data after 1976 brood year. The vertical dotted line is the targeted rebuilding level of 55 million lbs effective spawning biomass.

Miscellaneous Species – Gulf of Alaska

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Last updated: November 2006

RACE bottom trawl surveys in the Gulf of Alaska (GOA) are designed primarily to assess populations of commercially important fish and invertebrates. However many other species are identified, weighed and counted during the course of these surveys and these data may provide a measure of relative abundance for some of these species. Many of these species are not sampled well by the gear or occur in areas that are not well sampled by the survey (hard, rough areas, mid-water etc.) and are therefore encountered in small numbers which may or may not reflect their true abundance in the GOA. The fishing gear used aboard the Japanese vessels that participated in all GOA surveys prior to 1990 was very different from the gear used by all vessels since. This gear difference almost certainly affected the catch rates for some of these species groups. Apparent abundance trends for a few of these groups are shown in Figure 98. For each species group, the largest catch over the time series was arbitrarily scaled to a value of 100 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error.

Despite the numerous caveats, a few general patterns of abundance seem to be discernible from the data (Figure 98). Echinoderm abundances have generally been highest in the central GOA and their mean catch per unit effort (CPUE) has increased dramatically in this area since 1987. The percentage of hauls with echinoderms has also increased over time, leveling off in recent years at a very high percentage of tows in all areas, in a pattern remarkably similar to that found in the Aleutian Islands.

The abundance of jellyfish seems to be consistently higher in the central and eastern GOA than in the western GOA and 1990 seems to have been the year of highest abundance in these areas. Eelpout mean CPUE has been somewhat higher in the surveys in the 2000s than in previous years in the central and eastern GOA, although the estimates of mean CPUE were lower in 2005 than in 2003 in both areas. Poacher mean CPUE seems to consistently increase from east to west and rates of capture are also relatively high in the western GOA.

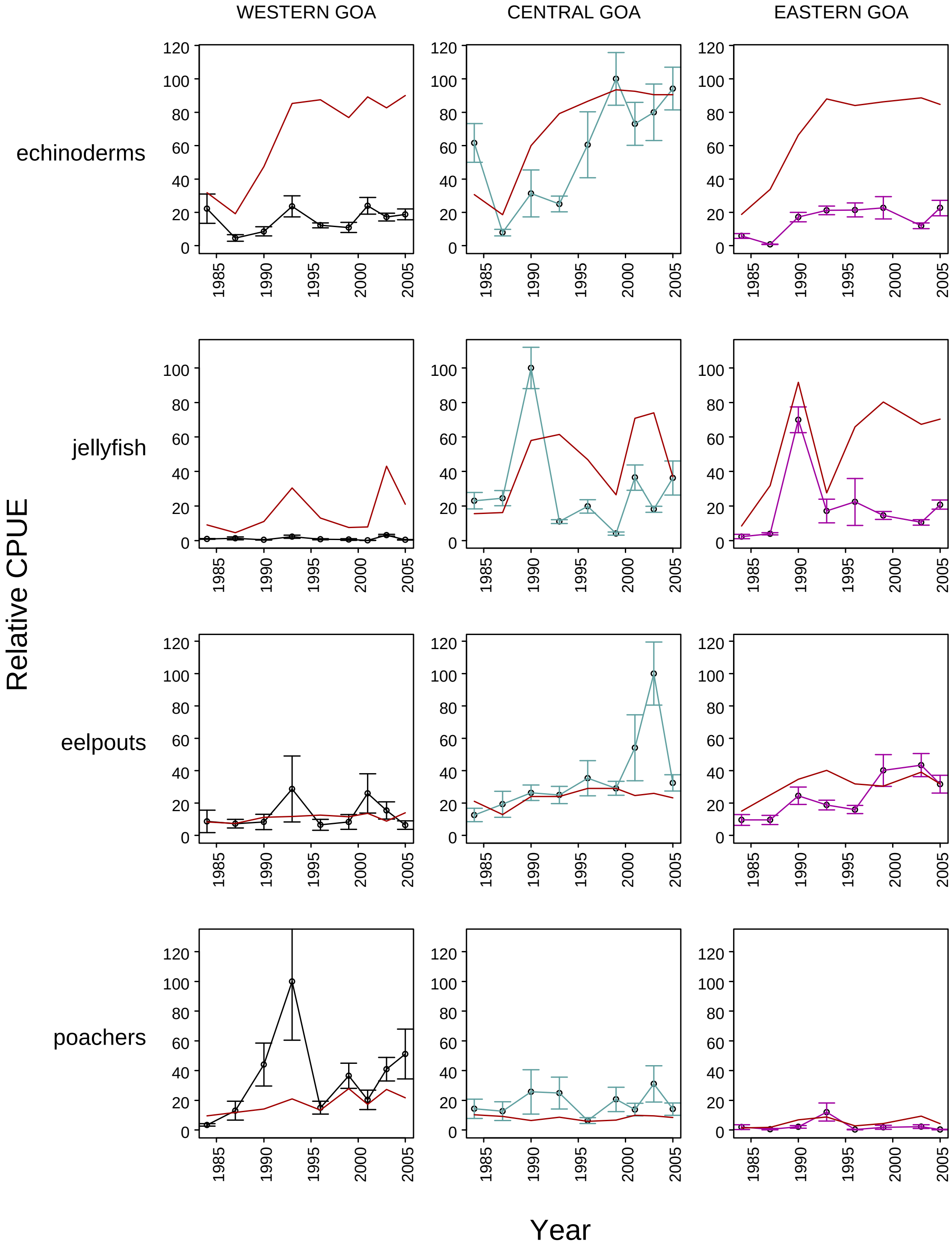

Figure 98. Relative mean CPUE of miscellaneous species by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2005. Error bars represent standard errors. The red lines represent the percentage of non-zero catches.

Jellyfish – Eastern Bering Sea

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Last updated: November 2006

The time series of jellyfish caught as bycatch in the annual Bering Sea bottom trawl survey was updated for 2006 (Figure 99). The largest catch over the time series was arbitrarily scaled to a value of 1 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error. The trend for increasing Relative CPUE that began around 1989 reported by Brodeur et al. (1999) did not continue in 2001-2006. The Relative CPUE of jellyfish decreased dramatically during the 2001-2006 period and was close to CPUE levels seen in the 1980s and early 1990s. Outbursts in jellyfish populations, such as the one in 2000, may be related to shifts in the physical or biological conditions on the eastern Bering Sea shelf (Brodeur et al. *in review*).

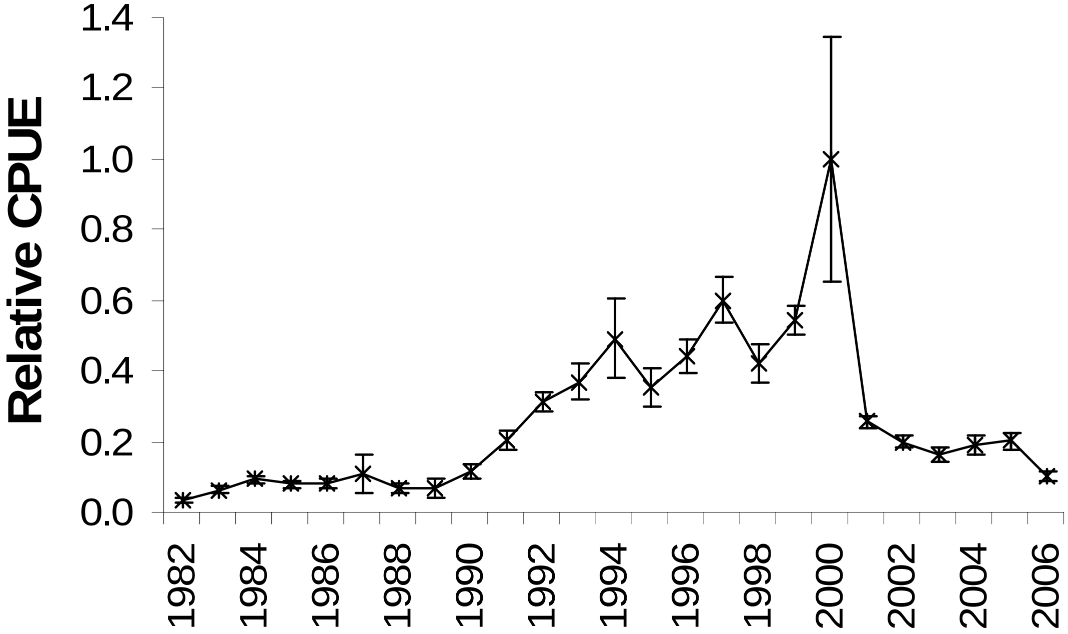

Figure 99. Relative CPUE of large medusae during the summer in the eastern Bering Sea from the NMFS bottom trawl survey, 1982-2006. Data points are shown with standard error bars.

Miscellaneous species - Eastern Bering Sea

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Last updated: November 2006

Three species of eelpouts are predominant on the eastern Bering Sea shelf: marbled eelpout (*Lycodes raridens*), wattled eelpout (*L. palearis*) and shortfin eelpout (*L. brevipes*). For each species group, the largest catch over the time series was arbitrarily scaled to a value of 1 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error. The Relative CPUE of this group appeared higher in the early 1980s than in the late 1980s to present (Figure 100). Although lower, Relative CPUE appears to be relatively stable in the recent time period. Further analyses are needed to examine CPUE trends at the species level. The Relative CPUE of poachers is dominated by the sturgeon poacher (*Podothecus acipenserinus*) and was low in the early 1980s but increased in the late 1980s to the mid-1990s. The Relative CPUE appeared to be on the rise during the first half of the new millennium but took a sharp turn downward in 2006 (Figure 100). Echinoderms on the shelf mainly consist of purple-orange seastar (*Asterias amurensis*), which is found primarily in the inner/middle shelf regions, and common mud star (*Ctenodiscus crispatus*), which is primarily an inhabitant of the outer shelf. The Relative CPUE values for the echinoderm group were lowest in 1985, 1986, and 1999, and highest in 1997. More research survey trawl gear selectivity and on the life history characteristics of non-target species is required to understand the possible reasons for these Relative CPUE trends.

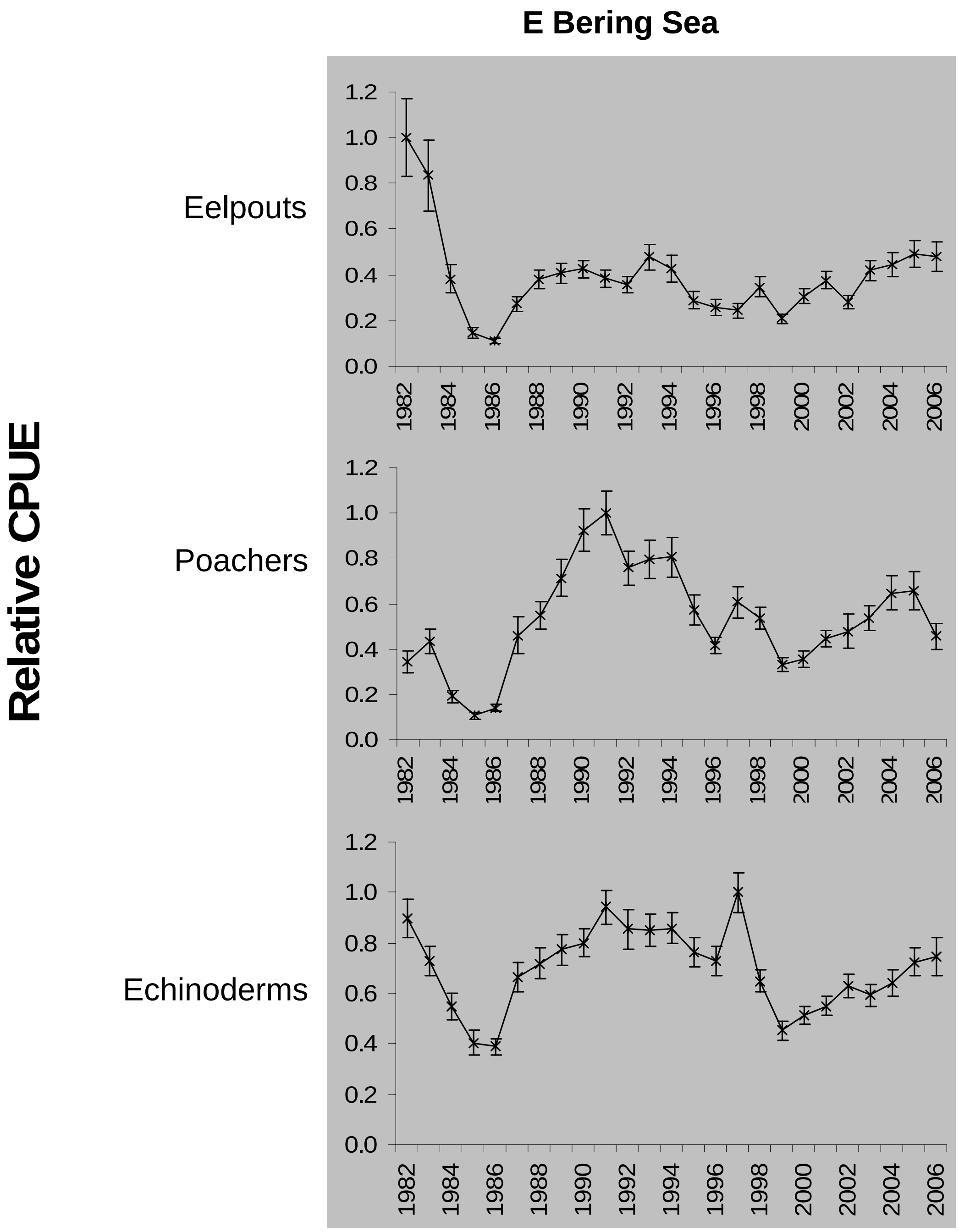

Figure 100. Relative CPUE of miscellaneous species caught in the eastern Bering Sea summer bottom trawl survey, 1982-2006. Data points are shown with standard error bars.

Miscellaneous Species– Aleutian Islands

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Last updated: November 2006

RACE bottom trawl surveys in the Aleutian Islands (AI) are designed primarily to assess populations of commercially important fish and invertebrates. However many other species are identified, weighed and counted during the course of these surveys and these data may provide a measure of relative abundance for some of these species. Many of these species are not sampled well by the gear or occur in areas that are not well sampled by the survey (hard, rough areas, mid-water etc.) and are therefore encountered in small numbers which may or may not reflect their true abundance in the AI. The fishing gear used aboard the Japanese vessels that participated in all AI surveys prior to 1991 was very different from the gear used by all vessels since. This gear difference almost certainly affected the catch rates for some of these species groups. Apparent abundance trends for a few of these groups are shown in Figure 101. For each species group, the largest catch over the time series was arbitrarily scaled to a value of 100 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error.

Echinoderm mean catch per unit effort (CPUE) increased rapidly between 1990 and 1997 in the eastern AI and has remained at consistently high levels since. The central and western AI have shown generally lower CPUEs over this period, while the lowest echinoderm CPUE has usually been in the southern Bering Sea. The 2006 survey showed a large increase in echinoderm CPUE in this area, however. Most remarkable are the similar trends in echinoderm frequency of occurrence in all areas, increasing rapidly between 1983 and 1991 and remaining high since, very similar to the pattern noted in the Gulf of Alaska.

The jellyfish pattern in terms of both mean CPUE and frequency of occurrence is also consistent across all areas of the AI. There was a sharp increase in the mid-1990s, followed by a steep decline in 1997 and a sharp increase in abundance since. The 2006 survey showed the highest level of jellyfish CPUE for all survey years, with a particularly large increase in the eastern AI.

Eelpout CPUEs have generally been highest in the central AI and have remained consistently high since 1991, the first survey that did not involve Japanese vessels with non-standard gear. Mean CPUE has also been relatively high in the eastern AI, but also much more variable. Catch rates have been lower in the western AI, and lower still in the southern Bering Sea. Poachers occur in a relatively large number of tows across the AI survey area, but mean CPUE trends are difficult to decipher. Poacher CPUE returned to very low levels in the southern Bering Sea in both 2002 and 2006 surveys, after reaching much higher levels in the 2000 and 2002 surveys.

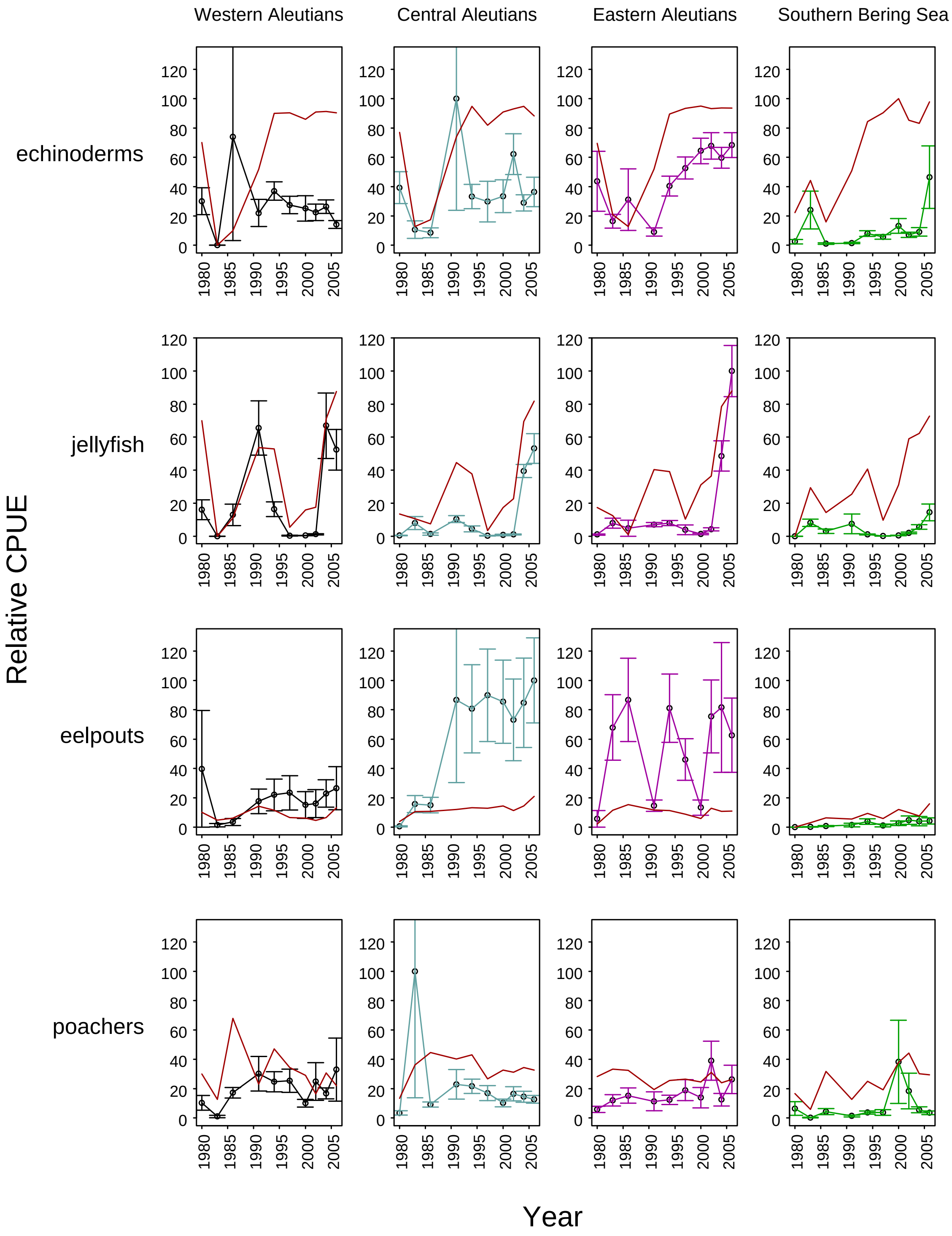

Figure 101. Relative mean CPUE of miscellaneous species by area from RACE bottom trawl surveys in the Aleutian Islands from 1980 through 2006. The bars represent standard errors. The red lines represent the percentage of non-zero catches.

Marine Mammals

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Note: Research summaries and data, as well as slides and posters of recent research efforts into population trends among marine mammals are available electronically on: http://nmml.afsc.noaa.gov and ***http://www.nmfs.noaa.gov/prot_res/PR2/Stock_Assessment_Program/sars.html***

Descriptions of the range, habitat, diet, life history, population trends and monitoring techniques of marine mammals in the Gulf of Alaska and Bering Sea were provided in previous Ecosystem Considerations Chapters (Livingston 2001, 2002, Boldt 2003). The text below summarizes an update of the status and trends for three pinniped species that are currently of particular concern and thought to have the most significant interactions with Alaskan groundfish fisheries, either because of direct takes or diet overlap. A general discussion of recent abundance surveys for large cetaceans is presented as well. A summary table of the best estimates regarding the status of all stocks of marine mammals in Alaskan waters through 2005 is provided.

Pinnipeds

Steller sea lion (*Eumetopias jubatus*) Last updated: November 2006

In November 1990, the NMFS listed Steller sea lions as “threatened” range-wide under the U.S. Endangered Species Act (55 Federal Register 49204, November 26, 1990) in response to a population decrease of 75% during the previous 15-year period in the core of their range in the Aleutian Islands and Gulf of Alaska. By 1997, two population stocks were identified, based largely on differences in genetic identity, but also on regional differences in morphology and population trends (Bickham et al. 1996, Loughlin 1997). The Western Stock, which occurs from 144°W (approximately at Cape Suckling, just east of Prince William Sound, Alaska) westward to Russia and Japan, was listed as “endangered” in June 1997 (62 Federal Register 24345, May 5, 1997). The Eastern Stock, which occurs from Southeast Alaska southward to California, remained classified as threatened. Population assessment for Steller sea lions is currently achieved by biennial aerial photographic surveys of non-pups (adults and juveniles at least 1 year-old) and pups, supplemented by on-land pup counts at selected rookeries each year.

The last complete aerial survey of the endangered Western Stock of Steller sea lions in Alaska (from Cape St. Elias, 144°W to Attu Island, 172°E) was conducted by NMFS in June 2004. The 2006 aerial survey was incomplete due to delays caused by a court injunction of all Steller sea lion research as well as bad weather. The 2004 survey was the first to use medium format, vertical photogrammetric techniques. In previous years, counts of non-pup sea lions were made from 35 mm slides shot obliquely (from the side windows) of aircraft. Based on comparison surveys, counts made from medium format photographs are approximately 3-4% higher than those from 35 mm slides because of the resolution of the film and the orientation of the photograph.

In 2004, there were a total of 28,730 non-pup Steller sea lions counted on the 262 sites surveyed in the range of the western stock. NMFS monitors the population at groups of ‘trend’ sites that have been consistently surveyed since the mid-1970s (N=87) or since 1991 (N=161). NMFS estimated that the western Steller sea lion population increased approximately 11-12% from 2000 to 2004 (Figures 102 and 103). In 2006, NMFS was able to survey only 53 of 87 1970s trend sites, and only 106 of 161 1990s trend sites. Because of the incomplete nature of the 2006 aerial survey, there is no new information to update the non-pup abundance trend for the entire western stock of Steller sea lions in Alaska.

Steller sea lion non-pup counts in the center of the range of the western stock (the western Gulf of Alaska and Eastern Aleutian Islands from the Shumagin Islands through the Islands of Four Mountains) remained relatively stable from 1991 to 2004 or 2006, showing oscillations around a mean. To the west, sea lion numbers decreased through the mid-1990s in both the Central and Western Aleutian Islands. Trend site counts stabilized at the 1998 level in the Central Aleutians, but continued to decline in the Western Aleutians through 2002 followed by a small increase between 2002 and 2004. To the east, trend site counts decreased sharply in both the Central and Eastern Gulf of Alaska through 1998. In the eastern Gulf of Alaska, counts increased between 1998 and 2004, but were stable between 2004 and 2006. Since 1998 in the central Gulf of Alaska, counts continued to decline but at a slower rate (Table 16, Figures 102 and 103).

Although not all 1990s trend sites in Alaska were surveyed in 2006, all 1990s trend sites were surveyed in two of the six Alaskan sub-areas:

- eastern Gulf of Alaska (N=13 sites) and
- eastern Aleutian Islands (N=27).

All 1990s trend sites except one were surveyed in two other sub-areas:

- western Gulf of Alaska (N=19 of 20) and
- western Aleutian Islands (N=9 of 10).

These complete or nearly complete sub-area surveys in 2006 convey some information about local trends. Counts of non-pup sea lions on 1990s trend sites in the eastern and western Gulf of Alaska, and eastern Aleutian Islands were essentially unchanged between 2004 and 2006. For each of these 3 sub-areas, counts had increased considerably (20-43%) between 2000 and 2004. Thus, the 2006 count indicates that the population of adult and juvenile Steller sea lions in these areas may have stabilized. In the western Aleutian Islands, non-pup counts on the 9 trend sites surveyed in 2006 declined 19% from 2004, suggesting that the decline observed in the western Aleutian Islands sub-area may be continuing. NMFS, along with its research partners in the North Pacific, is exploring several hypotheses to explain these trends, including climate or fisheries related changes in prey quality or quantity, and changes in the rate of predation by killer whales.

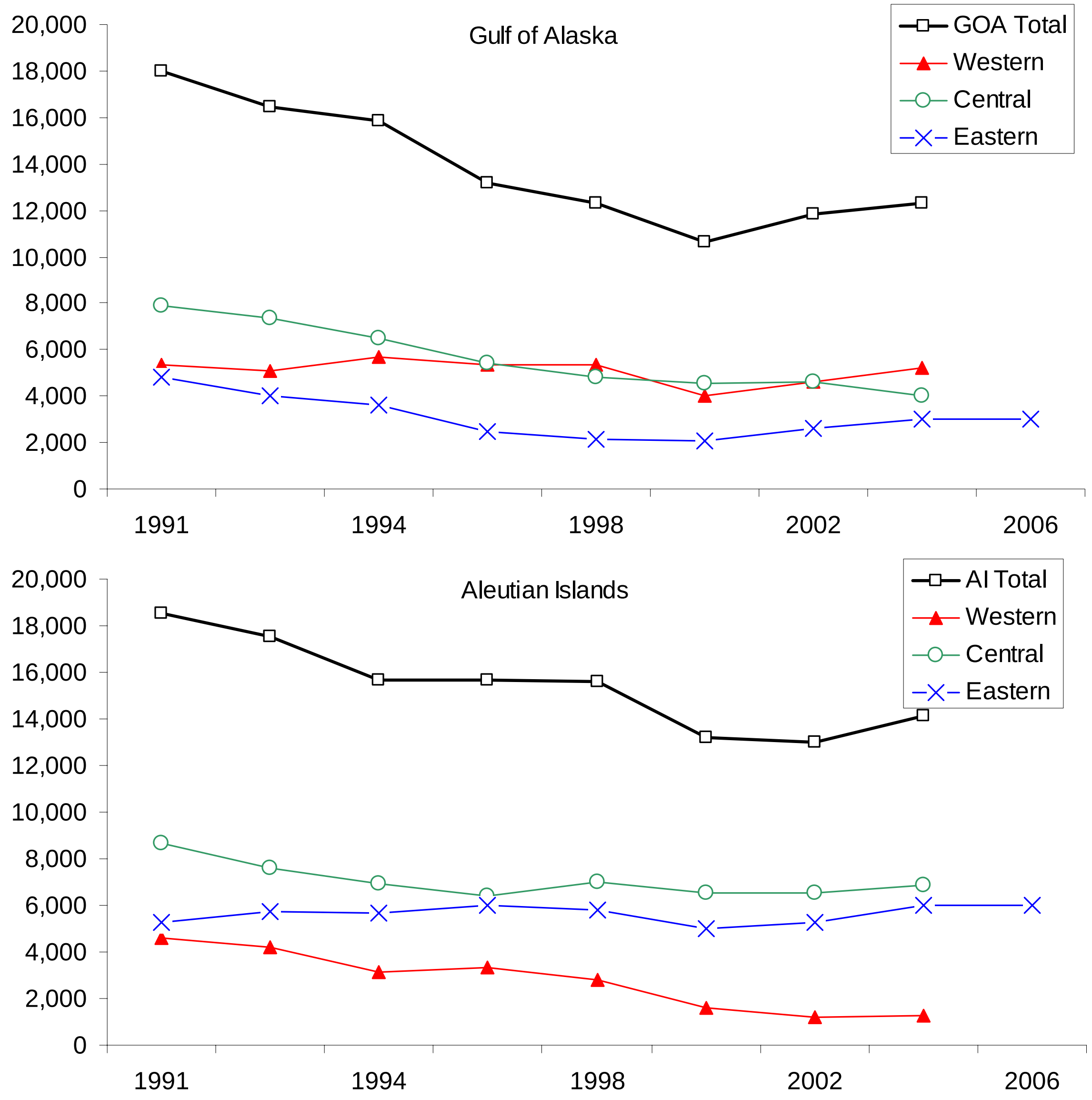

Figure 102. Counts of non-pup (adult and juvenile) Steller sea lions on rookery and haulout trend sites in the range of the western population from 1991-2006. Counts are aggregated by sub-area in the Gulf of Alaska (GOA; top) and Aleutian Islands (AI; bottom). Surveys in 1991-2002 used 35 mm oblique slides, while the 2004 and 2006 surveys used medium format vertical photographs. Counts in 2004 and 2006 displayed above have been reduced 3.64% from the actual count to account for the format differences (see text).

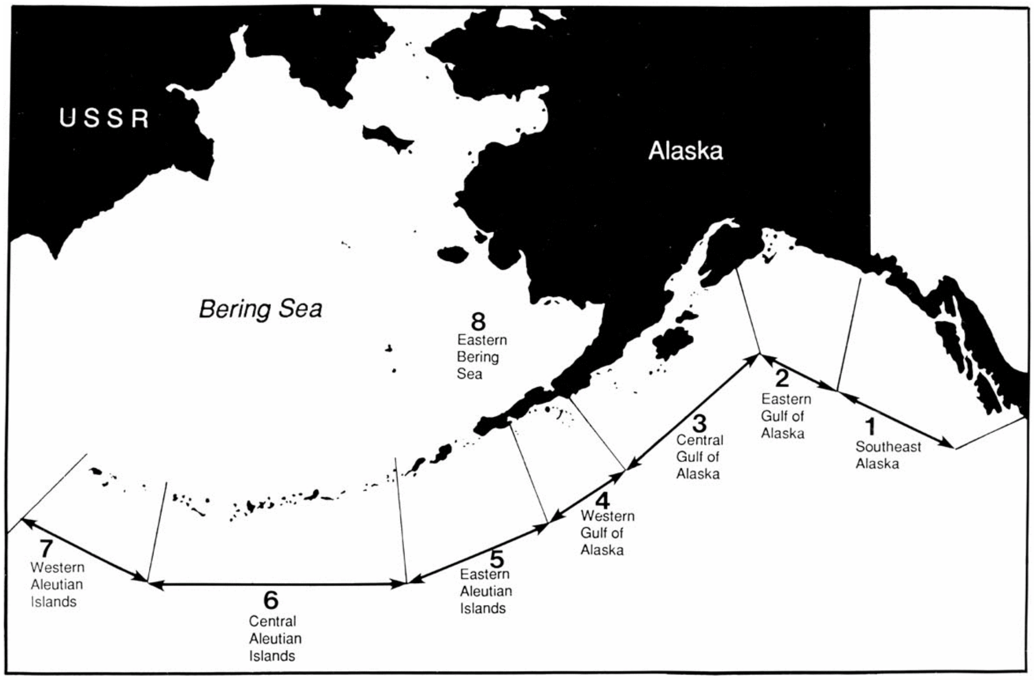

Figure 103. Map of Alaska showing areas within the range of the western Steller sea lion (subareas 2-7) surveyed in 2004.

Table 16. Counts of adult and juvenile (non-pup) Steller sea lions observed at rookery and haulout trend sites surveyed consistently since 1991 (N=161) in six sub-areas of the Alaskan range of the western stock during June and July aerial surveys from 1991 to 2006. Counts through 2002 were made visually or from 35 mm slides shot obliquely out the side windows of aircraft. Counts in 2004 and 2006 were made from medium format photographs shot vertically over rookery and haulout sites. Comparison studies suggest that counts from medium format photographs are approximately 3-4% greater than from 35 mm photographs; adjusted sub-area counts in 2004 and 2006 are listed. For the 2006 survey, a complete survey of trend sites only occurred in the eastern Gulf and eastern Aleutians.

	Gulf of Alaska				Aleutian Islands			
Year	Eastern	Central	Western	Total	Eastern	Central	Western	Total
1991	4,812	7,872	5,338	18,022	5,283	8,656	4,601	18,540
1992	3,981	7,358	5,112	16,451	5,707	7,633	4,199	17,539
1994	3,612	6,505	5,718	15,835	5,664	6,909	3,114	15,687
1996	2,450	5,400	5,356	13,206	5,967	6,368	3,334	15,669
1998	2,158	4,806	5,367	12,331	5,774	7,017	2,786	15,577
2000	2,102	4,555	3,996	10,653	4,990	6,560	1,633	13,183
2002	2,615	4,594	4,617	11,825	5,261	6,547	1,196	13,004
2004	3,015	4,028	5,233	12,276	5,991	6,885	1,286	14,162
2006	3,002				5,973			

Northern fur seal (*Callorhinus ursinus*) Last updated: November 2004

The northern fur seal ranges throughout the North Pacific Ocean from southern California north to the Bering Sea and west to the Okhotsk Sea and Honshu Island, Japan. Breeding is restricted to only a few sites (i.e., the Commander and Pribilof Islands, Bogoslof Island, and the Channel Islands) (NMFS 1993). During the breeding season, approximately 74% of the worldwide population is found on the Pribilof Islands in the Bering Sea (NMFS 1993). Two separate stocks of northern fur seals are recognized within U.S. waters: an Eastern Pacific stock and a San Miguel Island stock.

Northern fur seals were listed as depleted under the MMPA in 1988 because population levels had declined to less than 50% of levels observed in the late 1950s, with no compelling evidence that carrying capacity had changed (NMFS 1993). Fisheries regulations were implemented in 1994 (50 CFR 679.22(a)(6)) to create a Pribilof Islands Area Habitat Conservation Zone, in part, to protect the northern fur seals. Under the MMPA, this stock remains listed as "depleted" until population levels reach at least the lower limit of its optimum sustainable population (estimated at 60% of carrying capacity). A Conservation Plan for the northern fur seal was written to delineate reasonable actions to protect the species (NMFS 1993). The population size and trends of northern fur seals on the Pribilof Islands are estimated by NMFS biennially using a mark-recapture method (shear-sampling) on pups of the year.

Based on counts conducted during August 2004, it is estimated that 122,803 (SE = 1,290) pups were born on St. Paul Island and 16,876 (SE = 239) pups were born on St. George Island (Tables 17 and 18). The observed pup mortality rates of 3.27% on St. Paul Island and 2.46% on St. George Island were relatively low, and similar to estimates obtained in 2002. The 2004 pup production estimate for St. Paul Island is 15.7% less than the estimate in 2002 and 22.7% less than the estimate in 2000. The 2004 pup production estimate for St. George Island is 4.1% less than the estimate in 2002 and 16.4% less than the estimate in 2000. Estimated pup production has declined at 6.4% per year (SE = 0.78%, P = 0.01) on St. Paul Island, and at 4.6% per year (SE = 0.45%, P = 0.01) on St. George Island, from the estimated pup production in 1998 (Figure 104). Estimated pup production on the two islands, as a whole, has declined at 6.2% per year (SE = 0.58%, P = 0.01) since 1998. The 2004 pup production estimate on St. Paul Island is comparable with the level observed in 1918, while the St. George pup production estimate is below the level observed in 1916. During the time period of 1916 to 1918, the northern fur seal population was increasing at approximately 8% per year following the cessation of extensive pelagic sealing.

Table 17. Numbers of northern fur seal, *Callorhinus ursinus*, pups born on St. Paul Island, Alaska in 2004. Estimates are shown on numbers alive at the time of shearing, counts of dead pups, estimates of pups born, standard error of estimate (SE), and estimates of pup mortality rate (%).

Rookery	**Live**	**Dead**	**Born**	**SE**	**Mortality**
Lukanin	2,993	102	3,095	176.0	3.30
Kitovi	4,800	109	4,909	48.5	2.22
Reef	15,262	456	15,718	492.5	2.90
Gorbatch	9,569	417	9,986	96.0	4.18
Ardiguen	1,158	38	1,196	104.0	3.18
Morjovi	8,781	217	8,998	177.0	2.41
Vostochni	18,872	618	19,490	436.5	3.17
Polovina	2,511	70	2,581	108.0	2.71
Little Polovina[1]	67	2	69	4.9	2.90
Polovina Cliffs	10,889	177	11,066	503.0	1.60
Tolstoi	13,146	639	13,785	560.5	4.64
Zapadni Reef	4,916	171	5,087	245.5	3.36
Little Zapadni	10,021	418	10,439	204.0	4.00
Zapadni	15,799	585	16,384	682.0	3.57
Total	**118,784**	**4,019**	**122,803**	**1,289.8**	**3.27**

[1] Live and dead pups for Little Polovina were estimated to reduce disturbance to this diminishing rookery.

Table 18. Numbers of northern fur seal, *Callorhinus ursinus*, pups born on St. George Island, Alaska in 2004. Estimates are shown on numbers alive at the time of shearing, counts of dead pups, estimates of pups born, standard error of estimate (SE), and estimates of pup mortality rate (%).

Rookery	**Live**	**Dead**	**Born**	**SE**	**Mortality**
South	3,774	134	3,908	70.0	3.43
North	5,299	96	5,395	25.0	1.78
East Reef	915	20	935	55.0	2.14
East Cliffs	3,305	72	3,377	52.0	2.13
Staraya Artil	974	27	1,001	132.0	2.70
Zapadni	2,194	66	2,260	168.5	2.92
Total	**16,461**	**415**	**16,876**	**238. 9**	**2.46**

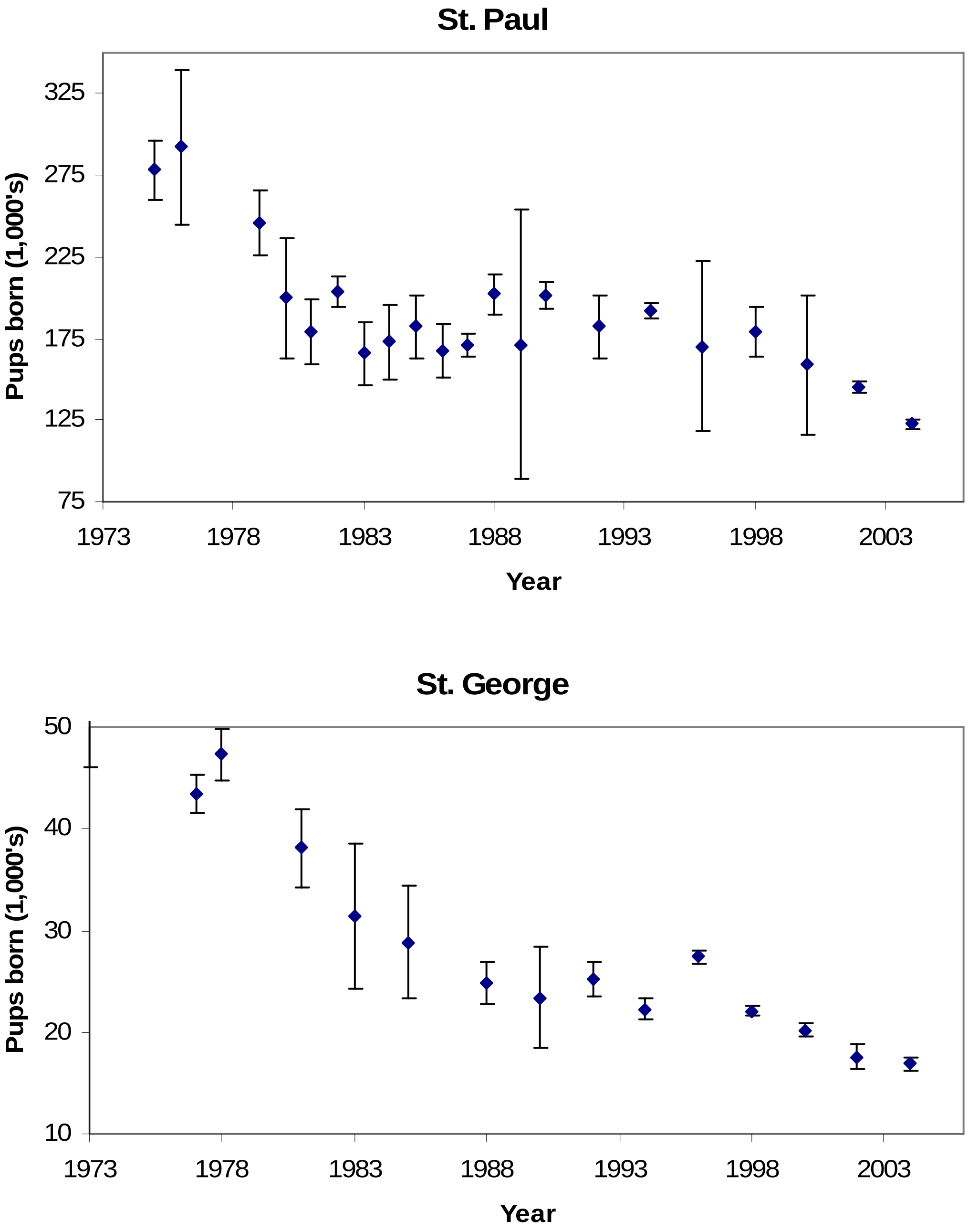

Figure 104. Northern fur seal pups born on the Pribilof Islands 1975-2004. Error bars are approximate 95% confidence intervals.

Harbor Seal (*Phoca vitulina*) Last updated: November 2004

Harbor seals inhabit coastal and estuarine waters off Baja California, north along the coastline to Alaska, including the Aleutian Islands and Bering Sea north to Cape Newenham and the Pribilof Islands. They haul out on rocks, reefs, beaches, and drifting glacial ice, and feed in marine, estuarine and occasionally fresh waters. Harbor seals are generally non-migratory (Scheffer and Slipp 1944, Frost et al. 1996). Population counts of harbor seals are conducted by aerial survey, but statistical treatments are undergoing substantial changes to account for environmental covariates that affect haulout, and therefore the likelihood that seals will be counted in the surveys. Based primarily on the significant population decline of seals in the Gulf of Alaska, the possible decline in the Bering Sea, and the stable population in southeast Alaska, three separate stocks have been recognized in Alaskan waters: 1) Southeast Alaska stock - occurring from the Alaska/ British Columbia border to Cape Suckling, Alaska (144°W); 2) the Gulf of Alaska Stock - occurring from Cape Suckling to Unimak Pass including animals throughout the Aleutian Islands, and 3) the Bering Sea Stock - including all waters north of Unimak Pass. Initial results of new genetic information indicate that the current boundaries between the three stocks need to be reassessed. Updated population estimates will be available after redefinition of stock boundaries (Angliss and Lodge 2004).

Statewide abundance

The National Marine Mammal Laboratory (Alaska Fisheries Science Center) conducted aerial surveys of harbor seals across the entire range of harbor seals in Alaska. Each of five survey regions was surveyed between 1996 - 2000, with one region surveyed per year (Boveng et al. 2003; Simpkins et al. 2003). The current statewide population estimate for Alaskan harbor seals is 180,017 (Table 19). This estimate, however, is believed to be low because it is based on incomplete coverage of terrestrial sites in Prince William Sound and of glacial sites in the Gulf of Alaska and the Southeast Alaska regions.

Table 19. Provisional regional and statewide population estimates for Alaskan harbor seals (subject to revision as part of analyses that are currently underway).

Survey Region	**Survey Year**	**Updated population estimate**	**Abundance estimate included in 1998 SARs**
SE Alaska, southern part	1998	79,937 (CV?)	37,450 (0.073) Based on 1993 surveys
SE Alaska, northern part	1997	32,454 (CV?)	
Gulf of Alaska	1996	35,982 (CV?)	29,175 (0.052) Based on a 1994 count for the Aleutians and a 1996 survey for the Gulf of Alaska
Aleutians	1999	9,993 (CV?)	
Bristol Bay (Bering Sea stock)	2000	21,651 (CV?)	13,110 (0.062) Based on 1995 surveys
Total		180,017 (CV?)	

Southeast Alaska Stock Abundance

Information on trends in abundance is available for harbor seal trend sites near Ketchikan, Sitka, and in Glacier Bay. Based on counts near Ketchikan between 1983 and 1998, abundance has increased 7.4% (95% CI: 6.1-8.7; significant; Small et al. 2003). Counts near Sitka failed to show a significant trend either between 1984-2001 or 1995-01 (Small et al. 2003). Information from Glacier Bay indicates a sharp overall decline of 25-48% in harbor seal abundance from 1992-98 (Mathews and Pendleton 2000).

Gulf of Alaska Stock Abundance

There are trend counts available from two areas inhabited by the Gulf of Alaska stock of harbor seals: Kodiak and Prince William Sound. Trend counts from Kodiak documented a significant increase of 6.6%/year (95% CI: 5.3-8.0; Small et al. 2003) over the period 1993-01, which was the first documented increase in harbor seals in the Gulf of Alaska. Harbor seals on Tugidak Island (SW of Kodiak) had declined 21%/year from 1976-78, and 7%/year from 1978-98 (Pitcher 1990). Frost et al. (1999) reported a 63% decrease in Prince William Sound from 1984-97; more recent information on trends in this area is not available.

Bering Sea Stock Abundance

Trend counts have been conducted in Bristol Bay only between 1998-01. During this period, counts indicated a non-significant trend of -1.3% (95% CI: -5.9-3.3; Small et al. 2003). Calculation of trends in abundance in this area is somewhat problematic due to the presence of a sympatric species, spotted seals, which may overlap the range of harbor seals but cannot be identified as a different species by aerial surveys.

Cetaceans

Last updated: November 2004

Wide-scale distribution surveys of large cetaceans have been conducted opportunistically for many years in Alaskan waters, with periodic short-term focus on estimating the abundance of specific populations or species. However dedicated surveys to determine the abundances of all observed cetaceans in Alaskan waters have only recently been made (Moore et al. 2002). Line transect surveys conducted during the summers of 2001-2002 indicated that two of three species of large whales regularly observed throughout the cruises were abundant in some portion of their range within former whaling grounds off coastal waters of the Aleutian Islands (Zerbini et al. 2004). The vicinity of the Aleutian Islands and Alaska Peninsula dominated as major whaling grounds in the North Pacific Ocean. Numerous stocks of large whales were extensively exploited, to the point of depletion, into the late 20th century including the North Pacific right whale (*Balaena japonica*), blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus*), sei (*Balaenoptera borealis*), humpback (*Megaptera novaeangliae*), and sperm whales (*Physeter macrocephalus*) and to a lesser degree minke whales (*Balaenoptera acutorostrata*). The recent findings of the two summer surveys conducted by Zerbini et al. (2004) are that humpback whales were abundant in historical whaling grounds north of the eastern Aleutian Islands, and fin whales were abundant in one of the two primary whaling areas: Port Hobron, south of the Alaska Peninsula. Minke whales were abundant during both cruises with concentrations in the eastern Aleutian Islands. Distribution patterns and areas of concentrations of humpbacks, fins, and minkes were similar overall between study years and agreed with distributions reported by other research efforts conducted across the Aleutians during this time (Sinclair et al. submitted). Similar to the findings of other surveys, no sightings of either blue or North Pacific right whales were observed in either cruise, indicating the continued depleted status of these species (Zerbini et al. 2004). However, it is of note that sightings of blue whales have been confirmed in other areas. Observations of blue whales in the Gulf of Alaska were recorded on July 15-16, 2004. Three individuals of this endangered species were seen about 100-150 miles southeast of Prince William Sound. These are the first documented sightings in the Gulf of Alaska in the past three decades. New stock assessments of killer whales are also included in Table 20. Only 2 of those stocks are considered strategic, and neither is known to interact significantly with the Alaskan groundfish fisheries.

Potential Causes of Declines in Marine Mammals

Direct Take/Fishery Interactions - Observable interactions between marine mammals and fisheries are generally restricted to direct mortality in fishing gear. In the absence of understanding the effect of individual takes upon the population as a whole, interpretation of the significance of removal of individuals is limited to a simple accounting of the number of individual animals killed. Based on counts of animals reported taken incidentally in fisheries up through 2003 (Angliss and Lodge 2004), none of the marine mammal incidental mortality estimates for Alaskan groundfish fisheries exceeded the potential biological removal (PBRs) (Hill and DeMaster 1999; Table 20). However, it should be noted that a number of species of marine mammals are incidentally killed in commercial fisheries activities (Table 20). Killer whales, humpback whales, and Steller sea lions have levels of mortality which may cause some federally-managed commercial fisheries to change categories in the List of Fisheries. While there are many fisheries that overlap within the range of depleted and endangered marine mammal stocks, few overall are observed, and the rate of observer coverage is low. Reliable estimates of PBRs for a number of stocks (i.e. harbor seals) are limited by the absence of updated population data. As it is acquired, stock assessment data will be used to evaluate the progress of each fishery towards achieving the goal of zero fishery-related mortality and serous injury of marine mammals, as outlined in the Marine Mammal Protection Act (MMPA) (Public Law 103-238, 1994).

Resource Competition - There is both direct and indirect overlap in the species and size of primary prey consumed by marine mammals and targeted in commercial fisheries. For example, adult female northern fur seals consume walleye pollock (*Theragra chalcogramma*) in adult and juvenile stages (Sinclair et al., 1994). Adult and juvenile walleye pollock are both consumed by adult and juvenile Steller sea lions as well (Merrick and Calkins 1996, Sinclair and Zeppelin 2002, Zeppelin et al. 2004). Thus, much of the recent effort to understand the decline among marine mammals has focused on their diet and foraging behavior. The hypothesis is that either direct or indirect competition for food with commercial fisheries may limit the ability of apex predators to obtain sufficient prey for growth, reproduction, and survival (NRC 1996). In the case of Steller sea lions, direct competition with fisheries may occur for walleye pollock (*Theragra chalcogramma*), Atka mackerel (*Pleurogrammus monopterygius*), salmon (Salmonidae), and Pacific cod (*Gadus macrocephalus*) (Calkins and Pitcher 1982, Sinclair and Zeppelin 2002, Zeppelin et al. 2004), while for northern fur seals, it may occur for walleye pollock and salmon (Kajimura 1984, Perez and Bigg 1986, Lowry 1982, Sinclair et al. 1994, 1996).

Competition may also exist where marine mammal foraging areas and commercial fishing zones overlap. Female northern fur seals from the Pribilof Islands forage extensively at distances greater than 81 nm (150 km) from rookeries (Robson 2001), placing them within range of commercial groundfish vessels fishing for walleye pollock on the eastern Bering Sea shelf during the summer and fall. Total catches of pollock, Pacific cod, and Atka mackerel within designated critical habitat for Steller sea lions in the Gulf of Alaska, eastern Bering Sea and Aleutians Islands increased from negligible levels in the late 1960s to over 1 million mt in the mid-1990s before declining to about 800,000 mt in 2004 (see below).

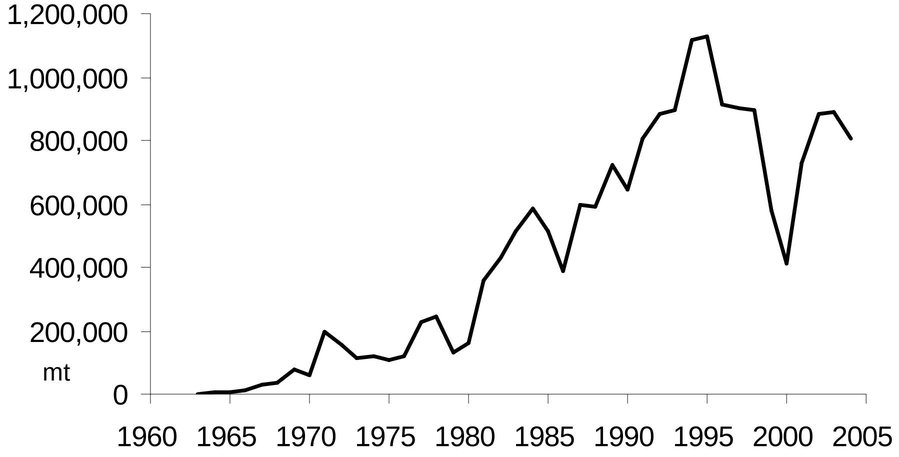

Figure 105. Total catches (mt) of pollock, Pacific cod and Atka mackerel in designated critical habitat for Steller sea lions from 1965-2004. Critical habitat for sea lions was designated in 1993.

Indirect Competition - More difficult to identify are the indirect effects of competition between marine mammals and fisheries for prey resources. Such interactions may limit foraging success through localized depletion (Lowe and Fritz 1996), destabilization of prey assemblages (Freon et al. 1992, Nunnallee 1991, Laevastu and Favorite 1988), or disturbance of the predator itself. Compounding the problem of identifying competitive interactions is the fact that biological effects of fisheries may be indistinguishable from changes in community structure or prey availability that might occur naturally.

Reduction in local abundance or dispersion of schools could make it more energetically costly for foraging marine mammals to obtain enough energy (prey) for successful growth and reproduction. Thus, the timing and location of fisheries, relative to foraging patterns of marine mammals could affect the predictability of the temporal and spatial distribution of their prey.

Environmental and climatic change - There is considerable uncertainty on how and to what degree environmental factors, such as the 1976/77 regime shift (Benson and Trites 2000), may have affected both fish and marine mammal populations. Some authors suggest that the regime shift changed the composition of the fish community resulting in reduction of prey diversity in marine mammal diets (Sinclair 1988, Sinclair et al. 1994, Piatt and Anderson 1996, Merrick and Calkins 1996), while others caution against making conclusions about long-term trends in Steller sea lion diets based on small samples collected prior to 1975 (Fritz and Hinckley 2005). Some suggest the overall biomass of fish was reduced by about 50 percent (Merrick et al. 1995, Piatt and Anderson 1996), while others saw an overall increase in biomass after the regime shift, in part because of a few years of very large recruitment in some species (e.g. pollock) (Beamish 1993, Hollowed and Wooster 1995, Wyllie-Echeverria and Wooster 1998). Determining what the individual magnitudes of the impacts that fisheries and climatic shifts have had on localized prey availability for foraging marine mammals is difficult because their effects could be similar as are the population responses. However, this interaction warrants research consideration and may require large-scale experimentation, as proposed by the National Research Council (NRC 2003) and the Steller Sea Lion Recovery Team (NMFS 2006), to unravel.

Hunt et al. (2002) proposed that the pelagic ecosystem in the southeastern Bering Sea alternates between bottom-up control in cold regimes and top-down control in warm regimes. In their proposed Oscillating Control Hypothesis, Hunt et al. (2002) hypothesized that when cold or warm conditions span decades, the survival and recruitment of piscivorous vs. planktivorous fishes are variably affected (Hunt et al. 2002).

Shima et al. (2000) looked at the GOA and three other ecosystems where pinniped populations, marked environmental oscillations, and extensive commercial fishing activity all occur. Among pinnipeds in the four ecosystems, only GOA Steller sea lions were decreasing in abundance. Shima et al. (2000) hypothesized that the larger size and restricted foraging habitat of Steller sea lions, especially for juveniles that forage mostly in the upper water column close to land, may make them more vulnerable than other pinnipeds to changes in prey availability, and spatial and temporal changes in prey, especially during the critical winter time period.

Summary of information on Alaska marine mammal stocks

Table 20. This summary table of Alaska marine mammal stocks includes estimates of fishery mortality and native subsistence harvest levels up through 2006. Fishery mortality is expressed as an annual average for the time period 1998-2006.

Species	**Stock**	**N (est)**	**CV**	**N(min)**	**Rmax**	**F(r)**	**PBR**	**Fishery mort.**	**Subsist mort.**	**Status**
Baird's beaked whale	Alaska	n/a		n/a	0.04	0.5	n/a	0		NS
Bearded seal	Alaska	n/a		n/a	0.12	0.5	n/a	0.68	6,789	NS
Beluga whale	Beaufort Sea	39,258	0.229	32,453	0.04	1	649	0	152	NS
Beluga whale	E. Chukchi Sea	3,710	n/a	3,710	0.04	1	74	0	65	NS
Beluga whale	E. Bering Sea	18,142	0.24	14,898	0.04	1	298	0	209	NS
Beluga whale	Bristol Bay	1,888	n/a	1,619	0.04	1	32	0	19	NS
Beluga whale	Cook Inlet	278	0.18	238	0.04	0.3	Undet.	0	1	S
Bowhead whale	W. Arctic	10,545	0.13	9,472	0.04	0.5	95	0	39	S
Cuvier's beaked whale	Alaska	n/a		n/a	0.04	0.5	n/a	0	0	NS
Dall's porpoise	Alaska	Unkn.		Undet.	0.04	1	Undet.	30	0	NS
Fin whale	NE Pacific	n/a		n/a	0.02	0.1	n/a	0.8	0	S
Gray whale	E. N. Pacific	18,813	0.07	17,752	0.047	1	417	6.7	122	NS
Harbor Porpoise	SE Alaska	17,076	0.265	13,713	0.04	0.5	137	0	n/a	NS
Harbor porpoise	Gulf of Alaska	41,854	0.214	34,740	0.04	0.5	347	0	n/a	NS
Harbor porpoise	Bering Sea	66,078	0.232	54,492	0.04	0.5	545	0	n/a	NS
Harbor seal	SE Alaska	112,391	0.04	108,670	0.12	1	3,260	0	1,092	NS
Harbor seal	Gulf of Alaska	45,975	0.04	44,453	0.12	0.5	1,334	24.2	795	NS
Harbor seal	Bering Sea	21,651	0.1	20,109	0.12	0.5	603	1.3	174	NS
Humpback whale	W. N. Pacific	394	0.08	367	0.07	0.1	1.3	0.4	0	S
Humpback whale	Cent.N. Pacific	4,005	0.095	3,698	0.07	0.1	12.9	3	0	S
Humpback whale	CNP-SEAK feeding area	961	0.12	868	0.07	0.1	3	1	0	
Killer whale	Alaska resident	1123	n/a	1123	0.07	0.5	11.2	1.5	0	NS
Killer whale	GOA, BSAI transient	314	n/a	314	0.04	0.5	3.1	0.4	0	NS
Killer whale	AT1 transients	8			0.04	0.5	0	0	0	S
Minke whale	Alaska	n/a		n/a	0.04	0.5	n/a	0	0	NS
North Pacific right whale	E. N. Pacific	n/a		n/a	0.04	0.1	n/a	0	0	S
Northern fur seal	E. North Pacific	721,935		709,881	0.086	0.5	15,262	0.5	754	S
Pacific white-sided dolphin	Cent.N. Pacific	26,880		26,880	0.04	0.5	n/a	0	0	NS
Ribbon seal	Alaska	n/a		n/a	0.12	0.5	n/a	0.8	193	NS
Ringed seal	Alaska	n/a		n/a	0.12	0.5	n/a	0.71	9,567	NS
Sperm whale	N. Pacific	n/a		n/a	0.12	0.1	n/a	0.5	0	S
Spotted seal	Alaska	n/a		n/a	0.12	0.5	n/a	0.88	5,265	NS
Stejneger's beaked whale	Alaska	n/a		n/a	0.04	0.5	n/a	0	0	NS
Steller sea lion	E. U. S.	47,886		44,555	0.12	0.75	2,000	2.6	0	S
Steller sea lion	W.U. S.	38,988		48,988	0.12	0.1	234	24.6	191	S

CV = combined CV; Status: S=Strategic, NS=Not Strategic, n/a = not available.
* = No reported take by fishery observers; however, observer coverage was minimal or nonexistent.
** = this does not include intentional take in British Columbia

Seabirds

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Last updated: November 2006

The 2005 seabird section provides information on incidental catch estimates, colony trend data for select seabird colonies, and a review of other work being completed. Readers interested in a discussion of seabird foraging and effects of food limitations on seabird populations should refer to the extensive information provided in the Ecosystem Considerations for 2001 (NPFMC 2000) and for 2003 (NPFMC 2002). Readers interested in fishery/seabird geographical overlap can rely on the discussion provided in the 2002 chapter (NPFMC 2002).

The U.S. Fish & Wildlife Service (USFWS) is the lead Federal agency for managing and conserving seabirds and is responsible for monitoring distribution, abundance, and population trends. The U. S. Geologic Survey – Biological Resources Division (USGS-BRD) plays a critical role in seabird research in Alaskan waters in support of these activities, focusing primarily on seabird colonies. Additionally, the National Marine Fisheries Service (NMFS), with its fisheries management responsibilities, plays a critical role in working with industry and other agencies to focus on characterizing seabird incidental takes and reducing incidental takes (bycatch) in commercial fisheries.

Distribution

<u>Pelagic</u>

Maps depicting historic (1970s - 1980s) distribution of selected seabirds and current fishing effort can be viewed in the Ecosystem Considerations for 2002 report (NPFMC 2001). The seabird data for these maps were taken from the North Pacific Pelagic Seabird Database (NPPSD 2004). At that time, the NPPSD was primarily comprised of data from surveys conducted during the Outer Continental Shelf Environmental Assessment Program. The pelagic distribution of seabirds in Alaskan waters has not been examined comprehensively in recent years, but several studies have been implemented that will provide current data on seabird distribution and abundance at sea. One such study is the stationary seabird surveys on longline and trawl fisheries research vessels. This program was initiated in 2002 by the Washington Sea Grant Program in collaboration with the International Pacific Halibut Commission, the Alaska Department of Fish and Game, and NMFS to complete "bird-feeder" type surveys on charter vessels conducting halibut and sablefish surveys. Counts of seabird abundance (for select groups) were performed after each set was brought aboard and within a standardized area astern. In 2004 the program was expanded to include groundfish charters operated by the Alaska Fisheries Science Center. The resulting data were used to examine the distribution of seabird species susceptible to longline bycatch (Melvin et al. 2004), and subsequently, a proposal to the NPFMC to reduce mitigation devices for seabirds in 'inside waters'.

In 2006, the U.S. Fish and Wildlife Service (USFWS) received a grant from the North Pacific Research Board to initiate an at-sea survey program for marine birds using ships of opportunity. This program began in May 2006, and has placed observers on 12 cruises for a total 160 observer-days at sea. The program is a cooperative venture with NOAA, which provides space for seabird observers on their fisheries research vessels. Other research programs and the Alaska Maritime National Wildlife Refuge have also provided ship time in Alaska waters. The data will be entered into the NPPSD for more current examination of seabird distribution relative to fisheries and to physical and biological factors.

Another avenue for determining seabird distribution at sea is via satellite telemetry, used to track far-ranging ocean wanderers. Rob Suryan (Oregon State University) has been tracking the endangered short-tailed albatross from its breeding colonies in Japan to its feeding grounds in Alaskan waters (Suryan et al. 2006). Scott Hatch (USGS, Anchorage, Alaska) has been tracking northern fulmars from multiple breeding colonies in Alaska during summer and winter foraging phases. His preliminary findings show distinctly different winter migration routes among birds from different colonies (Hatch 2006 - IV North American Ornithological Conference, Veracruz, Mexico [abstract; Hatch_1284.html]). Using spatial patterns in fulmar foraging patterns and fishing effort, he is preparing an estimate of bycatch risk and annual mortality rates from incidental take for the four main breeding colonies. This is the first such effort to quantitatively define incidental take relative to the population for an Alaskan seabird.

Colonies

(Not updated). The sizes of seabird colonies and their species composition differ among geographic regions of Alaska (Figure 106), due to differences in marine habitats and shoreline features (Stephensen and Irons 2003). In the southeastern GOA, there are about 135 colonies, and they tend to be small (<60,000 birds, and often <5,000). Exceptions are two colonies with 250,000-500,000 birds at Forrester and St. Lazaria Islands. Along the coast of north-central Gulf of Alaska (GOA), colonies are generally small but number over 850 locations, with larger colonies at the Barren and Semidi Island groups. Moving west along the Alaska Peninsula (with 261 colonies) and throughout the Aleutians (144 colonies), colonies increase in size, and include several with over 1 million birds and two with over 3 million birds. Large colonies of over 3 million birds are also found on the large islands of the Bering Sea (BS). Relatively few colonies are located along the mainland of the BS coast, and colonies along the Chukchi and Beaufort Seas are small and dispersed.

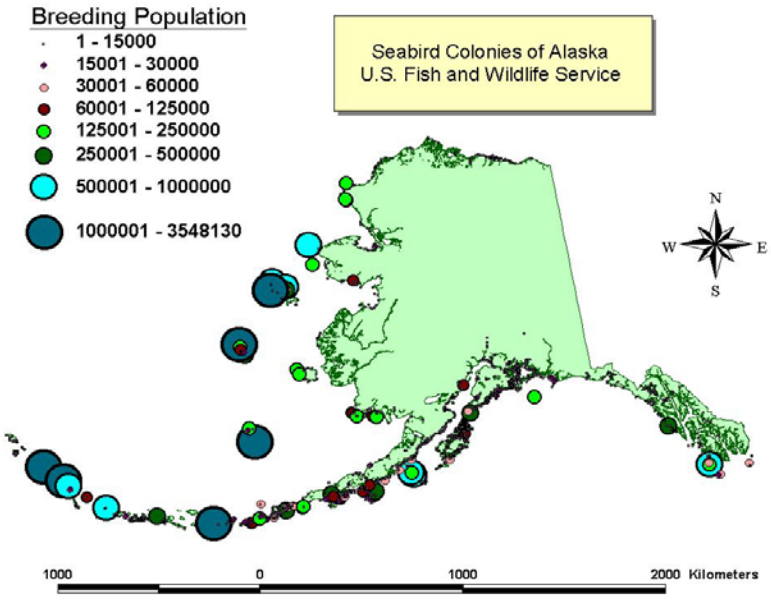


Figure 106. Seabird Colonies of Alaska. Beringian Seabird Colony Catalog (USFWS 2003).

Trends in Abundance and Productivity

Breeding populations were estimated to contain 36 million individuals in the BS and 12 million individuals in the GOA; total population size (including subadults and nonbreeders) is estimated to be approximately 30% higher. Five additional species occur in Alaskan waters during summer and contribute another 30 million birds. More recent analyses of updated colony data indicated that the eastern Bering Sea (EBS) supports about 20.3 million breeding seabirds, whereas the GOA has 7.2 million (Stephensen and Irons 2003).

Some seabirds are highly clustered into a few colonies, and 50% of Alaska's seabirds nest in just 12 colonies, 10 of which are in the EBS (Stephensen and Irons 2003). The USFWS and USGS-BRD monitor selected colonies on rotating schedules, described in detail in Dragoo et al. (2006) (see also, NPFMC 2002). Discussion of factors that influence seabird populations was presented in the Ecosystem Considerations for 2002 report (NPFMC 2001). For detailed summaries of seabird chronology, breeding success and population trends for species at specific sites refer to Dragoo et al. (2006), which includes data up to 2003.

Below, we summarize data presented in Dragoo et al. (2006) as well as some data updated through 2005 (D. Dragoo, U.S. Fish and Wildlife Service, personal communication), with a focus on broad regional trends, with colonies combined into five subregions based on geographic location and marine influences (Figure 107). The five subregions are: 1) the Northern Bering/Chukchi (NB/C), from Hall Island to Cape Lisburne, 2) Southeastern Bering Sea (SEBS), which includes the Pribilof Islands, eastern Aleutian islands and Bristol Bay area, 3) the Southwestern Bering Sea (SWBS), which includes central and western Aleutian Islands, 4) the Northern GOA (GOA), from the upper Alaska Peninsula to Prince William Sound, and 5) Southeastern Alaska (SEAK), which has only one colony at St. Lazaria Island. A population sample consists of data for a species at a given colony site, (Figures 108-110) with sample sizes varying among years and parameters being studied. Because birds with different diets and foraging behaviors can vary in their response to environmental changes, we also examined the regional trends for three feeding guilds of seabirds: planktivores (birds that eat primarily macro-zooplankton and invertebrates), surface piscivores (birds that primarily catch fish at the water's surface), and diving piscivores (birds that catch fish by diving into the water column). These guilds are simplified for this exercise, since most birds consume both plankton and fish to some degree. For this report, planktivores refers to storm-petrels and auklets, surface piscivores refers to kittiwakes and gulls, and diving piscivores refers to murres, puffins, rhinocerous auklets, and cormorants.

Overall, breeding chronology in 2003 (Figure 108a) was early or average, with early nesters predominate in the NB/C, SEBS, and SEAK. The highest number of late nesters was in SWBS, where no birds were early. Planktivores were mostly average in hatch date, especially in the SWBS, with a few species earlier in the NB/C and SEAK (Figure 108b). Surface-feeding piscivores (Figure 108c) tended to be average or late in 2003, with the exception of red-legged and black-legged kittiwakes in SEBS, which nested early (Dragoo et al. 2006). Diving piscivores had the largest proportions of samples (species x site) with earlier than average breeding chronology, although more divers were average in SEBS and birds were average or late in SWBS (Figure 108d). This represents a slight increase in later breeding, compared to 2002 when most birds were earlier than average, and there were no late breeders.

Seabird productivity in 2003 (Figure 109a) varied throughout regions and among species, but there was a trend of above average or average productivity in most regions. An exception was SWBS, where 42% of samples (n = 26) had below average productivity. Planktivores, concentrated in the SWBS, tended to have average or above average productivity (Figure 109b), with the exception of least and crested auklets (Dragoo et al. 2006). Surface piscivores (most cases being black-legged kittiwakes) were mostly above average, although there were below average samples in all but the NB/C subregion (Figure 109c). Productivity of diving piscivores was also mixed, although below average productivity dominated birds in the SWBS. The SWBS was also the only subregion where no diving piscivores had above average productivity. In summary, 2003 appeared to be an average or above average year for productivity for most planktivores and surface piscivores, but a larger proportion of diving piscivores (38 %, n= 32) had below average productivity. A similar pattern was observed in 2002, when diving piscivores showed more below average productivity than the other two feeding guilds (NPFMC 2005).

A more complete look at long-term trends in seabird productivity was derived using all available data and calculating the deviation from the long-term average for each year (Tables 21 and 22). Overall, piscivores went from generally negative or neutral productivity anomalies during 1994-1999, to generally positive anomalies in 2000-2004. However, there were differences among the five subregions. In the GOA, most seabirds did poor or average between ~ 1994 and 1998, but switched to positive anomalies between 1999 and 2002. A similar pattern is evident in the SEBS. In contrast, most birds in SWBS (particularly diving piscivores and planktivores) showed an opposite pattern, with higher productivity during ~ 1994-1997, lower productivity during 1998-1999, and average or mixed productivity between 2000 and 2002.

For seabirds in Alaska, it is apparent that, while there may be some regional and decadal patterns, changes in seabird productivity are not similar across regions, and can also vary among feeding guilds within the same region (Tables 21 and 22). There are always species or colonies that are exceptions (see Dragoo et al. 2006). Although general large-scale patterns are complicated by such species and colony effects, the combined long-term data suggest that major regions within both the Bering Sea and the GOA may be in opposition in terms of environmental conditions beneficial to seabird productivity. (This is speculative and requires further investigation).

Changes in seabird populations (Figure 110a) are less subject to annual fluctuations, since adults are long-lived and usually return to the same breeding colony. Because changes observed in a single year may not be meaningful, Dragoo et al. (2006) describe population trends for all years of available data through 2003, using linear regression models on log-transformed data. Of the 96 species x sites samples, declining seabird populations comprised 22%, while 20% showed increasing trends. The majority of samples showed no discernable change (58% of samples). Planktivores were stable or increasing at all monitored sites (Figure 110b), with the exception of least auklets at Kasatochi Island (Dragoo et al. 2006). Among surface piscivores, most populations were stable or increasing, although there were species with decreasing trends in SEBS, SWBS, and GOA (Figure 110c). The majority (59%, n = 54) of diving piscivore population trends (Figure 110d) were stable, although there were more negative trends in the GOA and SEBS. These same regions showed similar trends for diving piscivores in 2002.

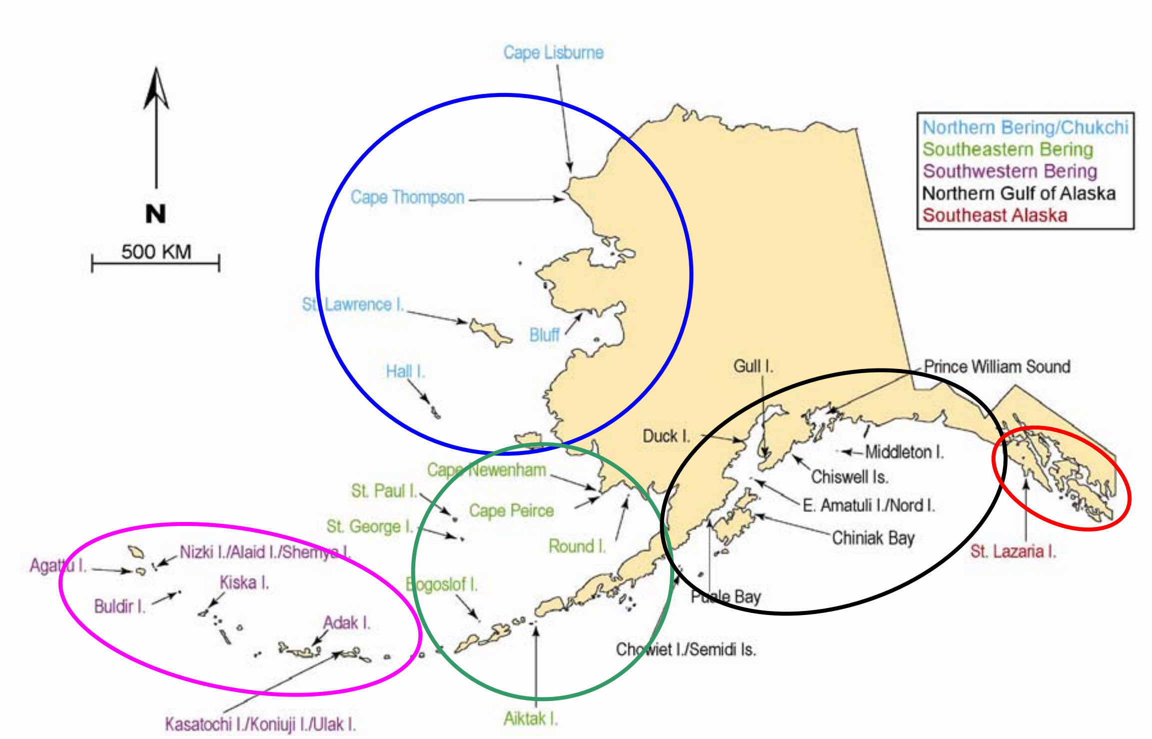


Figure 107. Five regions of Alaskan seabird colonies examined in this report. Reprinted with the permission of Dragoo et al. 2006.

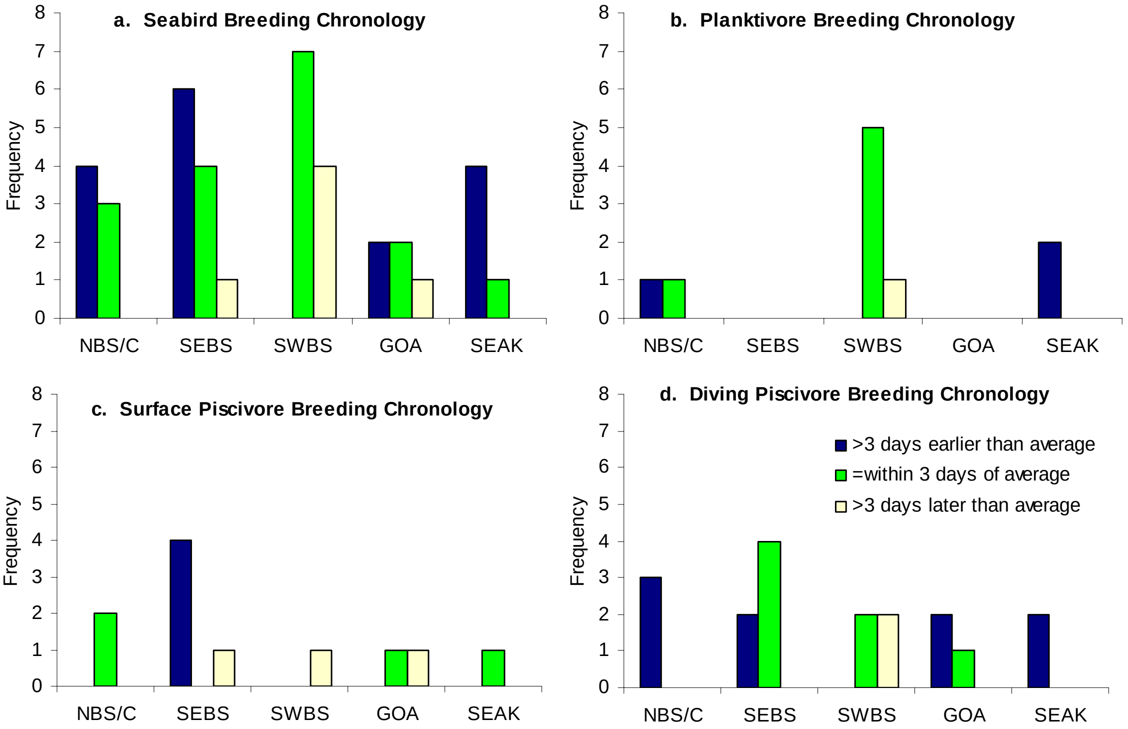


Figure 108. Seabird breeding chronology (by region and for three feeding guilds) for species monitored at selected colonies in Alaska in summer 2003. Frequency is the number of samples (species x site) for each region, showing earlier than average, average, or later than average dates for breeding. Chronology usually used hatch dates. Data are from Dragoo et al. 2006.

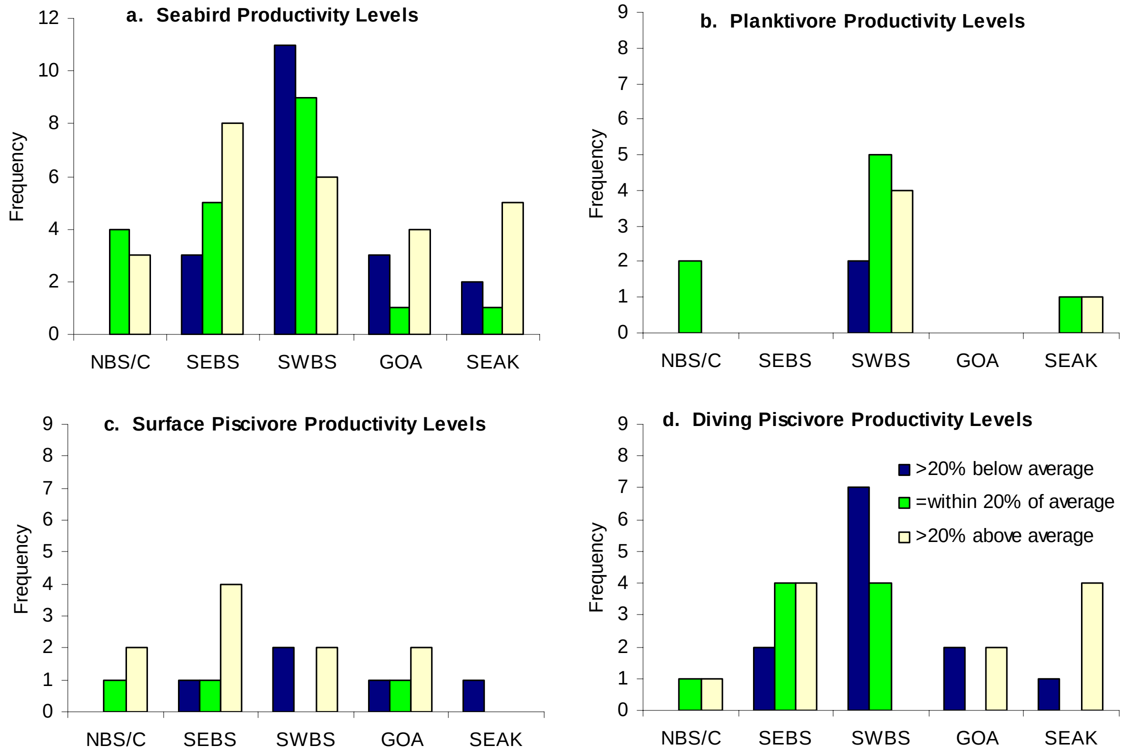


Figure 109. Seabird breeding success (by region and for three feeding guilds) for species monitored at selected colonies in Alaska in summer 2003. Frequency is the number of samples (species x site) for each region, showing below average, average, or above average productivity rates. Productivity was usually expressed as chicks fledged per egg (but see individual reports referenced in Dragoo et al. 2006 for variants). Data are from Dragoo et al. 2006.

Table 21. Seabird species codes (AOU code), common names, scientific names, and feeding guilds used in Table 22.

AOU code	Common name	Scientific name	Guild
PECO	pelagic cormorant	*Phalacrocorax pelagicus*	diving piscivore
RFCO	red-faced cormorant	*Phalacrocorax urile*	diving piscivore
FTSP	fork-tailed storm-petrel	*Oceanodroma furcata*	planktivore
LHSP	Leach's storm-petrel	*Oceanodroma leucorhoa*	planktivore
GWGU	glacous-winged gull	*Larus glaucescens*	surface piscivore
BLKI	black-legged kittiwake	*Rissa trydactyla*	surface piscivore
RLKI	red-legged kittiwake	*Rissa brevirostris*	surface piscivore
COMU	common murre	*Uria aalgae*	diving piscivore
TBMU	thick-billed murre	*Uria lomvia*	diving piscivore
ANMU	ancient murrelet	*Synthliboramphus antiquus*	planktivore
TUPU	tufted puffin	*Fratercula cirrhata*	diving piscivore
HOPU	horned puffin	*Fratercula corniculata*	diving piscivore
CRAU	crested auklet	*Aethia cristatella*	planktivore
WHAU	whiskered auklet	*Aethia pygmaea*	planktivore
PAAU	parakeet auklet	*Cyclorrhynchus psittacula*	planktivore
LEAU	least auklet	*Aethia pusilla*	planktivore
RHAU	rhinoceros auklet	*Cerorhina monocerata*	diving piscivore

Table 22. Average productivity anomalies for seabird species averaged across species in three feeding guilds (surface piscivores (SP), diving piscivores (DP), and planktivores (PL)) of the north Bering Sea/Chukchi Sea, southeast Bering Sea (SEBS), southwest Bering Sea (SWBS), Gulf of Alaska (GOA), and Southeast Alaska (SEAK). Anomalies were calculated as the estimated productivity for a given year minus the mean productivity over the whole time series and divided by the standard deviation, and then averaged over each species by region. Anomalies were divided into 7 categories for display purposes (see legend). See Table 21 for species codes.

Region	Guild	Species	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
NBS/Chukchi	SP	BLKI		.	-	.	.	++	+	+	+	+	-	-	.	+	.	-	.	.	-	.		-	.	.	.	.	+	-	.			
NBS/Chukchi	DP	COMU															.		+	-				+					+	.	-			
NBS/Chukchi	DP	TBMU															.		.	-				+	-	-	.		.	+	-			
NBS/Chukchi	PL	CRAU																											.	-	+			
NBS/Chukchi	PL	LEAU																											.	-	+			
SEBS	SP	BLKI		+	+	+	.	+	+	.	-	-	-	-	.	-	+	-	.	.	+	.	-	-	-	.	.	-	+	-	++	+	+	-
SEBS	SP	RLKI		+	+	++	-	.	.	-	-	-	-	-	.	-	+	-	.	+	+	.	.	-	-	.	+	.	+	.	+	-	.	-
SEBS	SP	GWGU																						-	-	+	+	-	.	+	.			
SEBS	DP	COMU			.		+			-			-	+	.	+	+	.	.	+	.	+	.	+	.	-	--	-	+	.	.	.	.	--
SEBS	DP	PECO													.	.	+	.	.	+	++	+	+	-	-	-	-	-	-	.	+			
SEBS	DP	RFCO			.	.	.							.	.	.	.	.	-		-	-	-	-	.	-	+	.	+	.	+			
SEBS	DP	TBMU			++	.	+			---			-	+	-	+	+	.	.	+	.	+	.	.	.	.	-	.	+	.	.	.	-	-
SEBS	DP	TUPU																						.	-	-	-	.	+	+	+			
SEBS	PL	FTSP																						.	-	-	.	+	.	+	+			
SEBS	PL	LHSP																						+	-	-	.	+	+	+	--			
SWBS	SP	BLKI															+	-	+	.	++	-	-	-	.	+	.	-	.	-	.			
SWBS	SP	RLKI															+	.	++	.	+	-	-	-	.	.	.	-	+	-	.			
SWBS	SP	GWGU																			.	-	-	.	.	++	-	.	-		+	+	.	.
SWBS	DP	COMU																							++	+	.	-	.	.	.			
SWBS	DP	HOPU										-	-	-	-	--	+	.	.	.	+	+	+	+	+	-	-	.	+	-			
SWBS	DP	PECO	+																++		-	-	+	.	.	+	-	.	+	.	.			
SWBS	DP	RFCO																							.	.	.	-	+	+	.			
SWBS	DP	TBMU															+	.	+	.	-	+	.	+	+	+	-	-	.	-	.			
SWBS	DP	TUPU															-	+	.	-	+	+	.	+	+	-	-	.	++	.	-			
SWBS	PL	PAAU																		.	+	.	.	+	+	.	+		.	--	-			
SWBS	PL	CRAU															--		-	-	+	+	.	+	.	.	+	+	.	-	.			
SWBS	PL	FTSP	-	--	-													-	+	+	+	.	+	+	.	-	+	.	+	.	+			
SWBS	PL	LEAU															.		--	+	.	.	-	++	+	.	-	-	.	.	.			
SWBS	PL	LHSP	--	--	--													.	+	+	.	.	+	+	.	+	+	.	.	.	.			
SWBS	PL	WHAU																	.	-	.	.	+	+	+	+	.		-	--	-			
GOA	SP	BLKI			.	+	.	.	.	++	+	.	+	.	.	-	+	.	-	-	.	.	.	.	.	.	-	-	.	+	+		-	-
GOA	SP	GWGU																						.	.	-	+	.			+			
GOA	DP	COMU						.	+	+								.	.	.	+	-	.	.	.	.	-	.	+	+	+		-	.
GOA	DP	HOPU																							+	.	-	+						
GOA	DP	PECO					.				++	++	+	+	-	-	-	-	.	.	-	+	-	-	.	.	.	.	+	+	+			
GOA	DP	RFCO																-	-	.	-	+	+	-	+	-	-	-	+	+	+			
GOA	DP	RHAU			+	-																.				-	.	+	+	+	-			
GOA	DP	TBMU						+	.	++								-	-	.	.	.		.			--			+	.		-	.
GOA	DP	TUPU																				+	.	.	-	-	-	+						
SEAK	SP	GWGU																							-	.	.	-	-	+	+			
SEAK	DP	COMU																					+	-	-	+	.	-	.	+	-			
SEAK	DP	PECO																					-	-	++	.	.	.	+	.	-			
SEAK	DP	RHAU																									-			+				
SEAK	DP	TBMU																					.	.	-	++	-	-	+	+	.			
SEAK	DP	TUPU																					-	--	+	+	.	.	.	.				
SEAK	PL	FTSP																					++	.	+	.	.	--	.	.				
SEAK	PL	LHSP																					+	.	+	+	.	-	.	--				

Legend

+++	X>2.7
++	2.7>X>1.6
+	1.6>X>0.5
.	0.5>X>-0.5
-	-0.5>X>-1.6
--	-1.6>X>-2.7
---	-2.7>X
	No data

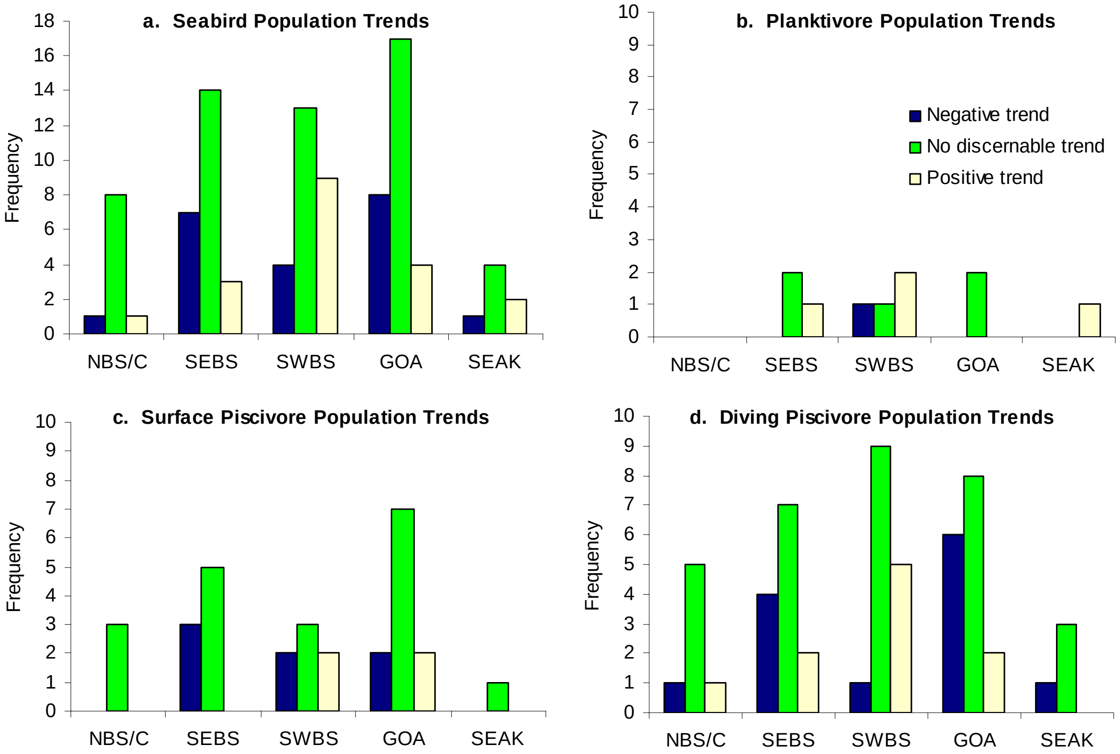


Figure 110. Seabird population trends (by region and for three feeding guilds) for species monitored at selected colonies in Alaska in summer 2003. Frequency is the number of samples (species x site) for each region, showing negative trends, no statistically significant trend, or positive trends in population, derived from linear regression models on log-transformed data, for samples with multiple years of data. Data are from Dragoo et al. 2006.

Ecosystem Factors Affecting Seabirds

Food Availability

Seabird foraging and effects of food limitations on seabird populations were addressed in the Ecosystem Considerations for 2000 report (NPFMC 1999). The Ecosystem Considerations for 2004 report (NPFMC 2003; Seabird section, Table 2) reviewed seabird biomass consumption in Alaska by combining estimates of seabird population and biomass in Stephensen and Irons (2003) with estimates of seabird energy needs in Hunt et al. (2000). For all species combined, estimated seabird daily energy needs (kj) was 15,228,691,302 kj in the EBS and 7,138,893,668 kj in the GOA (NPFMC 2003). The energetic requirements of seabirds in the Subarctic North Pacific Ocean and estimates of seabird biomass consumption for large marine regions are available in Hunt et al. (2000). This PICES document remains the most comprehensive examination of seabird diet and consumption for Alaskan waters.

Factors affecting food availability for seabirds include (1) forage fish availability and spatial/temporal changes due to ecosystem effects, (2) commercial fishery removals of forage fish, either through directed catch or bycatch, (3) enhancements to forage fish stock and availability due to commercial fishery removal of predators, and (4) provisioning of food to seabirds through discards and offal from commercial fisheries. We are unaware if a model of these factors has been completed for the North Pacific. There are no directed fisheries for forage fish in federal waters off Alaska, although seabirds also consume the juveniles of most commercial species. Work is being started at the Alaska Fisheries Science Center (AFSC) to address item 4, which may lay some groundwork to fill knowledge gaps with regard to the other items.

Fishery Interactions

Fisheries bycatch.

This section provides information on trends in seabird bycatch by fishery and by species or species group through 2004. Some of the information included here is available at http://www.afsc.noaa.gov/REFM/REEM/Seabirds/Default.htm or http://www.afsc.noaa.gov/refm/reem/doc/Seabird%20bycatch%20tables%201993-2004_13April2006.pdf

Bycatch summarized here is reported by the species or reporting groups developed in consultation with the U.S. Fish and Wildlife Service Region 7 (Anchorage, Alaska). Estimates of seabird bycatch from Alaskan groundfish fisheries are completed by NOAA Fisheries Alaska Fisheries Science Center staff each year using two sources of information. The first is data obtained from the North Pacific Groundfish Observer Program. These data are composed of, among other information, total catch and species composition from direct monitoring of fishing operations by NMFS-certified groundfish observers. The second source of information is from the Alaska Regional Office catch accounting system that reports total catch. Observer methods are detailed in the North Pacific Groundfish Observer Program Documents while a description of the catch accounting database is available at Alaska Groundfish Catch Accounting System.

Groundfish fisheries include fixed gear (pot and demersal longline) and trawl gear in federal waters of the Alaskan EEZ. Fishing takes place in three areas defined in North Pacific Fisheries Management Council Fishery Management Plans – the Aleutian Islands (AI), Bering Sea (BS), and the Gulf of Alaska (GOA).

Seabird bycatch summarized here is reported by the species or reporting groups developed in consultation with the U.S. Fish and Wildlife Service Region 7 (Anchorage, Alaska) (Table 23). At least 23 individual species, represented as a species or unidentified category, have been taken in the groundfish fisheries, including Laysan albatross (*Diomedea immutabilis*), black-footed albatross (*Diomedea nigripes*), short-tailed albatross (*Phoebastria albatrus*), Northern fulmar (*Fulmarus glacialis*), sooty shearwater (*Puffinus griseus*), short-tailed shearwater (*Puffinus tenuirostris*), unidentified storm petrel (*Oceanitidea*), herring gull (*Larus argentatus*), glaucus gull (*Larus hyperboreus*), glaucus-winged gull (*Larus glaucescens*), black-legged kittiwake (*Larus tridactyla*), red-legged kittiwake (*Larus brevirostris*), thick-billed murre (*Uria lomvia*), common murre (*Uria aalge*), tufted puffin (*Fratercula cirrhata*), king eider (*Somateria spectabilis*), loon unidentified (*Gaviidae*), grebe unidentified (*Podicipedidae*), cormorant unidentified (*Phalocrocoracidae*), jaeger/skua unidentified (*Stercorarius spp.*), tern unidentified (*Sternidae*), guillomot unidentified (*Cepphus spp.*), auklet/murrelet unidentified (*Alcidae:* several genera).

Longline Fisheries**:** Longline, or hook and line, fisheries in Alaskan waters are demersal sets and target groundfish or halibut. There are no observer coverage requirements for the halibut fleet. Information reported here are for demersal groundfish longline fisheries only. Longline fisheries in the BSAI are typically undertaken by vessels that are larger, stay at sea longer (up to 30 days), have onboard processing abilities, target Pacific cod (*Gadus macrocephalus*) and Greenland turbot (*Reinhardtius hippoglossoides*), use auto-bait systems, and deploy up to 55,000 hooks per day (Melvin et al. 2001). Conversely, longline vessels in the GOA typically are smaller, have shorter trip lengths (6 days), deliver bled fish on ice to shoreside processing plants, target sablefish (*Anoplopoma fimbria*), use tub or hand bait gear, and deploy up to 10,500 hooks per day (Melvin et al. 2001).

Between 1993 and 2003 the average annual bycatch in the combined BSAI and GOA longline fisheries was 13,551 seabirds (12,619 and 932 respectively; Tables 24-27). Over this period the average annual bycatch rates were 0.071 and 0.024 birds per 1,000 hooks in the BSAI and GOA, respectively. The period previous to 1998 was typified by large inter-annual variation in seabird bycatch, even with the implementation of the first generation of seabird avoidance regulations in 1997 (Figure 111). Beginning in 1998, seabird bycatch has trended downward. In 2002 many freezer-longliners fishing in the BSAI adopted the recommendations from studies completed by Melvin et al. (2001). Paired streamer lines meeting specific performance standards had proven to be very effective in reducing seabird bycatch during this study. NMFS completed revisions to seabird avoidance regulations in February 2004. Among other requirements, vessels larger than 55 feet length over all must use paired streamer lines except in certain weather conditions.

In the BSAI the annual bycatch of seabirds has been substantially reduced to the current numbers of about 5,000 birds (Figures 112 and 113). While seabird bycatch increased in 2003 over 2002, the rate remained constant while effort continued an upward trend (Figures 112 and 113). Note that a total of 3,835 seabirds were taken in BSAI longline fisheries in 2002 (Tables 24-26). This represents a steady reduction over the previous few years, and is a 6-fold decrease in the total number of birds taken from the high of over 24,000 birds in 1998. In the same time frame there has been a 7-fold reduction in the bycatch rate from 0.14 to 0.02 seabirds per 1,000 hooks (Table 24).

In the GOA seabird bycatch was also higher in 2003 (632 birds) than in 2002 (259 birds) (Tables 24 and 27). A very large increase in overall effort in 2003 was matched with a slight increase in overall seabird bycatch in the GOA. However, with steady increases in overall effort each year since 1998, the bycatch has decreased steadily from that high year. This is the first year since 1998 that bycatch was higher than the previous year. Bycatch in 2002 was the lowest yet recorded, and represented a 6-fold decrease from the high of 1,634 birds in 1996. The increase in seabird bycatch in 2003 causes concern, but with new regulations implemented for the 2004 season we are hopeful that the numbers will continue the downward trend observed since 1998 for both bycatch and the bycatch rate in the GOA (Figures 111-115).

Seabird bycatch in the BSAI and GOA longline fleets is linked to a variety of factors that have resulted in large inter-annual variation (Dietrich 2003). Some of these factors include food availability, environmental conditions, breeding success, and population levels. Other factors include fleet or vessel-specific factors and the effectiveness of mitigation measures. Seabird bycatch in 2002 was the lowest recorded for the longline fleet. Efforts by the longline fleet may have contributed substantially to the observed reduction, although no analysis has been completed to ascertain the contribution of various factors. In 2003 seabird bycatch in the BSAI increased by nearly 40% over 2002, while the bycatch rate remained fairly constant (0.019 vs 0.018 in 2002). The increased bycatch was likely due, in part, to a 28% increase in effort. However, other factors may also have been at work, given the reduction in bycatch between 1998 and 2002 of 84% while effort increased over this time by 23%. We also note that the seabird bycatch more than doubled in the GOA, while effort increased by about 1.5. Exploration of what contributed most to this upswing in bycatch is beyond the scope of this report but does represent an interesting area for further research. Efforts have been undertaken by NMFS, Washington Sea Grant, and industry associations to complete outreach activities and work with vessel owners and operators to further reduce bycatch. With these actions and the implementation of new regulations in 2004 that require paired streamer lines for all longline vessels over 60 feet the downward trend will hopefully continue

The species composition for seabird bycatch in the BSAI longline fishery is 59 percent fulmars, 20 percent gull species, 12 percent unidentified seabirds, 4 percent albatross species, 3 percent shearwater species, and 2 percent ‘all other’ species (Figures 116-117 and 119). Species composition in the GOA longline fishery is: 46 percent fulmars, 34 percent albatrosses, 12 percent gull species, 5 percent unidentified seabirds, 2 percent shearwater species, and less than 1 percent ‘all other’ species (Figures 118 and 119).

Pot: Seabird bycatch from groundfish pot fishing has traditionally been very limited. The overall average bycatch in this fishery, 1993 through 2004, is 55 seabirds (Table 28). That trend continues, with only 5 birds observed taken in 2004, extrapolating up to an estimated 60 total mortalities. No albatross have been taken in pot gear. Northern fulmars account for 37 of the 60 estimated birds in 2004. These birds obviously did not enter the pot while it was actively fishing on the bottom and are more likely the result of striking the vessel and gear before the pot is set.

Trawl: On trawl vessels only, observers use whole haul, partial haul, or basket sampling to record prohibited species bycatch and determine the species composition of the haul (AFSC 2004). With rarer species, such as salmon or halibut, it is important to maximize the sample size when possible. Conversely, when sampling for species composition the observer is limited by the amount of fish that can be sorted, weighed, and counted. Observers are often required to use two of these three sample types in a single haul in order to best accommodate the goals of prohibited species and species composition sampling (prohibited species are those that are not allowed to be retained and processed by groundfish operations and include salmon, herring, crab, and halibut – CFR 50 Section 679.21) (AFSC 2004).

Observers have been instructed to use the largest sample available when monitoring for seabird bycatch. Sample size was recorded when seabirds were found in the observer’s sample. When no birds were found the actual sample size used while monitoring for seabirds was not recorded due to the direction to use the largest sample size available. Unfortunately, not all observers used their largest monitored sample when looking for seabirds, which has complicated the analysis. Starting in 2004, observers were directed to record the sample size used when monitoring for seabirds regardless if any were found. However, for 1993 through 2003 it is not known with certainty which sample size was used to monitor for seabird bycatch in groundfish trawl operations. Because we know of a few cases where the largest sample available was not used, seabird bycatch has been calculated using two alternative methods based on the largest (alternative1) and smallest (alternative2) sizes of sampling effort recorded for fish species (Tables 29-31, Figure 120). In each of these two alternative calculation methods, a separate ratio estimator was used to bind the results of the catch ratios and variances of data from the three different sample sizes into arbitrary equal samples which were then inflated upwards to the total catch effort of the NMFS blend program. This provides two sets of estimates of seabird bycatch for trawlers.

While we cannot state with certainty which of the 2 estimates is more accurate, it is highly unlikely that all observers did the opposite of what they were instructed to do. It is much more likely that a few of the many observers deployed each year simply made a mistake. Therefore, while seabird bycatch on trawl vessels lies somewhere between the two estimates provided, alternative 1 (largest available sample size) probably provides the best estimate of seabird bycatch in the trawl fleet based on direct observer sampling (see caveat below).

As noted above, this issue was resolved for data collections beginning in the 2004 season. The sample size used to monitor for seabirds in all hauls is now recorded whether a bird was taken or not. The 2004 estimates were run as alternatives 1 and 2 (sample sizes for hauls with no seabird takes were ignored: alt 1 defaults to the largest sample size available whereas alt 2 defaults to the smallest) and method 2 (estimation procedure used the recorded sample size for all hauls). Method 2 aligns closely with the estimates from alternative 1 (Tables 29-31). Seabird bycatch is lowest in the GOA Region and generally higher in the BS, with the AI being intermediate but highest in 1996, 2001, and 2003 (Figure 121). Northern fulmars are again the most common species taken, constituting about 45% of the overall seabird bycatch in the combined groundfish trawl fleet when using the 1993-2004 average annual estimates

(Figure 122). That composition changes to about 76% when the 2000 through 2004 average annual estimates are used (Tables 29-31).

Another source of mortality for seabirds on trawl vessels are the trawl door cables (warps) and the cable that runs between the net monitoring device and the vessel (trawl sonar cable or third wire). To date, only anecdotal information is available from North Pacific groundfish fisheries, so the extent of the mortality from this cause is uncertain. A special project for observers was implemented in 2004 and expanded for the 2005 and 2006 fishing seasons. We are currently developing estimates on total trawl and trawl sonar effort and will use the 2004 through 2006 observer data to better characterize interaction rates and mortalities. A collaborative project was started in 2004 between the Alaska Fisheries Science Center and the Pollock Conservation Cooperative to promote development of seabird mitigation measures for groundfish catcher processor vessels. Funds were obtained from the NOAA Fisheries National Cooperative Research Program to assist with the development of these measures. Parallel to that, the Pollock Conservation Cooperative had been collaborating with Washington Sea Grant to conduct some preliminary work on interaction rates and further develop protocols drafted by Sea Grant, AFSC and University of Washington staff to be able to develop a rigorous field test of these measures. Washington Sea Grant coordinated with the Pollock Conservation Cooperative (with support from the AFSC and USFWS) to conduct such a rigorous test of these gear under commercial fishing conditions in the summer of 2005.

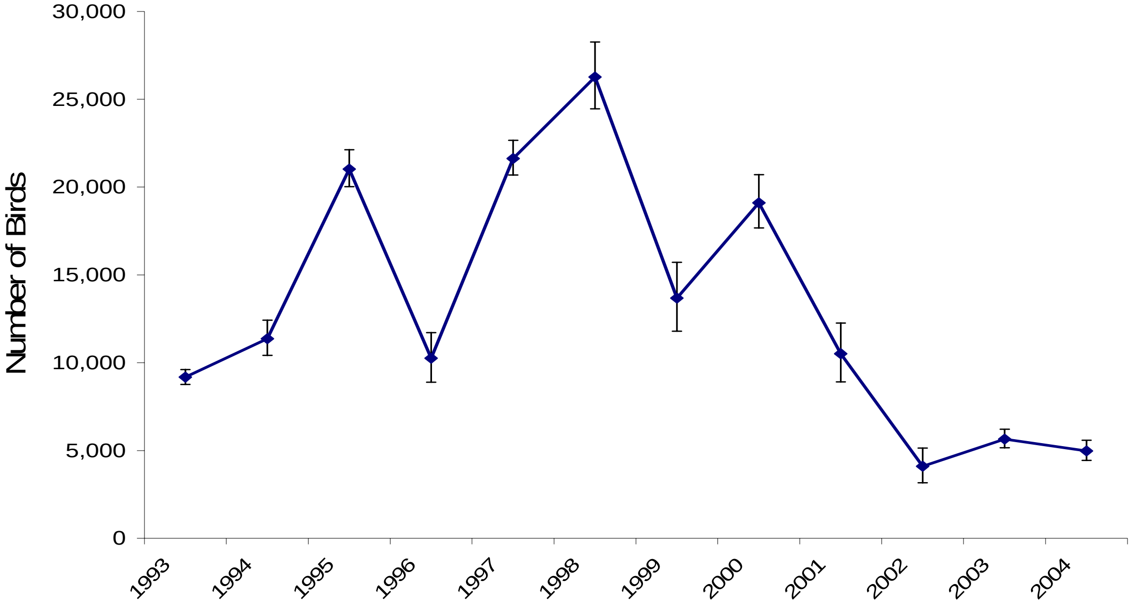


Figure 111. Total incidental take of seabirds in Alaskan combined demersal longline groundfish fisheries.

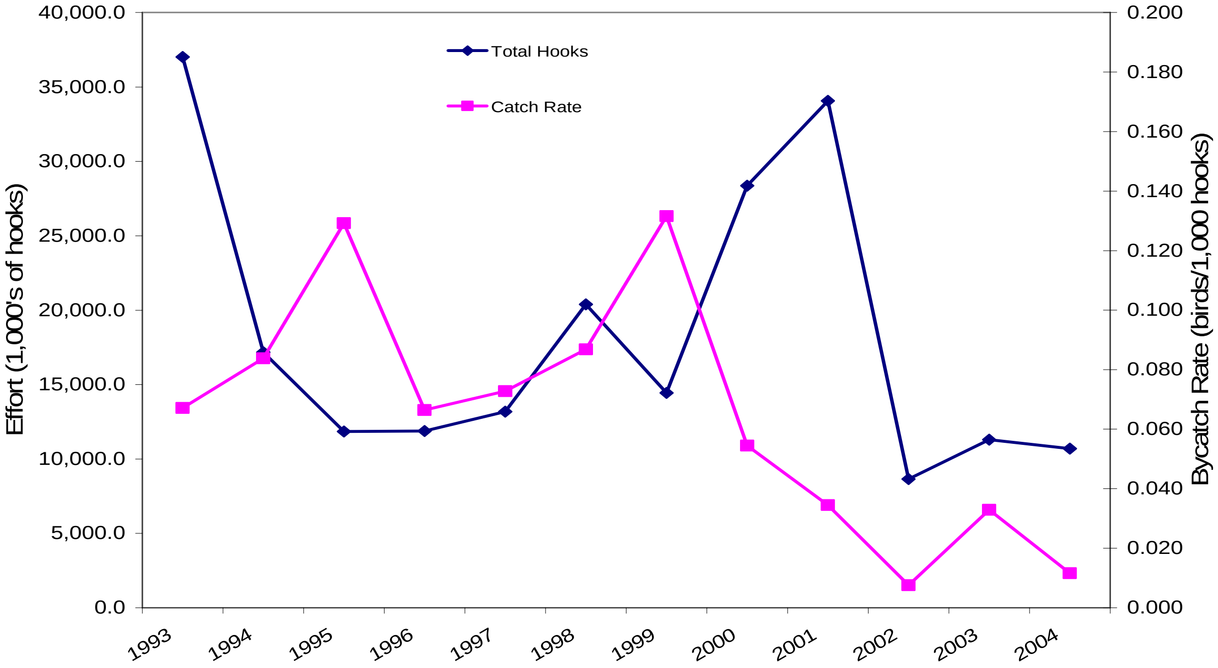


Figure 112. Total estimated hooks (in thousands) and bycatch rate of birds (birds per 1,000 hooks) in the Aleutian Islands Region demersal groundfish longline fishery.

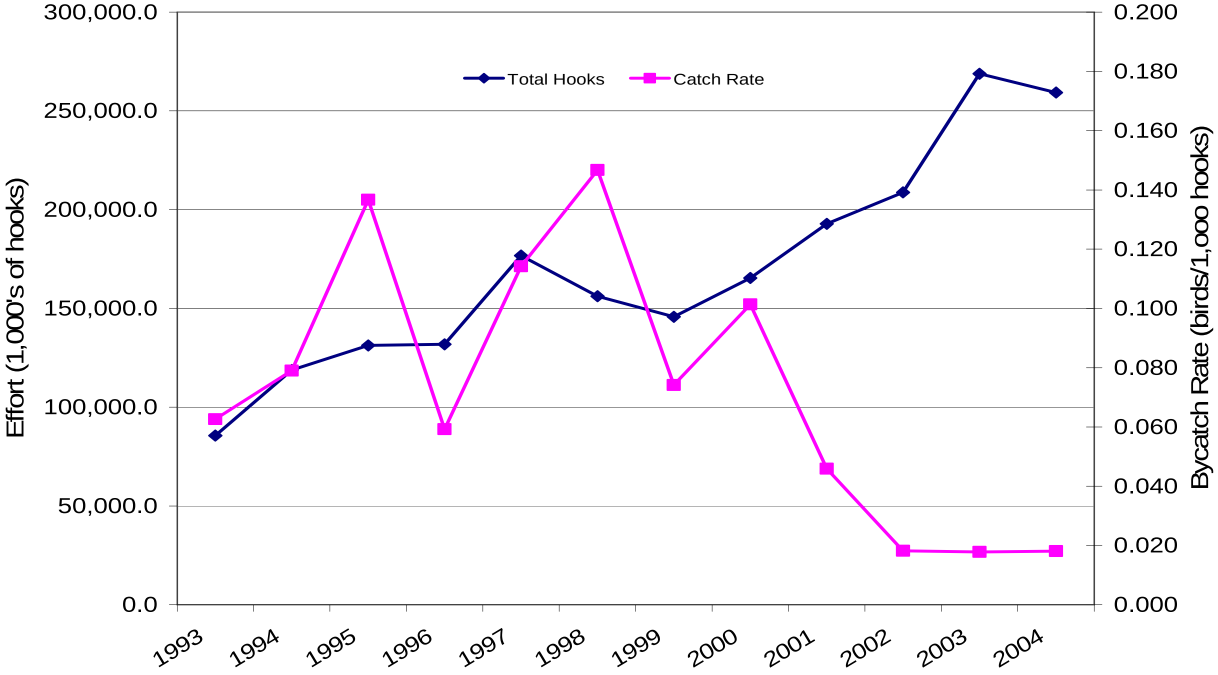


Figure 113. Total estimated hooks (in thousands) and bycatch rate of birds (birds per 1,000 hooks) in the Bering Sea Region demersal groundfish longline fishery.

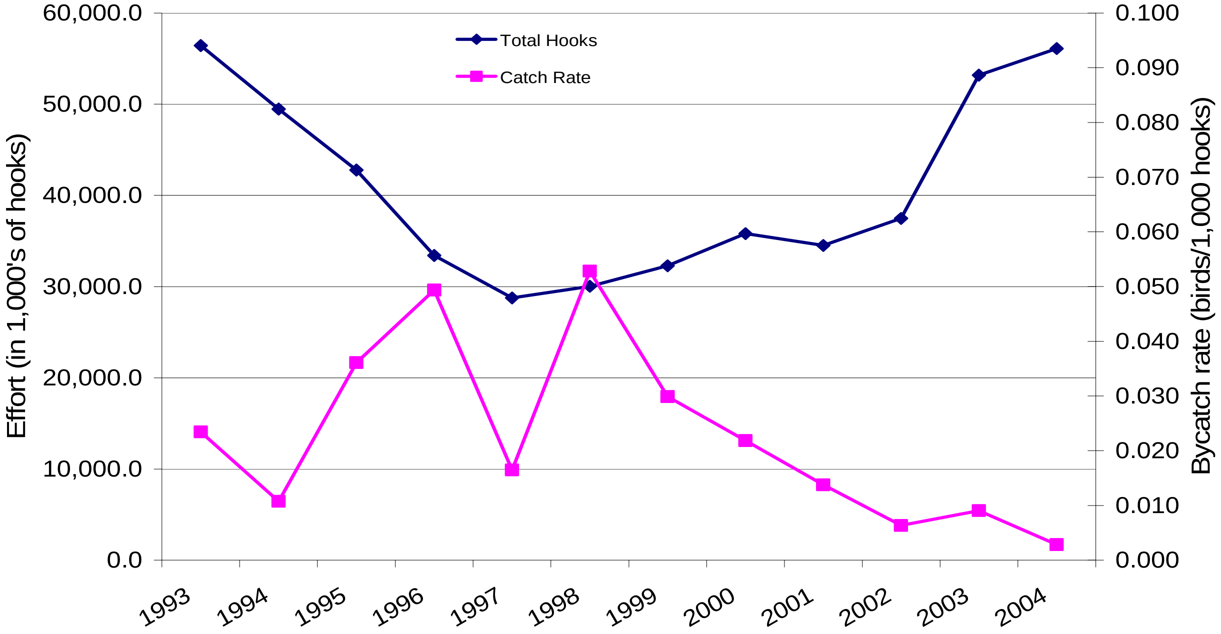


Figure 114. Total estimated hooks (in thousands) and bycatch rate of birds (birds per 1,000 hooks) in the Gulf of Alaska Region demersal groundfish longline fishery.

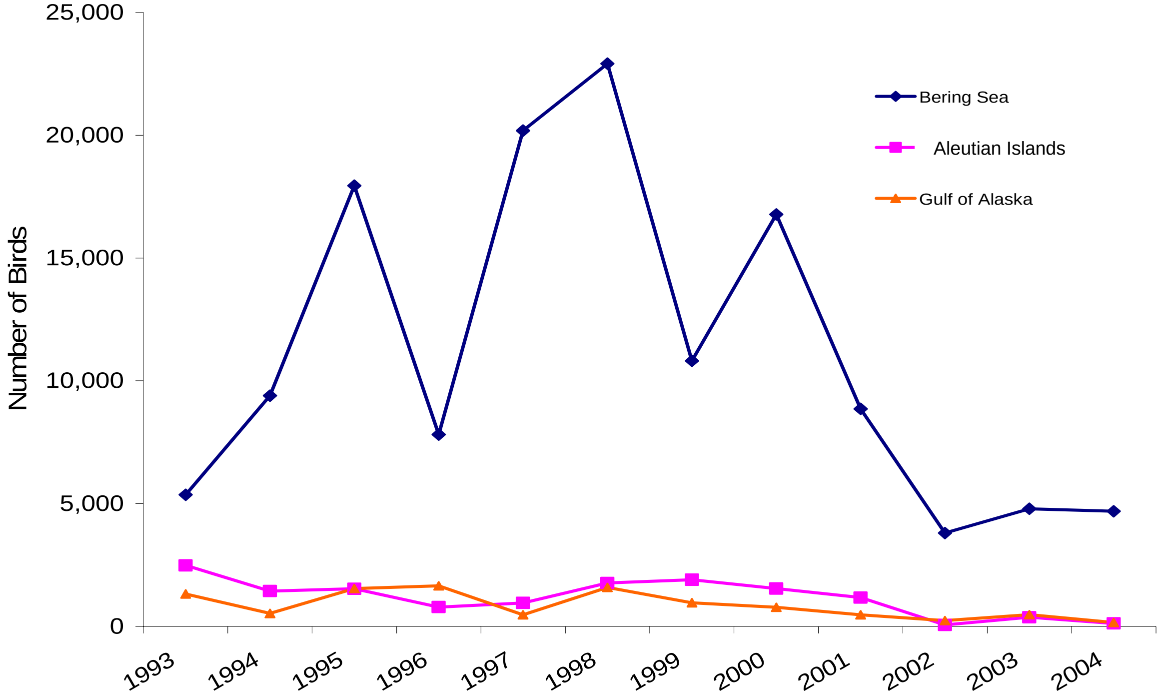


Figure 115. Seabird bycatch in the demersal groundfish longline fisheries by Fishery Management Region.

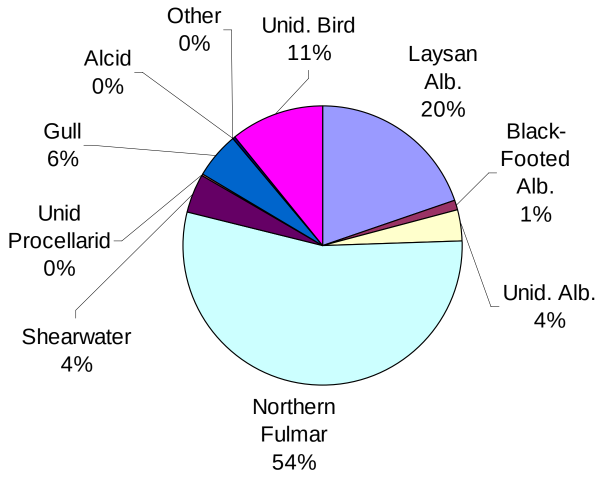


Figure 116. Species composition of seabird bycatch in the Aleutian Island Area demersal groundfish longline fishery using the average annual estimates, 1993 through 2004.

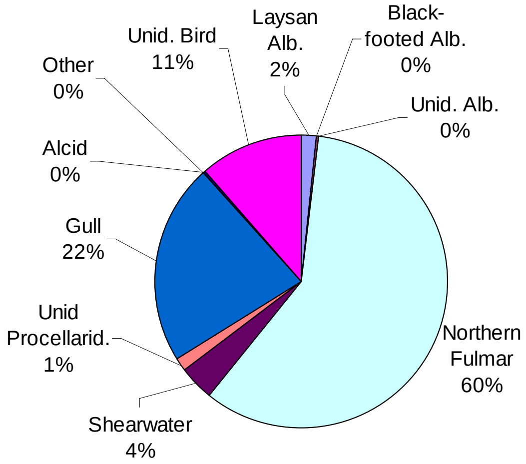


Figure 117. Species composition of seabird bycatch in the Bering Sea Area demersal groundfish longline fishery using the average annual estimates, 1993 through 2004.

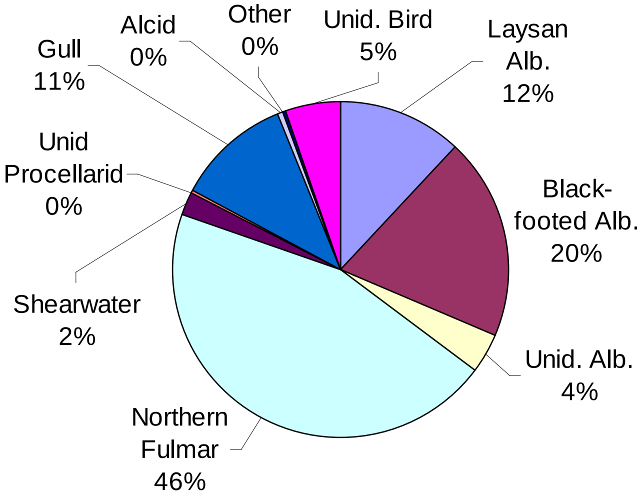


Figure 118. Species composition of seabird bycatch in the Gulf of Alaska Area demersal groundfish longline fishery using the average annual estimates, 1993 through 2004.

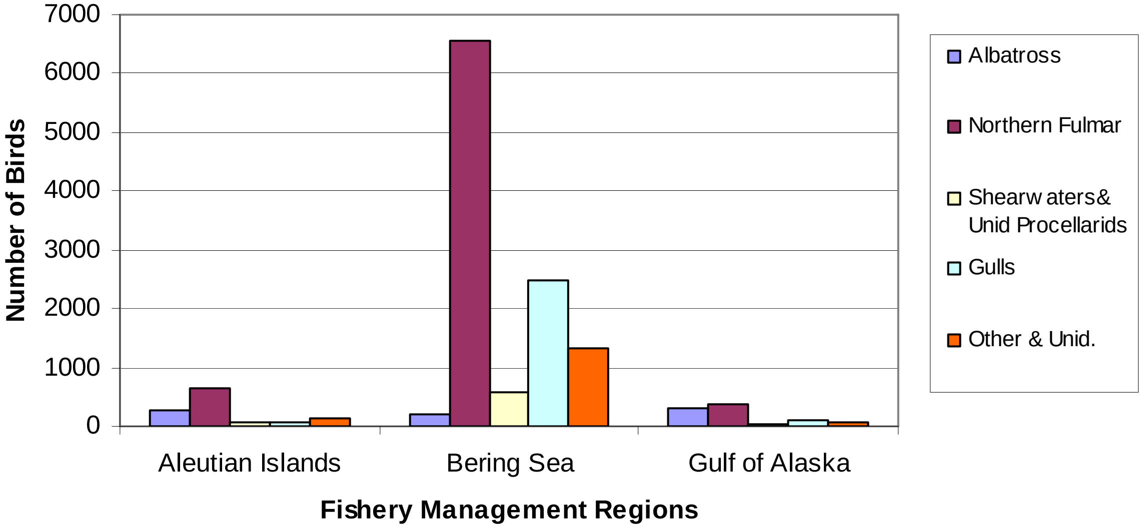


Figure 119. Estimated seabird bycatch summarized by species or species group for Alaskan demersal longline groundfish fisheries by fishery management regions.

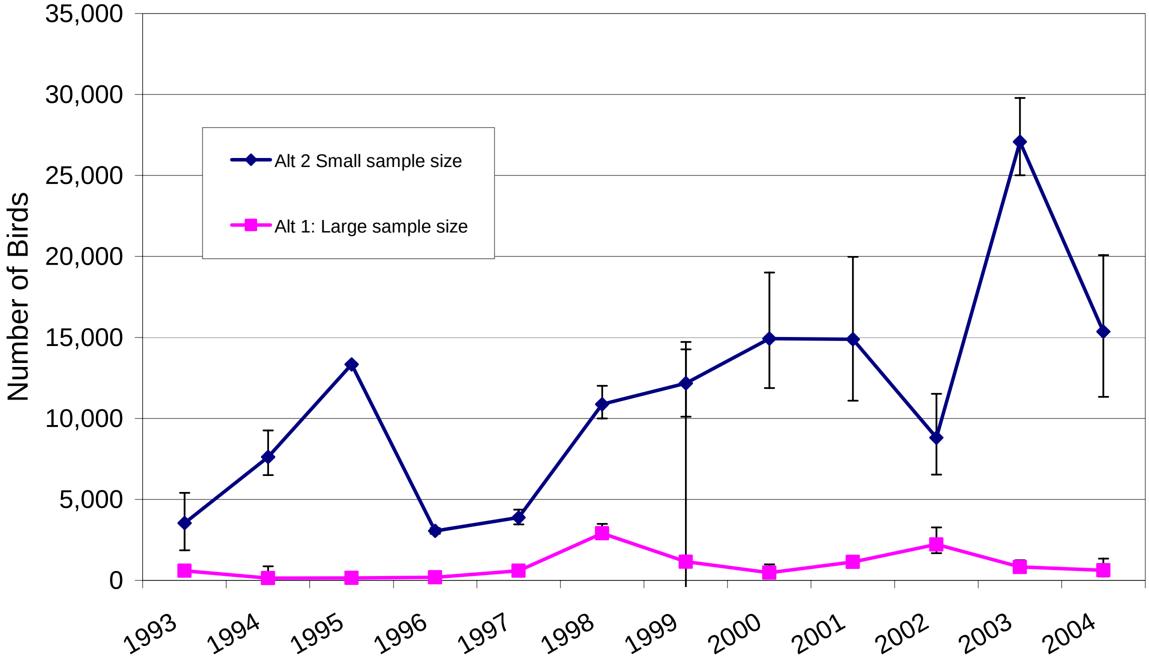


Figure 120. Seabird bycatch estimates for the Alaskan Groundfish Trawl fleet using two estimation procedures based on available sample sizes when no birds were observed. Data from 2004, when all sample sizes were recorded, closely approximates the Alternative 1 estimate.

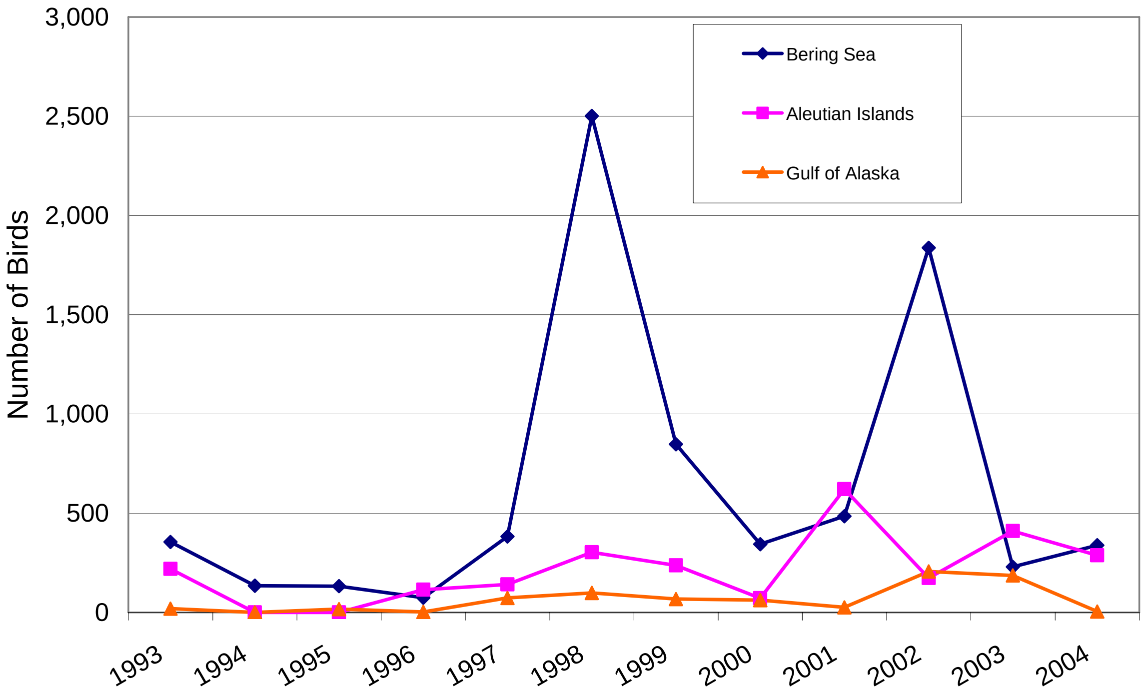


Figure 121. Seabird bycatch in groundfish trawl fisheries by area, using alternative 1 estimates.

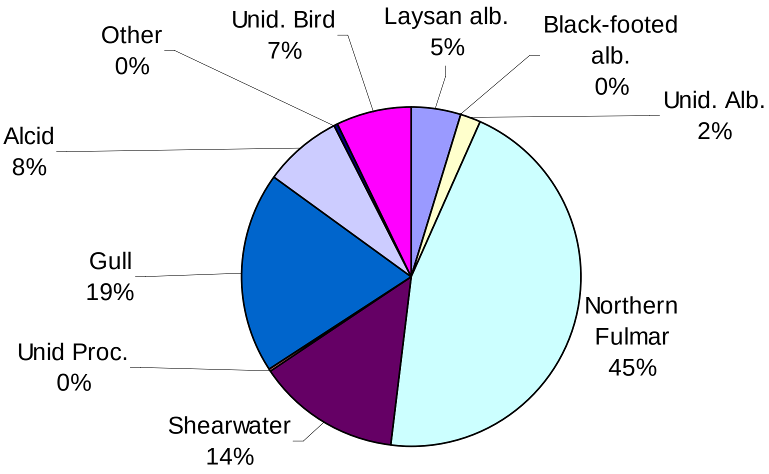


Figure 122. Species composition of seabird bycatch in the combined Alaskan groundfish trawl fisheries using the average annual estimates, 1993 through 2004.

Seabird bycatch trends by species or species groups.

When summarizing overall mortality for each species, all fisheries combined, the numbers are confounded by the need to produce two alternate estimates within the trawl fleet due to the sample size notation issue (see above, Figure 120 and Tables 29-31). Detailed numbers by species or species groups can be found at www.afsc.noaa.gov/refm/seabirds.

Short-tailed Albatross: In the NMFS analysis of 1993 to 2003 observer data, only three of the albatrosses taken during observer sampling were identified as short-tailed albatrosses (all were from the BSAI longline fishery). Two additional short-tailed albatross were recovered by observers from outside of their sample period. The analysis of 1993 to 2003 data resulted in an average estimate of one short-tailed albatross being taken annually in the BSAI groundfish hook-and-line fishery and zero short-tailed albatross being estimated taken annually in the GOA groundfish hook-and-line fishery. The incidental take limit established in the USFWS biological opinions on the effects of the hook-and-line (longline) fisheries on the short-tailed albatross is based on the actual reported takes and not on extrapolated estimated takes. There is currently an incidental take established for the trawl fishery as well. No short-tailed albatross have been recovered from that fishery, either through direct observer sampling or through anecdotal observations. The endangered short-tailed albatross population is currently increasing. The total population is estimated at about 1,900 (Greg Balogh, U.S. Fish and Wildlife Service, pers. comm.).

Laysan Albatross: Laysan albatross bycatch peaked in 1998 at about 2,000 birds and has been trending substantially downward since then to less than 150 birds in 2002 (Figure 123). The rise in Laysan albatross bycatch from 2002 to 2003 was driven both by the BSAI longline bycatch, and by birds taken in the trawl fishery. In the combined groundfish fisheries (longline and trawl), the 2003 estimated bycatch mortality of Laysan albatross was 432 birds when the higher estimate for the trawl fleet is used. Using the lower trawl estimate yields 365 birds. In 2002 the numbers were 105 and 49, respectively. The cause of this rise in bycatch is currently unknown, but might be attributed to the normal inter-annual variations seen in the past. When analyzed, the 2004 estimates should indicate whether efforts to reduce albatross mortalities through the use of mitigation measures have been successful. Efforts currently underway include implementation of regulations requiring improved seabird mitigation measures on longliners, coordination with the industry to complete vessel-specific bycatch reduction work, and continued research in both the longline and trawl fisheries on methods to deter birds from interacting with commercial fishing gear. The Laysan albatross population was estimated at 874,000 by BirdLife International (www.birdlife.org) in 2003, but that number includes only breeding pairs. The U.S. Fish and Wildlife Service is currently engaged in a population assessment. A bycatch level of 500 birds per year represents 0.06% of the Birdlife International population estimate. However, Laysan albatross bycatch is not constrained only to the groundfish fisheries in Alaska. They may be taken by demersal halibut and pelagic tuna and swordfish longline fisheries in the North Pacific as well.

Black-footed Albatross: No black-footed albatross have been recorded by observers in the Alaskan trawl fleets from 1998-2003, either within the observer sample or from an interaction with trawl cables. The bycatch of black-footed albatross is from the longline fisheries, and has been extremely variable over time (Figure 124). Most bycatch occurs in the GOA longline fisheries. After the peak of nearly 700 black-footed albatross taken in 1996, the bycatch has undergone a steady downward trend. Numbers rose again in 2003, due to a slight increase in bycatch rates coupled with a larger increase in overall effort in the GOA. Implementation of seabird avoidance regulations and other activities will hopefully reduce black-footed albatross bycatch. The USFWS was petitioned on 28 September 2004 to list the black-footed albatross as endangered under the U.S. Endangered Species Act, citing the decision by the IUCN to classify the species as endangered on the Red List in 2003 (www.redlist.org). World population estimates range from 275,000 to 327,753 individuals (Brooke 2004, NMFS 2004a). Bycatch in the Alaskan demersal groundfish fleet represent 0.07% of the lower of these population estimates. Note that the groundfish fishery is only one source of bycatch for this species throughout its range.

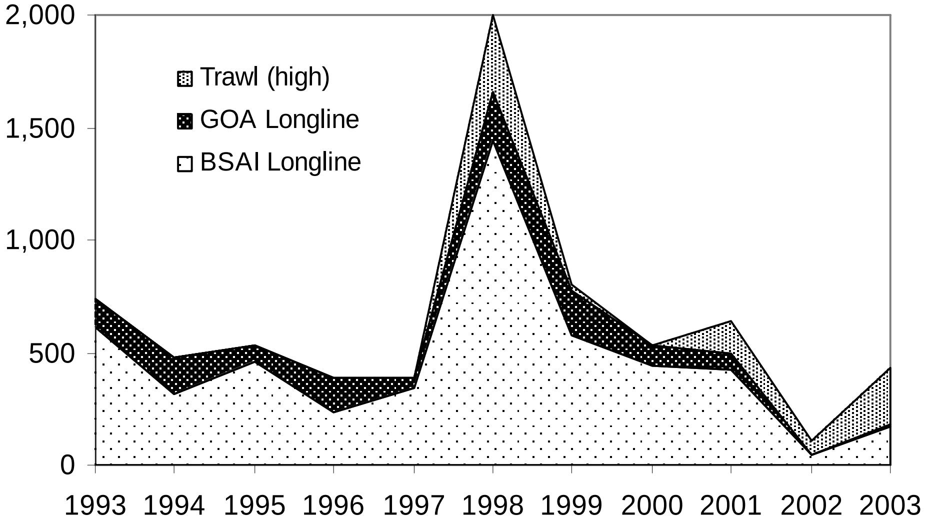


Figure 123. Combined bycatch in Alaskan groundfish fisheries for Laysan albatross, 1993 through 2003. Data for trawl fisheries begins in 1998.

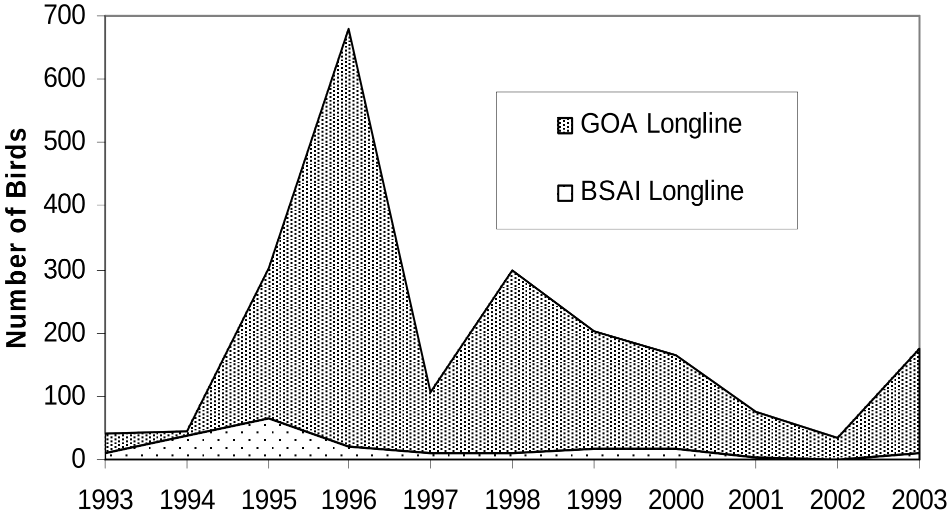
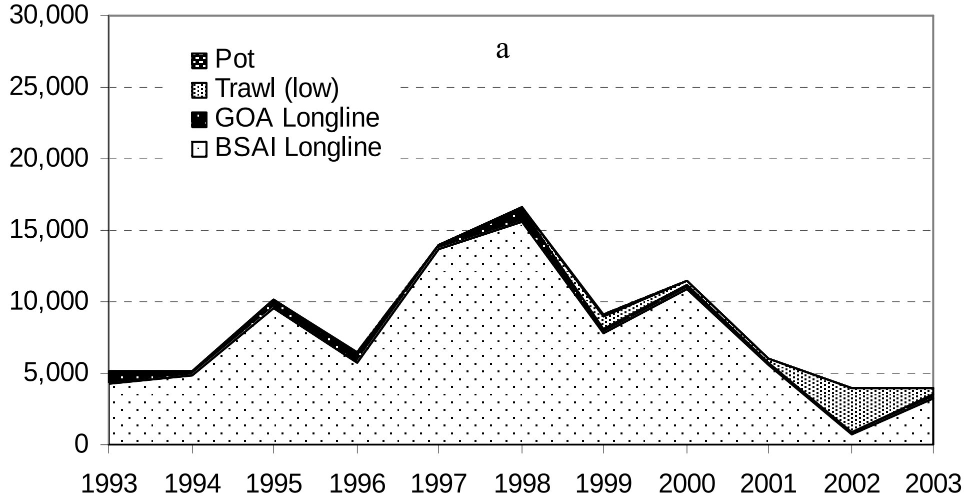


Figure 124. Combined bycatch in Alaskan groundfish fisheries for black-footed albatross, 1993 through 2003.

Unidentified Albatross: Not all albatross are identified by observers. This is due in some cases to inexperience with seabird identification, but is most likely due to birds that are not retrieved on board and thus cannot be examined closely by observers. Observers are currently instructed to return albatross to port if they cannot identify them. Seabird identification for observers focuses on albatross identification characteristics, and species identification materials are provided to observers. These efforts have reduced the number of unidentified albatross recorded. The annual estimate over the past 5 years is about 8 unidentified albatross, which likely represent a sample size of one or two individual birds per year recorded by observers as unidentified.

Northern Fulmar: The northern fulmar is the most frequent species taken among all fisheries combined. Discussion of northern fulmar bycatch is especially confounded by the need to provide two sets of possible bycatch numbers for the trawl fleet. Figure 125 shows northern fulmar bycatch combined for all fisheries, with longline and pot represented from 1993 onward and trawl included since 1998. The alternate methods for the trawl fleet are noted by a low estimate (Figure 125a) and a high estimate (Figure 125b). Total bycatch of fulmars in the longline fisheries peaked in 1999 and dropped substantially since, with a slight increase in the last year. Bycatch in the trawl fleet is difficult to judge at this time, given the need to report estimates using these alternate methods. While the higher estimate procedure results in almost 30,000 mortalities, that number should be used with great caution. The actual number may be much lower than that estimate. Additional analyses of these data are necessary. Conversely, those numbers do not include mortalities from interactions with trawl cables. Note also that some components of the trawl industry are working closely with NMFS and Washington Sea Grant to develop mitigation measures for seabirds. The Northern fulmar population was previously estimated at 2.1 million birds by the USFWS in 1998. A bycatch rate of 30,000 birds is 1.4% of this population estimate.



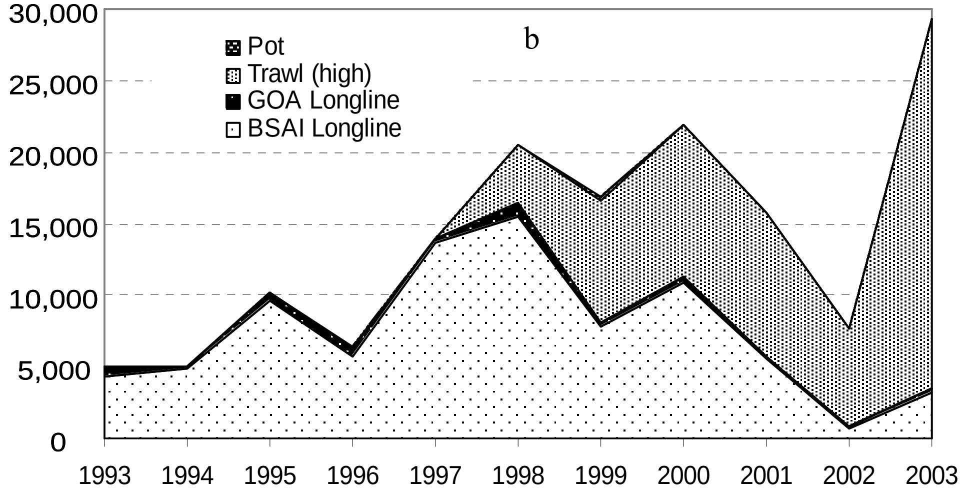


Figure 125. Estimated northern fulmar bycatch in North Pacific groundfish fisheries, using low (a) and high (b) estimation procedures for the trawl fishery. Data from the trawl fishery prior to 1997 are not included.

Shearwater species: Observers are not required to identify sooty and short-tailed shearwaters to species. They record them as unidentified dark shearwater. Other shearwaters occur rarely in the Bering Sea and Gulf of Alaskan, so identification materials have not been provided. Any occurrence of shearwaters other than sooty or short-tailed would likely be recorded in one of the unidentified categories. Using the trawl estimation method that results in a higher estimate, the annual average bycatch, 1999 through 2003, from all sources is 1,566. Using the lower estimate from the trawl fleet would yield an average of 482 birds.

Total shearwater bycatch peaked at 3,500 in 2001 and has decreased to less than 500 in 2003. These numbers are negligible when compared to population estimates that over 50 million for these two species.

Gull species: Observers are not asked to identify gulls, other than kittiwakes, to species. The combined annual bycatch for gull species, 1999-2003, using the high trawl estimate, is 2,915. The BSAI longline fishery currently accounts for 90% of this bycatch.

Population Effects of Bycatch

Effects of the bycatch in groundfish fisheries off Alaska of albatross and other seabirds at the population level are uncertain (Melvin et al. 2001). With the exception of the short-tailed albatross, data on the number, size and geographic extent and mixing of seabird populations are poorly understood. Seabird mortality in Alaska groundfish fisheries represents only a portion of the fishing mortality that occurs, particularly with the albatrosses. Mortality of black-footed and Laysan albatrosses occurs also in the Hawaiian pelagic longline fisheries and may be assumed to occur in other North Pacific pelagic longline fisheries conducted by Japan, Taiwan, Korea, Russia, and China (Brothers et al. 1999, Lewison and Crowder 2003). Assessments of overall mortality, which fisheries contribute to that mortality, and what effect these fisheries have on populations from both mortality and food provisioning aspects is an area where research is needed. The lack of good population assessments for many of these species creates barriers in moving forward with these studies, although the USFWS is currently engaged in improved population assessments for the albatross species.

Competition for food resources

Seabirds and commercial fisheries may compete in several ways. Competition could be direct, if both are targeting forage fish, or indirect when fisheries affect prey availability in other ways. Additionally, commercial fisheries may provide food resources to seabird species that then compete directly with other seabird species. These factors may apply in the open ocean for non-breeders as well as near colonies during the breeding season.

Most of the groundfish fisheries occur between September and April (NMFS 2001), and do not overlap temporally with the main seabird breeding period that occurs from May through August (DeGange and Sanger 1987, Hatch and Hatch 1990, Dragoo et al. 2000, 2003). Seabird attachment to the colony is most likely to overlap with fisheries effort during the early (pre and early egg-laying) and late (late chick-rearing and fledging) portion of their breeding season. Juvenile birds, generally on their own and not experienced foragers, would also be most abundant at sea during the fall fisheries. Groundfish fisheries might affect prey availability indirectly around seabird colonies even though they do not overlap with the seabird's breeding season. These potential effects include boat disturbance, alteration of predator-prey relations among fish species, habitat disturbance, or direct take of fish species whose juveniles are consumed by seabirds (see seabird section in Ecosystem Considerations chapter, NPFMC 2000, for review).

If seabirds are in competition with other upper-trophic level consumers, it suggests that the seabirds might, at a local scale, also impact fish populations. Overall consumption of fish biomass by seabirds is generally low, estimated at < 4 % (Livingston 1993); however, seabirds may impact fish stocks within foraging range of seabird colonies during summer (Springer et al. 1986, Birt et al. 1987). Fifteen to eighty percent of the biomass of juvenile forage fish may be removed by birds each year near breeding colonies (Wiens and Scott 1975, Furness 1978, Springer et al. 1986, Logerwell and Hargreaves 1997). Consequently, seabirds may therefore be vulnerable to factors that reduce forage fish stocks in the vicinity of colonies (Monaghan et al. 1994).

These issues need to be explored further in the North Pacific. Direct assessments or modeling of these interactions are needed to gain a better understanding of the various competitive aspects for seabirds and commercial groundfish fisheries in Alaskan waters.

Provision of food resources

Commercial fishing vessels operate in one of several modes. Fish are caught and delivered to a mothership or shoreside processor, or fish are caught and processed on board the vessel. The latter vessels are known as catcher/processor vessels and they provide a steady stream of processed fish (offal) overboard. Seabirds feed on this resource, and are attracted to vessels that process at sea. The interplay between the temporal and spatial availability of offal, the total amounts discharged by vessels, and how much use of this food resource seabirds use is not well documented in Alaskan waters. Generally, vessels that have been steadily processing fish will have hundreds of birds in attendance, composed primarily of northern fulmars, but also including kittiwakes, shearwaters, gulls, albatross, and other species.

There have been a series of regulations implemented over the years that affect both discards and offal. How these regulations have changed the availability of discards and offal to seabirds and how those changes have affected seabirds are unknown. This is an area that NMFS staff expect to explore, in collaboration with other researchers, starting in 2004.

Table 23. Species and species group categories used in tables 3 through 9. Any species or species group heading not listed in a table means that there was no bycatch in that category[1].

Species/species Group	Includes	Scientific Name
Short-tailed Albatross	n/a	*Phoebastria albatrus*
Laysan Albatross	n/a	*Diomedea immutabilis*
Black-footed Albatross	n/a	*Diomedea nigripes*
Unidentified Albatross	Short-tailed, Laysan, or black-footed.	n/a
Northern Fulmar	n/a	*Fulmarus glacialis*
Shearwaters	Unidentified Shearwater Sooty Shearwater Short-tailed shearwater	*Puffinus* spp *Puffinus griseus* *Puffinus tenuirostris*
Unidentified Procellarid	All of the above	Procellariiformes
Gull	Unidentified gulls Herring gulls Glaucous gulls Glaucous-winged gulls	*Laridae* *Larus argentatus* *Larus hyperboreus* *Larus glaucescens*
Alcid	Unidentified alcids, Guillemots Murres Puffins Murrelets and auklets	*Alcidae* *Cepphus* spp. *Uria* spp. *Fraturcula* spp. Several genera
Other Seabird	Miscellaneous birds – could include: Loons Grebes Cormorants Seaducks Jaeger/skuas Kittiwakes Terns Storm petrels	 *Gaviidae* *Podicipededae* *Phalocrocoracidae* *Anatidae* *Stercorariidae* *L. tridactyla, L. brevirostris* *Sternidae* *Oceanitidae*
Unidentifid Seabird	All of the above	

[1] A complete list of the species and species group categories used by North Pacific Groundfish Observers while monitoring is available in the Groundfish Observer Manaual (AFSC 2004).

Table 24. Annual estimates of fishery effort, total birds taken, catch rates, and percent hooks observed in Alaskan groundfish demersal longline fisheries by fishery management region and for all Alaskan waters combined, 1993 through 2004.

Area and Year	Effort (No. of hooks in 1,000s)	Number of Birds	95% Confidence Bounds	Incidental catch rate (Birds per 1,000 hooks)	Percent of hooks observed
Aleutian Islands					
1993	37,009.6	2,485	1,927-3,204	0.067	21.1
1994	17,171.1	1,440	1,170-1,771	0.084	25.2
1995	11,846.7	1,531	1,170-2,004	0.129	23.2
1996	11,885.3	791	573-1,088	0.066	25.8
1997	13,177.2	958	698-1,318	0.073	18.9
1998	20,388.2	1,770	1,472-2,129	0.087	25.8
1999	14,444.4	1,901	1,266-2,854	0.132	19.8
2000	28,366.2	1,545	1,144-2,087	0.054	20.8
2001	34,066.4	1,177	894-1,547	0.035	20.8
2002	8,646.9	66	41-107	0.008	31.2
2003	11,294.7	372	236-586	0.033	11.5
2004	10,700.0	124	81-193	0.012	16.9
Aleutian Island Average Annual Estimates					
1993-2004	18,249.7	1,180	1,071-1,300	0.065	21.6
2000-2004	18,614.8	656	548-788	0.035	20.2
Bering Sea					
1993	85,605.4	5,364	4,683-6,142	0.063	26.2
1994	118,840.4	9,393	8,446-10,448	0.079	24.2
1995	131,313.3	17,944	16,664-19,323	0.137	24.1
1996	131,832.2	7,814	7,004-8,716	0.060	23.3
1997	176,756.6	20,187	18,404-22,145	0.114	21.2
1998	156,154.2	22,912	21,185-24,780	0.147	23.0
1999	145,818.6	10,817	9,610-12,175	0.074	25.0
2000	165,450.9	16,775	15,288-18,408	0.101	23.0
2001	192,878.7	8,860	7,993-9,818	0.046	20.9
2002	208,784.3	3,802	3,324-4,348	0.018	22.1
2003	268,874.0	4,794	4,325-5,314	0.018	22.8
2004	259,288.4	4,694	4,284-5,141	0.018	19.8
Bering Sea Average Annual Estimates					
1993-2004	170,133.8	11,113	10,781-11,455	0.065	22.6
2000-2004	219,055.8	7,785	7,397-8,192	0.036	21.6
Gulf of Alaska					
1993	56,431.2	1,322	1,090-1,606	0.023	10.2
1994	49,464.6	531	419-676	0.011	4.9
1995	42,775.5	1,544	1,341-1,779	0.036	12.6
1996	33,416.5	1,649	1,273-2,137	0.049	10.7
1997	28,756.6	474	339-663	0.016	9.7
1998	30,039.7	1,587	1,016-2,480	0.053	7.9
1999	32,277.3	964	765-1,216	0.030	8.5
2000	35,806.0	782	484-1,262	0.022	6.4
2001	34,505.2	475	318-710	0.014	7.7
2002	37,472.5	238	143-396	0.006	9.2
2003	53,190.3	482	297-783	0.009	6.5

Area and Year	Effort (No. of hooks in 1,000s)	Number of Birds	95% Confidence Bounds	Incidental catch rate (Birds per 1,000 hooks)	Percent of hooks observed
2004	56,099.1	161	84-307	0.003	5.0
Gulf of Alaska average annual estimates					
1993-2004	40,852.6	851	766-946	0.021	8.1
2000-2004	43,414.6	428	337-544	0.010	6.8
All Alaska fishery management regions combined					
1993	179,046.2	9,171	8,225-10,226	0.051	20.1
1994	185,473.0	11,364	10,361-12,467	0.061	19.2
1995	185,935.5	21,019	19,657-22,477	0.113	21.4
1996	177,134.0	10,254	9,309-11,291	0.058	21.1
1997	218,699.3	21,619	19,803-23,607	0.099	19.5
1998	206,582.1	26,269	24,380-28,306	0.127	21.1
1999	192,540.3	13,682	12,248-15,285	0.071	21.8
2000	229,623.0	19,102	17,504-20,849	0.083	20.1
2001	261,450.3	10,512	9,569-11,544	0.040	19.1
2002	254,903.7	4,106	3,612-4,667	0.016	20.5
2003	333,359.0	5,648	5,102-6,252	0.017	19.8
2004	326,087.5	4,979	4,554-5,444	0.015	17.2
All Alaska fishery management regions combined average annual estimates					
1993-2004	229,236.2	13,144	12,782-13,516	0.057	19.9
2000-2004	281,085.2	8,869	8,452-9,307	0.032	19.3

Table 25. Estimated incidental take and actual number of seabirds observed taken in the Aleutian Islands fishery management region groundfish demersal longline fishery, 1993 through 2004. Numbers in parenthesis (shaded rows) are the 95% confidence intervals.

Year	No. Obs.	Albatrosses			Northern Fulmar	Shear-waters	Unid. Procel-larids	Gulls	Alcids	Other Sea-birds	Unid. Seabirds	Totals
		Laysan	Black-footed	Unid.								
1993	550	571	12	355	1,017	0	0	184	3	0	343	2,485
		(437-746)	(5-29)	(228-555)	(611-1,695)			(133-253)	(1-13)		(157-746)	(1,927-3,204)
1994	388	307	37	76	434	27	0	24	0	0	535	1,440
		(228-414)	(17-78)	(50-116)	(300-628)	(8-94)		(21-30)			(348-823)	(1,170-1,771)
1995	390	316	23	26	1,006	22	10	99	0	0	29	1,531
		(176-567)	(11-50)	(16-43)	(689-1,469)	(10-48)	(2-42)	(62-156)			(14-61)	(1,170-2,004)
1996	222	106	20	34	160	304	2	23	0	0	142	791
		(72-155)	(6-70)	(18-64)	(100-254)	(148-623)	(1-7)	(13-42)			(78-258)	(573-1,088)
1997	179	270	8	10	599	20	9	10	0	0	32	958
		(185-394)	(2-36)	(3-32)	(373-963)	(5-73)	(3-28)	(3-32)			(16-64)	(698-1,318)
1998	460	449	4	0	638	125	4	167	0	4	379	1,770
		(295-683)	(1-18)		(474-859)	(83-188)	(1-18)	(109-257)		(1-15)	(243-591)	(1,472-2,129)
1999	399	231	17	0	1,535	9	4	100	0	0	5	1,901
		(177-300)	(7-40)		(933-2,527)	(2-41)	(1-18)	(48-210)			(1-23)	(1,266-2,854)
2000	325	196	11	5	1,149	27	0	110	0	0	47	1,545
		(144-268)	(3-35)	(1-23)	(772-1,712)	(13-56)		(71-171)			(24-92)	(1,144-2,087)
2001	245	126	0	0	938	65	0	43	0	0	5	1,177
		(76-209)			(671-1,311)	(40-103)		(24-76)			(1-22)	(894-1,547)
2002	66	47	0	0	10	5	0	4	0	0	0	66
		(25-86)			(4-25)	(1-23)		(1-15)				(41-107)
2003	74	135	0	0	216	0	0	0	0	21	0	372
		(63-290)			(118-394)					(6-74)		(236-586)
2004	24	52	0	0	28	16	0	10	0	0	18	124
		(27-100)			(13-61)	(3-78)		(3-32)			(8-40)	(81-193)
Average Annual Estimates												
1993-2004	na	234	11	42	644	52	2	65	0	2	128	1,180
		(205-267)	(7-16)	(31-59)	(550-755)	(35-76)	(1-5)	(54-78)	(0-1)	(1-6)	(98-167)	(1,071-1,300)
2000-2004	na	111	2	1	468	23	0	33	0	4	14	656
		(86-145)	(1-7)	(0-5)	(366-598)	(15-35)		(24-47)		(1-15)	(8-23)	(548-788)

Table 26. Estimated incidental take and actual number of seabirds observed taken in the Bering Sea fishery management region groundfish demersal longline fishery, 1993 through 2004. Numbers in parenthesis (shaded rows) are the 95% confidence intervals.

		Albatrosses											
Yr	No. Obs.	Short-tailed	Laysan	Black-footed	Unid.	Northern Fulmar	Shear-waters	Unid. Procel-larids	Gulls	Alcids	Other Sea-birds	Unid. Seabirds	Totals
1993	1,392	0	49	0	0	3,153	65	0	647	11	4	1,435	5,364
			(29-83)			(2,582-3,849)	(34-123)		(430-974)	(4-36)	(1-16)	(1,200-1,716)	(4,683-6,142)
1994	2,312	0	4	0	0	4,555	656	351	1,718	4	4	2,101	9,393
			(1-20)			(3,954-5,247)	(495-870)	(247-499)	(1,333-2,214)	(1-20)	(1-18)	(1,568-2,814)	(8,446-10,448)
1995	4,442	0	148	43	12	8,811	308	474	3,892	4	45	4,207	17,944
			(104-210)	(19-96)	(5-31)	(7,884-9,847)	(221-429)	(295-760)	(3,268-4,635)	(1-17)	(24-84)	(3,538-5,003)	(16,664-19,323)
1996	1,780	4	130	0	27	5,571	185	14	1,484	46	50	303	7,814
		(1-19)	(79-216)		(13-53)	(4,806-6,457)	(118-288)	(6-37)	(1,250-1,762)	(14-144)	(25-103)	(235-389)	(7,004-8,716)
1997	3,944	0	125	4	3	15,187	354	169	3,429	0	9	907	20,187
			(86-183)	(1-19)	(1-15)	(13,505-17,079)	(206-609)	(112-257)	(2,667-4,408)		(3-28)	(606-1,356)	(18,404-22,145)
1998	5,390	8	982	5	4	14,955	1,018	17	4,252	53	45	1,573	22,912
		(3-24)	(720-1,339)	(1-23)	(1-17)	(13,391-16,701)	(846-1,226)	(8-39)	(3,626-4,985)	(31-90)	(23-89)	(1,288-1,926)	(21,185-24,780)
1999	2,894	0	313	0	0	6,466	492	418	2,172	4	47	905	10,817
			(253-387)			(5,412-7,725)	(398-609)	(224-778)	(1,802-2,613)	(1-15)	(22-101)	(628-1,305)	(9,610-12,175)
2000	3,543	0	260	5	10	9,879	533	86	4,454	5	16	1,527	16,775
			(172-391)	(2-21)	(3-29)	(8,573-11,384)	(411-693)	(54-137)	(3,852-5,150)	(1-22)	(8-35)	(1,171-1,992)	(15,288-18,408)
2001	1,742	0	281	5	5	4,595	394	96	2,431	2	33	1,018	8,860
			(197-400)	(1-21)	(1-21)	(3,901-5,412)	(293-528)	(61-153)	(2,049-2,884)	(1-8)	(15-74)	(758-1,367)	(7,993-9,818)
2002	859	0	5	0	5	695	149	20	2,536	10	17	365	3,802
			(1-24)		(1-22)	(585-826)	(102-219)	(7-53)	(2,095-3,071)	(3-32)	(7-40)	(276-482)	(3,324-4,348)
2003	1,049	0	47	10	0	2,748	289	14	1,373	11	45	257	4,794
			(23-94)	(3-32)		(2,408-3,137)	(220-379)	(4-46)	(1,088-1,734)	(4-29)	(26-76)	(192-343)	(4,325-5,314)
2004	894	0	37	11	3	1,934	710	97	1,260	39	23	580	4,694
			(18-74)	(4-36)	(1-10)	(1,661-2,253)	(558-904)	(59-160)	(1,055-1,505)	(20-76)	(11-51)	(448-750)	(4,284-5,141)
Average Annual Estimates													
1993 - 2004	na	1	198	7	6	6,546	429	146	2,471	16	28	1,265	11,113
		(0-3)	(170-231)	(4-12)	(4-9)	(6,258-6,847)	(393-470)	(117-187)	(2,327-2,623)	(11-23)	(22-36)	(1,163-1,376)	(10,781-11,455)
2000 - 2004	na	0	126	6	4	3,970	415	63	2,411	14	27	749	7,785
			(99-160)	(3-13)	(2-9)	(3,651-4,317)	(365-472)	(48-81)	(2,221-2,618)	(8-22)	(19-38)	(648-866)	(7,397-8,192)

Table 27. Estimated incidental take and number of seabirds observed taken in the Gulf of Alaska fishery management region groundfish demersal longline fishery, 1993 through 2004. Numbers in parenthesis (shaded rows) are the 95% confidence intervals.

		Albatrosses										
Year	No. Obs.	Laysan	Black-footed	Unid.	Northern Fulmar	Shearwaters	Unid. Procellarids	Gulls	Alcids	Other Seabirds	Unid. Seabirds	Totals
1993	318	128	29	3	842	59	0	45	0	3	213	1,322
		(78-211)	(15-57)	(1-14)	(648-1,094)	(31-114)		(23-90)		(1-11)	(131-346)	(1,090-1,606)
1994	126	169	7	8	258	26	0	30	0	0	33	531
		(106-269)	(2-22)	(3-24)	(181-368)	(10-70)		(7-127)			(13-84)	(419-676)
1995	374	68	239	378	529	40	6	105	0	4	175	1,544
		(42-109)	(181-317)	(290-493)	(381-733)	(20-81)	(1-25)	(67-166)		(2-11)	(120-256)	(1,341-1,779)
1996	250	155	665	0	674	15	0	121	0	0	19	1,649
		(104-233)	(490-903)		(424-1,071)	(4-52)		(30-498)			(6-57)	(1,273-2,137)
1997	74	31	97	0	281	8	0	47	0	0	10	474
		(7-127)	(51-187)		(177-449)	(2-24)		(24-93)			(3-33)	(339-663)
1998	184	241	321	4	951	13	0	57	0	0	0	1,587
		(117-495)	(125-825)	(1-18)	(506-1,788)	(4-42)		(29-116)				(1,016-2,480)
1999	159	214	184	0	242	50	0	249	0	9	16	964
		(147-312)	(91-370)		(165-354)	(21-118)		(145-430)		(2-43)	(5-55)	(765-1,216)
2000	72	96	155	0	317	0	0	180	0	0	34	782
		(47-195)	(89-271)		(140-716)			(55-592)			(7-174)	(484-1,262)
2001	45	69	73	17	191	20	0	96	6	0	3	475
		(29-165)	(36-146)	(4-86)	(116-314)	(4-99)		(25-365)	(1-29)		(1-14)	(318-710)
2002	51	0	33	0	107	0	0	81	0	0	17	238
			(17-65)		(52-219)			(27-237)			(6-44)	(143-396)
2003	37	12	156	0	216	0	0	41	41	0	16	482
		(5-30)	(58-418)		(113-410)			(13-128)	(7-230)		(3-80)	(297-783)
2004	17	31	24	0	0	0	0	93	0	0	13	161
		(11-88)	(10-58)					(35-244)			(3-62)	(84-307)
Average Annual Estimates												
1993-2004	na	101	165	34	384	19	1	96	4	1	46	851
		(82-125)	(131-208)	(26-44)	(320-460)	(13-28)	(0-2)	(67-136)	(1-19)	(1-4)	(35-61)	(766-946)
2000-2004	na	42	88	4	166	4	0	98	9	0	17	428
		(26-67)	(57-137)	(1-17)	(112-246)	(1-20)		(53-182)	(2-45)		(7-41)	(337-544)

Table 28. Estimated incidental take and actual number of seabirds observed taken in the demersal pot fishery in Alaskan waters, 1993 through 2004, all fishery management regions combined. Numbers in parentheses (shaded rows) are the 95% confidence intervals.

Year	No. Obs.	Northern Fulmar	Shearwaters	Unid. Procellarids	Gulls	Alcids	Unid. Seabirds	Totals
1993	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0
1995	6	9	7	0	3	19	0	38
		(3-33)	(1-33)		(1-15)	(4-92)		(15-103)
1996	9	80	0	2	0	0	7	89
		(27-235)		(1-8)			(2-30)	(33-238)
1997	4	16	0	0	0	11	0	27
		(6-43)				(2-52)		(10-68)
1998	2	18	0	0	15	0	0	33
		(4-92)			(3-73)			(10-114)
1999	47	166	9	14	0	0	0	189
		(95-290)	(2-43)	(5-35)				(114-313)
2000	1	0	0	0	0	0	42	42
							(9-207)	(9-207)
2001	3	14	0	0	3	0	0	17
		(4-52)			(1-12)			(6-53)
2002	6	18	0	0	0	0	3	21
		(8-42)					(1-13)	(10-44)
2003	10	91	4	0	0	59	0	154
		(36-230)	(1-16)			(12-290)		(63-372)
2004	5	60	0	0	0	0	0	60
		(20-183)						(20-183)
Average Annual Estimates								
1993-2004	na	39	2	1	2	7	4	55
		(27-58)	(1-5)	(1-3)	(1-6)	(2-25)	(1-17)	(40-79)
2000-2004	na	37	1	0	1	12	9	60
		(20-69)	(0-3)		(0-2)	(2-58)	(2-41)	(32-107)

Table 29. Estimated incidental take and actual number of seabirds observed taken in the Aleutian Islands fishery management region groundfish trawl fleet, 1993 through 2004. Alternate methods of take estimation are based on largest (Alt 1[1]) or smallest sample size (Alt 2 – shaded area) available during seabird monitoring. Sample size used for monitoring seabirds was recorded in 2004 for all samples regardless of birds taken (Meth 2).

Year	No. Obs.	Est. Type	Laysan Albatross	Northern Fulmar	Shear-waters	Gulls	Alcids	Unid. Seabirds	Totals
1993	3	Alt 1	0	0	219	0	0	0	219
		Alt 2	0	0	486	0	0	0	486
1994	0	Alt 1	0	0	0	0	0	0	0
		Alt 2	0	0	0	0	0	0	0
1995	0	Alt 1	0	0	0	0	0	0	0
		Alt 2	0	0	0	0	0	0	0
1996	1	Alt 1	0	0	0	0	0	115	115
		Alt 2	0	0	0	0	0	229	229
1997	4	Alt 1	99	0	0	0	0	42	141
		Alt 2	193	0	0	0	0	1,692	1,885
1998	9	Alt 1	285	14	0	5	0	0	304
		Alt 2	371	36	0	9	0	0	416
1999	21	Alt 1	8	223	6	0	0	0	237
		Alt 2	22	258	158	0	0	0	438
2000	7	Alt 1	0	72	0	0	0	0	72
		Alt 2	0	428	0	0	0	0	428
2001	11	Alt 1	7	254	360	0	0	0	621
		Alt 2	119	499	488	0	0	0	1,106
2002	8	Alt 1	2	171	0	0	0	0	173
		Alt 2	30	518	0	0	0	0	548
2003	6	Alt 1	121	202	0	44	44	0	411
		Alt 2	230	202	0	86	86	0	604
2004	3	Alt 1	0	287	0	0	0	0	287
		Alt 2	0	344	0	0	0	0	344
		Meth 2	0	287	0	0	0	0	287
Average Annual Estimates									
1993 – 2004	n/a	Alt 1	44	102	49	4	4	13	216
		Alt 2	81	190	94	8	7	160	540
2000-2004	n/a	Alt 1	26	197	72	9	9	0	313
		Alt 2	76	398	98	17	17	0	606

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[1] Observers were instructed to use the largest sample size available when monitoring for seabirds. Alt 1 likely represents a closer approximation of estimated incidental takes.

Table 30. Estimated incidental take and actual number of seabirds observed taken in the Bering Sea fishery management region groundfish trawl fleet, 1993 through 2004. Alternate methods of take estimation are based on largest (Alt 1[1]) or smallest sample size (Alt 2 – shaded area) available during seabird monitoring. Sample size used for monitoring seabirds was recorded in 2004 for all samples regardless of birds taken (Meth 2).

			Albatross									
Year	No. Obs.	Estimate Type	Laysan	Unid.	Northern Fulmar	Shear-waters	Unid. Procel-larids	Gulls	Alcids	Other Seabirds	Unid. Seabirds	Totals
1993	20	Alt 1	0	176	0	126	2	0	1	0	49	354
		Alt 2	0	516	0	323	769	0	2	0	1,381	2,991
1994	45	Alt 1	0	0	36	88	0	4	0	0	6	134
		Alt 2	0	0	3,832	3,083	0	414	0	0	285	7,614
1995	19	Alt 1	0	40	28	0	0	0	11	0	53	132
		Alt 2	0	60	1,495	0	0	0	10,963	0	779	13,297
1996	18	Alt 1	0	0	49	2	6	3	3	0	11	74
		Alt 2	0	0	1,139	88	1,102	268	43	0	178	2,818
1997	50	Alt 1	0	0	5	101	0	0	120	0	156	382
		Alt 2	0	0	319	799	0	0	120	0	678	1,916
1998	35	Alt 1	0	0	67	344	1	1,967	109	3	10	2,501
		Alt 2	0	0	3,922	1,353	163	781	543	2,489	1,108	10,359
1999	131	Alt 1	0	0	395	125	0	0	313	3	10	846
		Alt 2	0	0	8,687	1,198	0	0	528	79	970	11,462
2000	93	Alt 1	0	0	219	16	3	42	2	0	63	345
		Alt 2	0	0	10,101	3,075	156	117	333	0	599	14,381
2001	129	Alt 1	2	0	283	14	13	7	2	4	161	486
		Alt 2	26	0	10,847	406	1,077	288	68	297	721	13,730
2002	58	Alt 1	0	0	1,687	7	0	8	8	13	113	1,836
		Alt 2	0	0	5,876	597	0	72	879	123	474	8,021
2003	69	Alt 1	0	0	190	2	2	27	7	0	2	230
		Alt 2	0	0	24,988	128	173	0	481	0	527	26,297
2004	65	Alt 1	0	0	145	46	0	2	128	5	13	339
		Alt 2	0	0	7,476	2,961	0	485	1,116	1,226	1,708	14,972
		Meth 2	0	0	147	46	0	2	128	5	13	341
Average Annual Estimates												
1993-2004	n/a	Alt 1	0	18	259	73	2	172	59	2	54	639
		Alt 2	2	48	6,557	1,168	287	202	1,256	351	784	10,655
2000-2004	n/a	Alt 1	0	0	505	17	4	17	29	4	71	647
		Alt 2	5	0	11,858	1,433	281	193	575	329	806	15,480

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[1] Observers were instructed to use the largest sample size available when monitoring for seabirds. Alt 1 likely represents a closer approximation of estimated incidental takes.

Table 31. Estimated incidental take and actual number of seabirds observed taken in the Gulf of Alaska fishery management region groundfish trawl fleet, 1993 through 2004. Alternate methods of take estimation are based on largest (Alt 1[1]) or smallest sample size (Alt 2 – shaded area) available during seabird monitoring. Sample size used for monitoring seabirds was recorded in 2004 for all samples regardless of birds taken (Meth 2).

Year	Total Catch	Est. Type	Northern Fulmar	Shear-waters	Unid. Procel-larids	Alcids	Unid. Seabirds	Totals
1993	1	Alt 1	0	19	0	0	0	19
		Alt 2	0	56	0	0	0	56
1994	0	Alt 1	0	0	0	0	0	0
		Alt 2	0	0	0	0	0	0
1995	2	Alt 1	0	14	0	0	1	15
		Alt 2	0	27	0	0	3	30
1996	1	Alt 1	0	0	2	0	0	2
		Alt 2	0	0	2	0	0	2
1997	1	Alt 1	73	0	0	0	0	73
		Alt 2	73	0	0	0	0	73
1998	1	Alt 1	98	0	0	0	0	98
		Alt 2	98	0	0	0	0	98
1999	2	Alt 1	0	0	0	67	0	67
		Alt 2	0	0	0	268	0	268
2000	1	Alt 1	62	0	0	0	0	62
		Alt 2	121	0	0	0	0	121
2001	1	Alt 1	25	0	0	0	0	25
		Alt 2	48	0	0	0	0	48
2002	3	Alt 1	206	0	0	0	0	206
		Alt 2	246	0	0	0	0	246
2003	2	Alt 1	186	0	0	0	0	186
		Alt 2	186	0	0	0	0	186
2004	1	Alt 1	0	0	0	4	0	4
		Alt 2	0	0	0	43	0	43
		Meth 2	0	0	0	3	0	3
Average Annual Estimates								
1993-2004	n/a	Alt 1	54	3	0	6	0	63
		Alt 2	64	7	0	26	0	97
2000-2004	n/a	Alt 1	96	0	0	1	0	97
		Alt 2	120	0	0	9	0	129

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[1] Observers were instructed to use the largest sample size available when monitoring for seabirds. Alt 1 likely represents a closer approximation of estimated incidental takes.

Research Needs

The Alaska Groundfish Fisheries draft Programmatic SEIS included several research and/or analysis needs identified by scientists currently researching seabirds in the BSAI and GOA ecosystems (NMFS 2001, pp. 4.3-1 and 4.3-50). As the information gaps are filled, the view of how seabirds are affected by fisheries may change. Additional research and analysis needs were identified in the Alaska Groundfish Fisheries Final Programmatic SEIS (NMFS 2004b) and by other seabird scientists (Kathy Kuletz, USFWS and Shannon Fitzgerald, Alaska Fisheries Science Center, personal communication). Table 32 summarizes these research needs and notes the status of efforts. Steps toward addressing many of the identified research needs (Table 32) have been made, although in most cases these are works in progress. Efforts are underway to develop quantitative models to evaluate the potential for population-level impacts of fisheries on seabirds. For fulmars and albatrosses, this effort includes identification of colonies of provenance of birds taken in longline fisheries in Alaska.

Table 32. Research needs identified for seabird ecology and seabird/fishery interactions for groundfish fisheries in Alaska. STAL = Short-tailed albatross; LAAL = Laysan albatross; BFAL = black-footed albatross. NRC = National Research Council

Category	Research and analysis needs	Current Status	Authors or Contacts
Population level effects	Quantitative models on population-level impact of bycatch	BFAL model available; pelagic longline fishery	Lewison & Crowder 2003
	Seabird Population Assessments	Efforts underway for BFAL & LAAL STAL (unpubl.).	Seivert, USFWS Cochrane and Starfield, USFWS
	Assess bycatch mortality at the colony level.	2001-2003: genetic profiling of fulmar populations 2002-2003: Genetic profiling of albatrosses	Hatch, USGS-BRD, Anchorage. Walsh, U of Washington
	Quantitative models on impacts of fishery discards & offal.	NRC Fellowship began at AFSC in 2004	Fitzgerald & Edwards, NMFS
	Cost/benefit model of mortality and food provisioning	NRC Fellowship began at AFSC in 2004	Fitzgerald & Edwards, NMFS
Distribution & fisheries	Seasonal pattern of offal discharge vs seabird energy needs.	NRC should lay groundwork for this effort in 2005	Fitzgerald & Edwards, NMFS
	Short-tailed albatross spatial & temporal distribution	2001: Satellite telemetry studies begin on Torishima Island 2003 and 2005: At-sea capture in Alaska.	Balogh, USFWS Anchorage Balogh, USFWS Anchorage
	Pelagic Distribution of Seabirds	N. Pacific Pelagic Seabird Database begun in 2002; Stationary seabird surveys began in 2002. N. Pacific Pelagic Seabird Observer Program began in May 2006	USGS-BRD & USFWS, WA Sea Grant Kuletz, USFWS, with NOAA vessels & support from NPRB grant
Food & foraging	Examine temporal & spatial scale of seabird aggregations with respect to ephemeral & stable oceanographic features & prey aggregations.	Analysis of data on STAL underway Work on albatrosses available for central & S. Pacific Special publication on Aleutian Islands includes seabirds.	Suryan et al., Oregon State U. various publications
	Identify & quantify seabird food items.	Great deal of work completed; see Fish. Oceanogr. 14 (2005); Hunt et al. 2000, 2002; Dragoo et al. 2006.	Various authors
	Define seabird feeding areas (horizontally & vertically) Define relationship between feeding and fishing areas. Describe seabird diet during fall through spring months	Satellite telemetry for STAL and northern fulmar (NOFU) No comprehensive study; but preliminary review in NPFMC 2002. No comprehensive study for winter. Estimates for June-Sept. in PICES report no. 14 (Hunt et al. 2000).	Suryan et al., Oregon State U. (STAL) and Scott Hatch, USGS (NOFU) 2002 overview: Kuletz, USFWS
	Examine regional patterns of prey use & trends over time.	Compilation of data from seabird colonies monitored during breeding season are available through 2003.	Dragoo et al. 2006, USFWS
	Examine saturation effect from pulsed fisheries	No work has been completed in the North Pacific on seabird's ability to take advantage of offal and discards.	
Gear & mitigation methods	Characterize seabird interaction with trawl cables and gear.	Preliminary work with electronic monitoring in 2002 Observer special project continuing in 2006.	Fitzgerald, NMFS
	Develop mitigation measures to reduce seabird interactions on trawl vessels	Measures developed and tested in 2005	WA Sea Grant, NMFS, Pollock Conservation Cooperative
	Analysis of multi-year data sets of factors affecting seabird bycatch	Thesis completed on factors affecting seabird bycatch in demersal groundfish longline vessels.	Dietrich University of Washington
	Evaluate effective methods for setting longlines underwater	Various projects, 1999 – ongoing.	Industry, WA Sea Grant, NMFS, and USFWS
	Evaluate integrated weight longlines	Ongoing since 2002	Melvin, WA Sea Grant

Ecosystem or Community Indicators

Alaska Native Traditional Environmental Knowledge of Climate Regimes

By Heather Lazrus, Alaska Fisheries Science Center
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Last updated: November 2005

Alaska Natives who traditionally inhabitant marine ecosystems accumulate a great deal of place-based knowledge about the environment with which they interact through daily observation and experience. Environmental changes associated with successive climate regimes have been recognized and captured by the knowledge systems of Alaska Natives. Traditional environmental knowledge (TEK) is useful to natural resource managers by drawing their attention to environmental changes or by corroborating scientifically described transitions between climate regimes. To illustrate this, a brief qualitative time series organized into three generally accepted climate regimes in the Bering Sea Aleutian Islands (BSAI) region has been constructed with information extracted from the *NOAA Fisheries Alaska Native Traditional Environmental Knowledge Database*. References in text refer to page numbers of individual observations in (Sepez et al. 2003; see also Sepez 2003). It should be noted that the information compiled in the *NOAA Fisheries Alaska Native Traditional Environmental Knowledge Database* was not necessarily elicited in response to specific questions about climatic changes. Additional research is needed to more closely correlate Alaska Native TEK with scientific observations in the BSAI region.

- **1947 – 1975**

In the vicinity of St Lawrence, the early half of the 1900s was characterized by calm weather and predictable ice formation (1). Around Savoonga ice would have begun to solidify by October in the 1930s and 1940s. People's perceptions of winter were largely based on the hunting activities made possible by solid ice formation (16,1). In the mid 1940s the area from Gambell north to Nome appeared to be solid ice (11). Observations beginning in the later part of this period of changes in sea ice formation, from solid to increasingly patchy, were understood to affect walrus migration (11). Since the 1960s early spring break-up of sea ice may have contributed to observed declines in spotted seal populations (19). Rising sea levels and corresponding coastal erosion became a problem, marking significant changes along the coastline from the 1960s to early 1970s and rendering the harvesting of sculpins unusually difficult (7).

- **1976/1977 – 1988**

Throughout the BSAI region and beginning in the late 1970s, winds increased in frequency and intensity and shifted somewhat to the south, average temperatures warmed, and ice melted or moved away from shorelines early (5, 16). Changed wind patterns additionally affected wave patterns, bringing about higher waves and increasing erosion from heightened wave energy hitting the coasts. High winds and waves make it difficult for people to use boats for hunting, near-shore sea beds are affected by coastal erosion and wave energy leading to destruction of kelp colonies and other bottom dwelling plants, which negatively affects shallow feeders such as eiders which depend on these plants (17). Both shifting winds and warmer temperatures contributed to delayed ice formation (19). Ice began to remain unstable throughout the cold season and melt earlier and more rapidly in the springtime in the region around Elim (15). While most seal species seemed to be doing well, spotted seal populations began to decline in the 1960s and 1970s which could be have been due to young seals becoming stranded when the ice melted prematurely (19).

- **1989 – 1998**

Increased westerly winds seem to be part of a trend in changing wind patterns which contribute to delays in the packing of ice and a delayed freeze, sometimes occurring as late as December (3, 11). Precipitation patterns have shifted, with the major snowfalls of the year coming in late winter and early spring (19). Increasingly frequent mild winters and warm springs seemed to correspond with bad hunting seasons for harbor and spotted seals (22). In 1998 a significant decline of seabird populations which may have been weather-related was observed across the BSAI. Decreases in salmon populations, such as Yukon River Chinook salmon, and clams in Mekoryuk Bay, as well as increases in other shellfish were observed during this period (13). Ice formation patterns were delayed during this period when ice was not consistently solidified until early to mid December as opposed to mid October (16). This indicates that sea ice was formed by cold winds and does not contain the nutrients which are important during spring thaws and come from the nutrient-rich sea bottom. Less snow and colder winters were observed, especially in the winter of 1998/1999. Between 1996 and 1998, when spring weather arrived early, reduced sea ice, heightened wave action and subsequent increased sedimentation may have contributed to the poor health of walrus populations and was also detrimental to young, near shore spotted seal populations in the vicinity of Nome (19).

Biodiversity as Index of Regime Shift in the Eastern Bering Sea

By Gerald R. Hoff, AFSC
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Last updated: November 2003

Many investigators have identified events in environmental and biological data from the North Pacific that indicate regime shifts, or reorganizations of the ecosystem at the environmental and biological level. Measurable climate events were identified in the mid-1970s, late 1980s, and the late 1990s that have been correlated with environmental phenomenon including Pacific Decadal Oscillation, El Niño Southern Oscillation, sea ice coverage, and summer time sea surface temperatures. The far reaching effect that climate change has on the ecosystem is not well mapped out, but many studies have shown strong correlations between climate change and recruitment of fish and invertebrates, and plankton production in the North Pacific. Biodiversity indices are robust measures for large ecosystem monitoring and possible indicators of regime shift phenomenon.

Data used for this study was collected by the Groundfish Assessment Program of the Resource Assessment and Conservation Engineering (RACE) Division, which surveys the eastern Bering Sea (EBS) shelf on an annual basis during summer (May-August). Use of biological survey data to monitor regime shifts is possible due to the consistent nature of this multispecies survey.

Biodiversity indices (richness and evenness) were used as indicators for species compositional changes over a 24-year period (1979-2002) and related the trends and changes evident with reported regime shift events in the EBS. Richness and evenness indices use the proportional biomass estimates of each assemblage to estimate a value that reflects the relative number of abundant species in the assemblage (richness) and the distribution of the species proportionalities (evenness).

For this analysis, two species guilds, flatfish and roundfish were identified, where the flatfish guild included all Pleuronectiformes recorded from the EBS survey (11 species or species groups), and the roundfish guild (40 species or species groups) excluding walleye pollock and Pacific cod due to their extremely large biomass. Biodiversity measures were calculated using Ludwig and Reynolds recommendations for species richness and evenness which are considered robust measures and allow the use of biomass estimate proportions for biodiversity indices.

A piecewise model was used to detect a break in the biodiversity time series, indicating a significant ecosystem change had occurred. Two linear models describe the biodiversity trends before and after a break (Figure 126). The data set for richness and evenness for each guild showed a continuous period of change from the late 1970s through the late 1980s, followed by a period of stasis until the present (Figure 126). The diversity indices suggest an event in the 1970s sparked ecosystem changes that were perpetuated into the late 1980s and early 1990s. The event in the late 1980s countered the 1970s event, and the system tended to stabilize at a new level from the early 1990s through 2002.

Biodiversity indices for the EBS fish guilds concur with the timing of a significant climactic event in the late 1980s. This study indicates that survey data can be used as a robust measure of large ecosystem change and corroborates shifts related to climate and environmental changes.

Given the greatly improved species identification levels and standardization now in use on the RACE groundfish surveys, assemblages can be studied which include more fish species and invertebrates. Improved resolution of the species groups may detect more subtle changes in the ecosystem than previously possible.

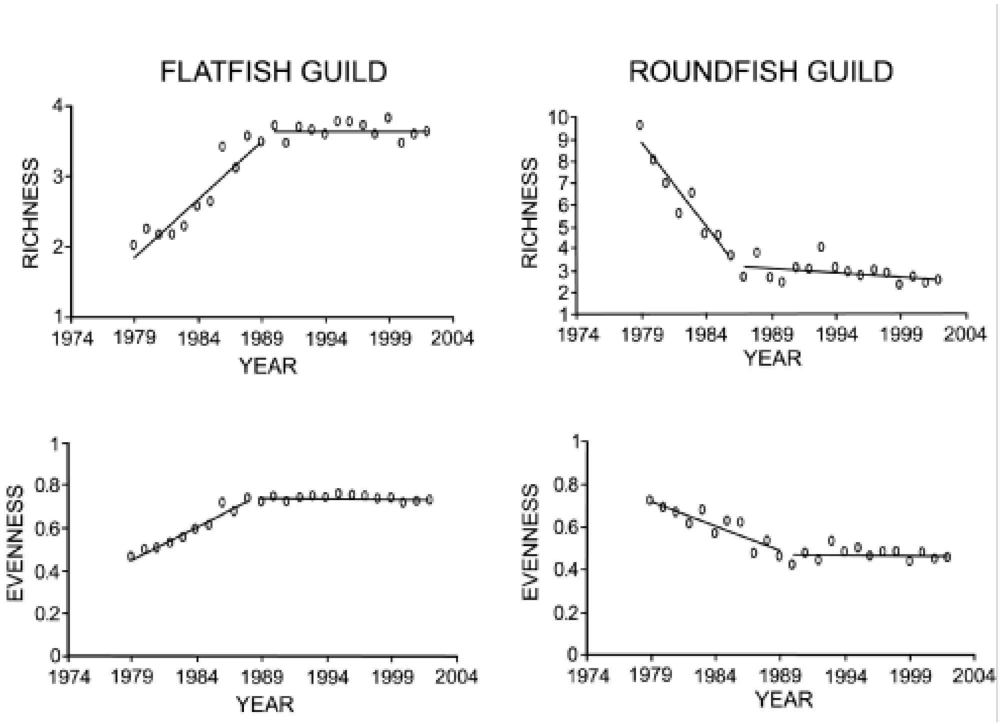

Figure 126. Plots of biodiversity (richness and evenness) indices for two fish guilds (flatfish and roundfish) from the eastern Bering Sea. Biodiversity showed a distinct shift in trends in the late 1980s which corresponds to reported regime shift events.

Combined Standardized Indices of recruitment and survival rate

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Last updated : August 2006

Description of indices: This section provides indices of overall recruitment and survival rate (adjusted for spawner abundance) across the major commercial groundfish species in the Eastern Bering Sea / Aleutian Islands (BSAI, 11 stocks) and Gulf of Alaska (GOA, 12 stocks, rex sole was added this year). Time series of recruitment and spawning biomass for demersal fish stocks were obtained from the 2005 SAFE reports (NPFMC 2005a and b). Survival rate (SR) indices for each stock were computed as residuals from a spawner-recruit model. Both a Ricker and Beverton-Holt model (with or without first-order autocorrelated errors) were fit to each stock's recruitment and female spawning biomass data and the model with the best fit (based on the small-sample Akaike Information Criterion) was used to compute the SR index. Each time series of log-transformed recruitment (logR) or SR indices was standardized to have a mean of 0 and a standard deviation of 1 (hence giving equal weight to each stock in the combined index, see below). Log-recruitment or SR series were lined up by year-class, resulting in matrices of logR / SR indices by year with missing values at the beginning and end of many series. A combined standardized index of recruitment (CSI_R) and survival (CSI_{SR}) was computed by simply averaging indices within a given year across stocks. Prior to standardizing the series, missing values at the ends of several series were estimated by imputation using additive regression, bootstrapping, and predictive mean matching as implemented in the "hmisc" package for S-Plus and R (Frank Harrell, Univ. of Virginia, available at StatLib at http://lib.stat.cmu.edu/). Multiple imputations were obtained by bootstrap resampling to estimate the variability in the averaged index that results from filling in missing values. Uncertainty in the stock-specific estimates of logR and SR indices was not accounted for; therefore the most recent estimates of the combined indices should be interpreted with caution.

Status and trends: The CSI_R suggests that recruitment of demersal species in the GOA and BSAI followed a similar pattern with mostly above-average recruitments from the mid- or late 1970s to the late 1980s, followed by below-average recruitments during the early 1990s (GOA) or most of the 1990s (BSAI; Figure 127). Because estimates at the end of the series were based on only a few stocks and are highly uncertain, we show the index through 2001 only, the last year for which data for at least 6 stocks was available. The main difference between this year's and last year's indices is the strong indication for above-average recruitment in the GOA from 1994-2000 (with the exception of 1996, which had a very low recruitment index). A similar trend was evident in the Bering Sea, but was much less pronounced. The CSI_{SR} indices showed very similar patterns. As in previous years, indices from both regions were unusually high in 1984, when 19 out of 23 stocks had above-average log-recruitment and SR indices relative to the 1970-2001 period.

Factors causing trends: Trends in recruitment are a function of both spawner biomass and environmental variability. Trends in survival rate indices, which are adjusted for differences in spawner biomass, are presumably driven by environmental variability but are even more uncertain than recruitment trends. Typically, spawner biomass accounted for only a small proportion of the overall variability in estimated recruitment. The observed patterns in recruitment and survival suggest decadal-scale variations in overall groundfish productivity in the Gulf of Alaska and Bering Sea that are moderately to strongly correlated between the two regions (CSI_R: $r = 0.38$; CSI_{SR}: $r = 0.56$). These variations in productivity are correlated with and may in part be driven by variations in large-scale climate patterns such as the PDO or more regional measures such as ocean temperatures. The Nov-Mar PDO index for the preceding winter was positively correlated with all of the indices, but the correlation was significant at the 90% level for the CSI_{SR} index in the GOA only (r = 0.31, p =0.088). The same index was positively correlated with bottom temperatures at GAK 1 station (r = 0.50, p = 0.004).

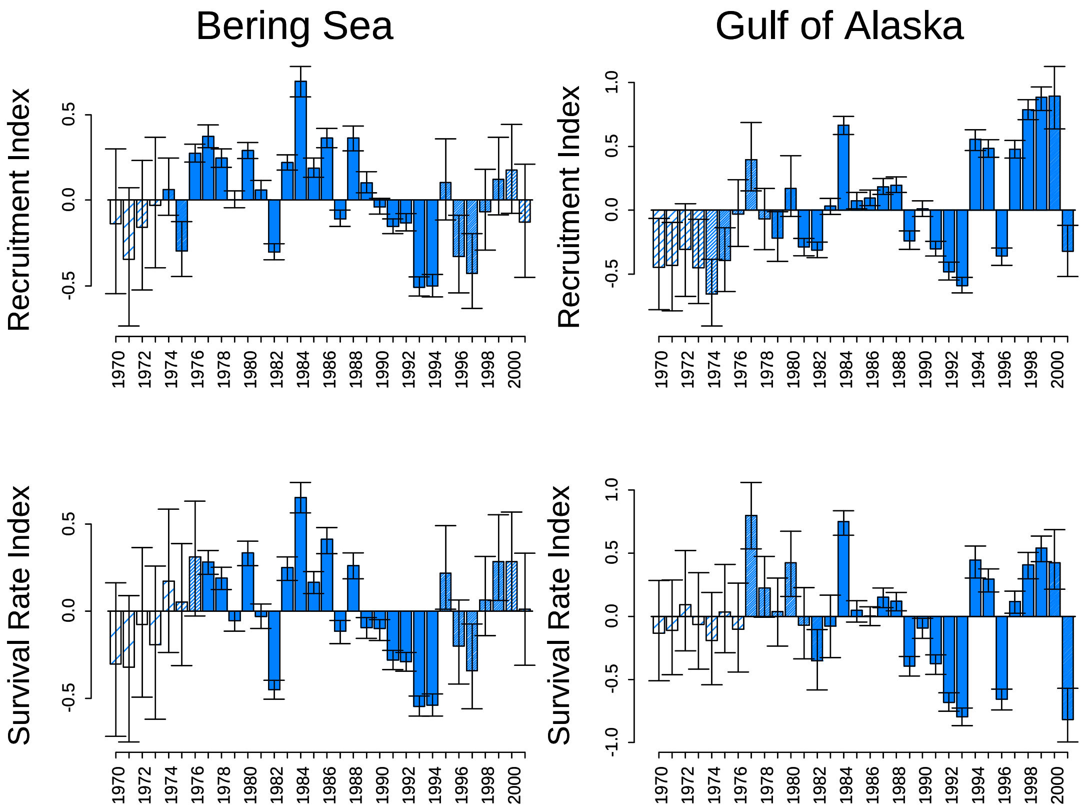

Figure 127. Combined Standardized Indices of recruitment (top) and survival rate (stock-recruit residuals, bottom) by year class across demersal stocks in the Bering Sea / Aleutian Island region (11 stocks) and in the Gulf of Alaska (12 stocks). Solid blue bars represent years with data for all stocks or stock groups. Lighter shading corresponds to years with more missing stocks. Series were truncated in 1970 and only years with data for at least 6 stocks were included. Bootstrap confidence intervals (95%) depict uncertainty resulting from filling in missing values but assume that survival and recruitment are estimated without error.

Average local species richness and diversity of the groundfish community

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Last updated: September 2005

Description of indices: This section provides indices of local species richness and diversity based on standard bottom trawl surveys in the western (west of 147°N) Gulf of Alaska (GOA) and Eastern Bering Sea (EBS). The average number of fish taxa per haul and the average Shannon-Wiener index of diversity (Magurran 1988) by haul were computed based on CPUE (by weight) of each fish species (or taxon). Indices were based on a total of 55 fish taxa in the GOA and 47 fish taxa in the EBS. Taxa were included at the lowest possible taxonomic level, i.e. at a level that was consistently identified throughout all surveys. Indices were computed following Mueter & Norcross (2002). Briefly, annual average indices of local richness and diversity were estimated by first computing each index on a per-haul basis, then estimating annual averages by modeling haul-specific indices as a function of geographic location, depth, date of sampling, area swept, and year.

Status and trends: Average species richness and diversity of the groundfish community in the Gulf of Alaska increased from 1990 to 1999 with both indices peaking in 1999 and sharply decreasing thereafter (Figure 128). Species richness and diversity on the Eastern Bering Sea shelf have undergone significant variations from 1982 to 2004 (Figure 129). Species diversity increased from 1983 through the early 1990s, was relatively high and variable throughout the 1990s, decreased significantly after 2001, and increased again to its long-term average in 2004.

F**actors causing observed trends**: The average number of species per haul depends on the spatial distribution of individual species (taxa). If species are, on average, more widely distributed in the sampling area the number of species per haul increases. Spatial shifts in distribution from year to year lead to high variability in local species richness in certain areas, for example along the 100 m contour in the Eastern Bering Sea. These shifts appear to be the primary drivers of changes in species richness.

Local species diversity is a function of the number of species and their relative abundance in each haul. In the GOA average species diversity followed changes in local richness. In contrast, trends in species diversity in the EBS differed from those in richness. For example, low species diversity in the EBS in 2003 occurred in spite of high average richness, primarily because of the high dominance of walleye pollock, which increased from an average of 18% of the catch per haul in 1995-98 to 30% in 2003, but decreased again to an average of 21% in 2004. The effect of fishing on species richness and diversity are poorly understood at present. Because fishing primarily reduces the relative abundance of some of the dominant species in the system, species diversity is expected to increase relative to the unfished state. However, changes in local species richness and diversity are strongly confounded with natural variability in spatial distribution and relative abundance.

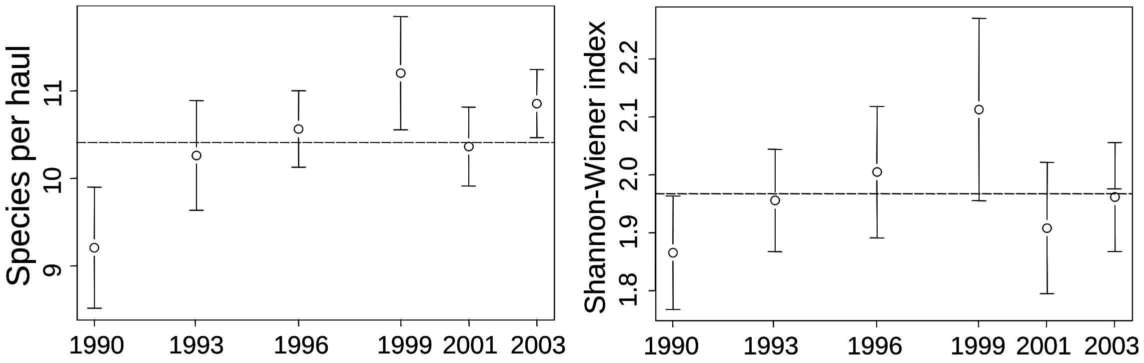

Figure 128. Model-based annual averages of species richness (average number of species per haul), and species diversity (Shannon-Wiener index) in the western Gulf of Alaska, 1990-2003, based on 55 fish taxa collected by standard bottom trawl surveys with 95% confidence intervals. Model means were adjusted for differences in area swept, depth, date and time of sampling, and geographic location among years.

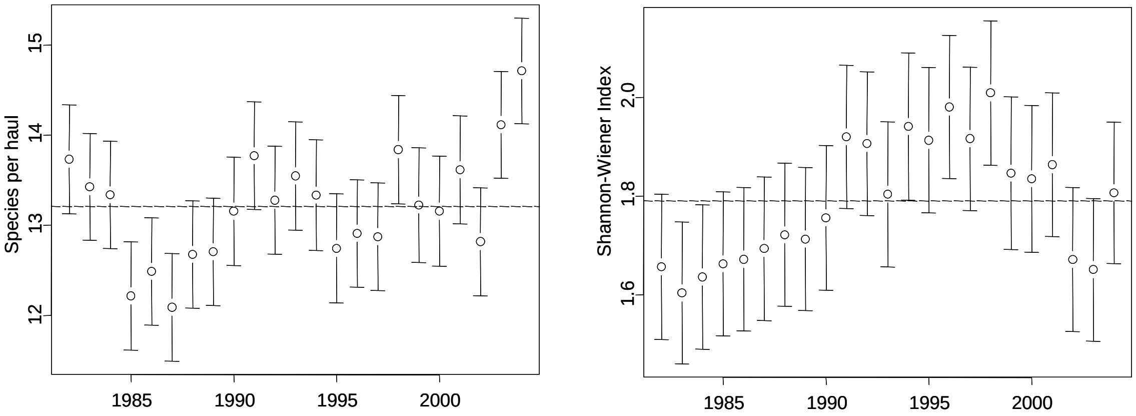

Figure 129. Model-based annual averages of species richness (average number of species per haul), and species diversity (Shannon-Wiener index) in the Eastern Bering Sea, 1982-2004, based on 47 fish taxa collected by standard bottom trawl surveys with 95% confidence intervals. Model means were adjusted for differences in area swept, depth, date of sampling, bottom temperature, and geographic location among years.

Total catch-per-unit-effort of all fish and invertebrate taxa in bottom trawl surveys

Contributed by Franz Mueter, Sigma Plus Statistical Consulting, Fairbanks, Alaska
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Last updated: September 2005

Description of index: The index provides a measure of overall abundance of demersal and benthic species. Average catch-per-unit-effort of all fish and invertebrate taxa captured by standardized bottom trawl surveys in the Eastern Bering Sea (EBS) and Gulf of Alaska (GOA) was estimated. Spatial and temporal patterns in total CPUE of all taxa combined were modeled using Generalized Additive Models (GAM) as a function of depth, location, Julian day, and area swept following Mueter & Norcross (2002). Although catches were standardized to account for the area swept by each haul we included area swept in the model because of differences in catchability of certain taxa with changes in net width (Dave Somerton, Alaska Fisheries Science Center, NMFS, personal communication) and because there was strong evidence that total CPUE tends to decrease with area swept, all other factors being constant. The model for the EBS further included bottom temperatures, which appeared to strongly reduce CPUEs at low temperatures (< 1˚C). At present, it is not clear whether this effect is due to actual changes in abundance or temperature-dependent changes in catchability of certain species. The index did not account for gear differences which may affect results prior to 1988 in the Bering Sea because they are strongly confounded with interannual differences. Total CPUE over time was computed separately for the eastern and western GOA because of large differences in species composition and because no survey was conducted in the eastern GOA in 2001. CPUE in the GOA for the 1984 and 1987 surveys were not estimated because a large portion of these surveys used non-standard gear types. Trends in CPUE over time in the eastern GOA were highly uncertain due to large differences in sampling dates among years and are not presented here.

Status and trends: Total survey CPUE in the western GOA first peaked in 1993/96 and decreased significantly between 1996 and 1999 (Figure 130). CPUE increased again from 2001 to 2003, which had the highest observed CPUE value of the time series. Total CPUE in the EBS has undergone substantial variations and peaked in 1994 (Figure 131), similar to the GOA. There was an apparent long-term increase in CPUE from 1982-2003 (Generalized least squares regression with first-order autocorrelated errors: slope = 0.014 per year, t = 1.74, P = 0.097). However, estimated means prior to 1988 may be biased due to unknown gear effects. Log-transformed CPUE in the EBS was near the long-term mean from 2000-2002 and, similar to the GOA, increased in 2003/2004.

Factors causing observed trends: Commercially harvested species account for over 70% of the survey catches. Therefore fishing is expected to be a major factor determining trends in total survey CPUE, but environmental variability is likely to account for a substantial proportion of overall variability in CPUE through variations in recruitment and growth. The increase in survey CPUE in the EBS from 2002 to 2003/04 primarily resulted from increased abundances of walleye pollock and a number of flatfish species (arrowtooth flounder, yellowfin sole, rock sole, and Alaska plaice). The increase in the GOA between 2001 and 2003 was largely due to a substantial increase in the abundance of arrowtooth flounder, which accounted for 43% of the total survey biomass in 2003.

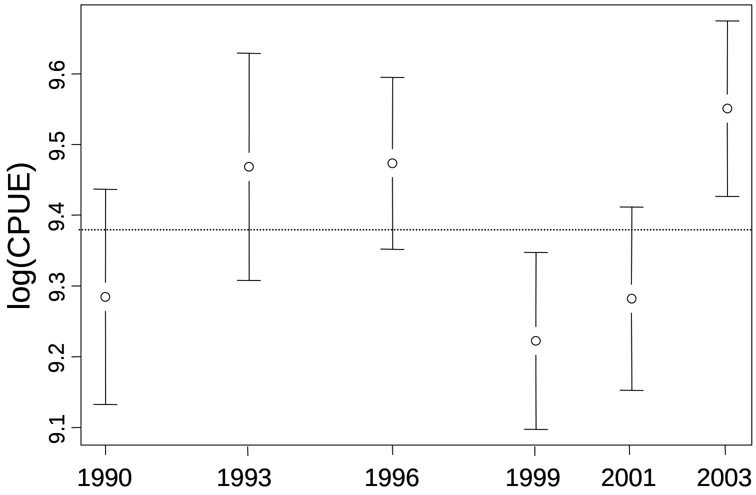

Figure 130. Model-based estimates of log(CPUE) for all fish and invertebrate taxa captured in bottom trawl surveys from in the western Gulf of Alaska (west of 147˚ W) by survey year with approximate 95% confidence intervals. Estimated means were adjusted for differences in depth, day of sampling, area swept and sampling locations among years.

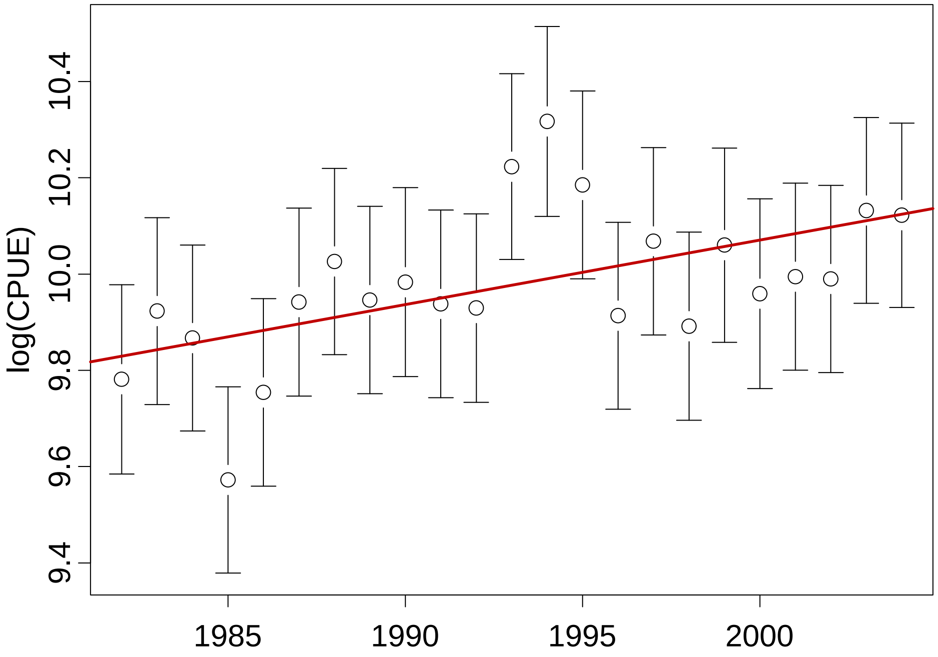

Figure 131. Model-based estimates of total log(CPUE) of all fish and invertebrate taxa captured in bottom trawl surveys from 1982 to 2004 in the Bering Sea with approximate pointwise 95% confidence intervals and long-term linear trend. Estimates were adjusted for differences in depth, bottom temperature, day of sampling, area swept, and sampling location among years. Gear differences prior to 1988 were not accounted for.

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 Alan Haynie and Terry Hiatt, Alaska Fisheries Science Center
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Last updated: August 2006

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. A variety of 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 for the hook and line fishery and 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 Figure 132. 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.

Since the mid-1990s, the pollock and flatfish fleets have contracted with Sea State, Inc. to share and aggregate information about bycatch. Sea State receives information from the North Pacific Groundfish Observer Program about the bycatch rates of participating vessels, and then identifies "hotspots", which depending upon the fishery, designate either voluntary recommendations or mandatory exclusions from high-bycatch areas. Sea State also sends regular "Dirty 20" lists of vessels with high bycatch to the participating fleets and communicates other information about bycatch trends and rates. Beginning in 1994, in a related attempt to control salmon bycatch in the BSAI trawl fisheries (which account for about 95% of salmon bycatch), the North Pacific Fisheries Management Council (NPFMC) and NMFS established chum and chinook Salmon Savings Areas (SSA), which are closed by regulation in parts of the Bering Sea and at times when salmon bycatch had been highest according to historical observer data.

Despite efforts by industry and regulators to control prohibited-species bycatch, however, both chinook salmon and "other salmon" (OS) bycatch have increased dramatically in recent years. The OS bycatch more than doubled in both 2003 and 2004 compared to the previous years and increased again by about 57% in 2005. The increases in 2003 and 2005 are in line with increases in salmon abundance, which is reflected by the increase in the overall catch of OS, which increased by about one-third in both years. But the OS bycatch also more than doubled in 2004, despite an almost 6% reduction in the overall catch.

The key problem is that closures of the SSA have not been working. The highest chum salmon bycatch rates lately have occurred outside of the chum SSA and after its closure. Similar problems occurred in 2003-05 with chinook salmon bycatch outside of the chinook SSA—the highest bycatch rates were encountered by the pollock trawl fleet outside of the SSA after regulations had forced its closure. The resulting chinook salmon bycatch was about 28% higher in 2003, 46% higher in 2004, and 96% higher in 2005 than the long-term average over the period 1994-2002. In 2006 for the first time ever, the chinook SSA was closed to fishing during the pollock ‘A’ season, which had a very large economic impact on the pollock fishery. To address these problems, the NPFMC is considering other measures to control salmon bycatch. These measures include establishing new regulatory salmon-savings systems, such as the Voluntary Rolling Hot Spots (VRHS) system implemented during the 2006 ‘A’ pollock season, under which high bycatch vessels are prohibited from fishing in high-bycatch areas for a certain time period. By NPFMC and NMFS actions, vessels participating in the VRHS system are scheduled to be exempted from Salmon Savings Area closures beginning in August 2006. The NPFMC will also consider new fixed-area closures and the development of some form of individual-vessel, salmon-bycatch accountability program. The latter could take the form of tradable individual bycatch quotas (IBQ) or a system of financial incentives that would reward vessels for minimizing bycatch and/or penalize vessels with high bycatch rates.

Annual estimates of bycatch for the years 1994-2002 come from NMFS Alaska Region’s blend data; 2003-05 estimates are from the Alaska Region’s Catch-Accounting System.

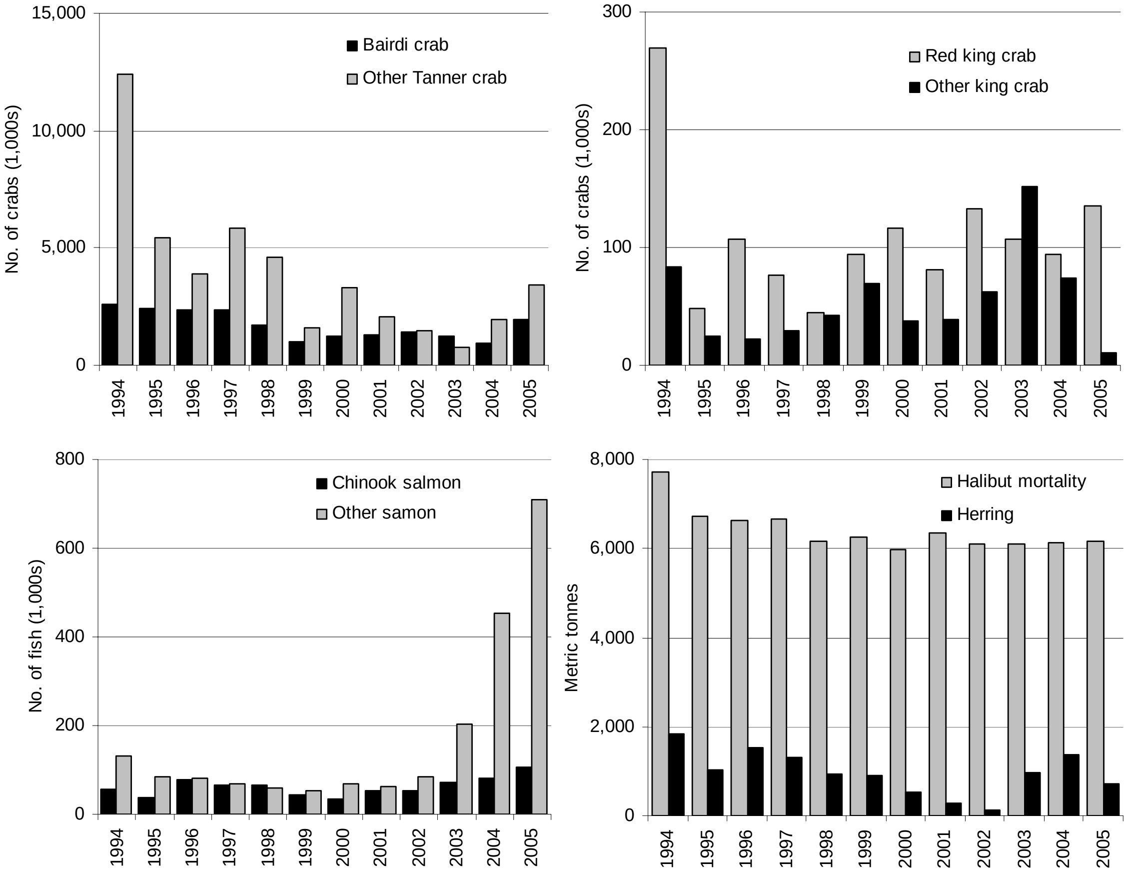

Figure 132. Bycatch of tanner and king crab, salmon, halibut, and herring in groundfish fisheries off Alaska, 1994-2005.

Time trends in groundfish discards

Contributed by Terry Hiatt, Alaska Fisheries Science Center
Contact: Terry.Hiatt@noaa.gov
Last updated: August 2006

In 1998, the amount of managed groundfish species discarded in Federally-managed groundfish fisheries dropped to less than 10% of the total groundfish catch in both the Bering Sea/Aleutian Islands and the Gulf of Alaska (Figure 133). These decreases are explained by reductions in the discard rates of pollock and Pacific cod that resulted from regulations implemented in 1998 prohibiting discards of these two species. Discards in the Gulf of Alaska increased somewhat between 1998 and 2003, but have declined again in recent years. Discards in both regions are much lower than the amounts observed in 1997, before implementation of improved-retention regulations. Estimates of discards for 1994-2002 come from NMFS Alaska Region's blend data; estimates for 2003-05 come from the Alaska Region's catch-accounting system. It should be noted that although these sources provide the best available estimates of discards, the estimates are not necessarily accurate because they are based on visual observations by observers rather than data from direct sampling.

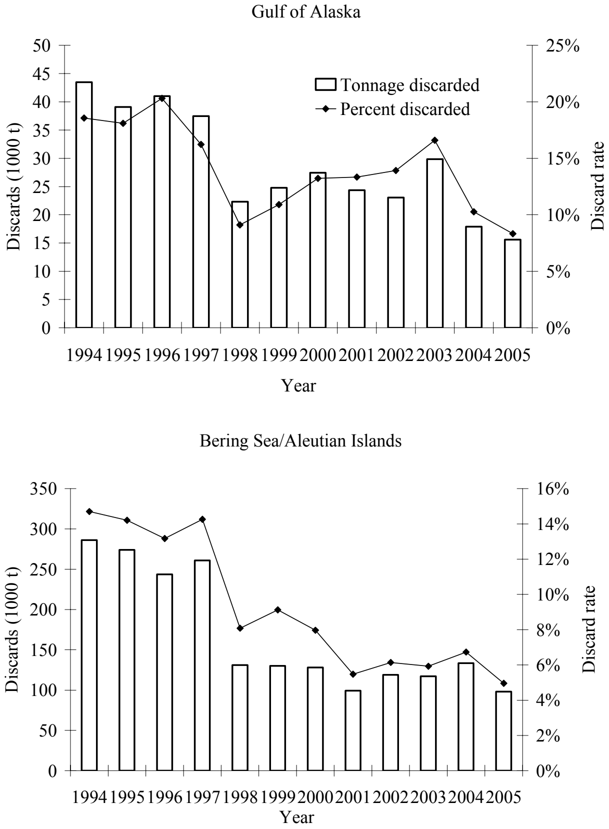

Figure 133. Total biomass and percent of total catch biomass of managed groundfish discarded in the GOA and BSAI areas, 1994-2005. (Includes only catch counted against federal TACs).

Time Trends in Non-Target Species Catch

Contributed by Sarah Gaichas and Jennifer Boldt, Alaska Fisheries Science Center
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Last updated: August 2006

In addition to prohibited and target species catches, groundfish fisheries also catch non-target species (Figure 134). There are four categories of non-target species: 1.) forage species (gunnels, sticheids, sandfish, smelts, lanternfish, sandlance), 2.) HAPC (seapens/whips, sponges, anemones, corals, tunicates), 3.) non-specified species (grenadiers, crabs, starfish, jellyfish, unidentified invertebrates, benthic invertebrates, echinoderms, other fish, birds, shrimp), and 4.) other species (sculpins, unidentified sharks, salmon sharks, dogfish, sleeper sharks, skates, octopus, squid). The “other species” catch is included in the groundfish discards (Hiatt, this report).

In both the BSAI and GOA, non-specified catch comprised the majority of non-target catch during 1997-2005 (Figure 134). Since 2003, scyphozoan jellyfish (45-53% of non-specified catches 2003-2005) represented the largest biomass of the non-specified catch in the BS, followed by sea stars (20-25% of non-specified catches 2003-2005) and grenadiers (15-20% of non-specified catches 2003-2005). In the AI, non-specified catch has been at least 4 times lower than that in the BS (since 2003), and grenadiers dominate the non-specified catch (85-95% of non-specified catches 2003-2005). In the GOA since 2003, the dominant non-specified catch has been comprised of grenadiers (82-92% of non-specified catches 2003-2005) followed by sea stars (4-12% of non-specified catches 2003-2005).

HAPC biota and forage species are also presented in Figure 134, but are small relative to the non-specified catch. Forage catch represents a larger proportion of the total non-target catch in the GOA than HAPC biota catch; whereas, the opposite is true in the BSAI. HAPC biota catch estimates range from 922 to 2548 mt (anemones, sponges, and corals) in the BSAI, and from 15 to 46 mt, (primarily anemones) in the GOA. HAPC biota bycatch decreased slightly in 2005 to 1345.5 mt in the BSAI and increased slightly to 32.1 mt in the GOA. Non-target forage catches consist primarily of smelts and range from 19 to 83 mt in the BSAI and from 27 to 1052 mt in the GOA. In 2005, the bycatch of forage species was at a record low in the BSAI (15.5 mt) and at a record high in the GOA (1052.8 mt). The large catches of forage fish in the GOA in 2005 were primarily due to large catches of eulachon.

Most non-target catch is discarded as well as some target catch. Non-target catches are roughly half as large as the target discard estimates in the GOA; whereas, non-target catches are approximately 10-20% as large as the target discard estimates in the BSAI. It should be noted that although the blend estimates are the best available estimates of discards, they are not necessarily accurate because they are based on visual observations of observers rather than data from direct sampling. Catch since 2003 has been estimated using the Alaska Region’s new Catch Accounting system.

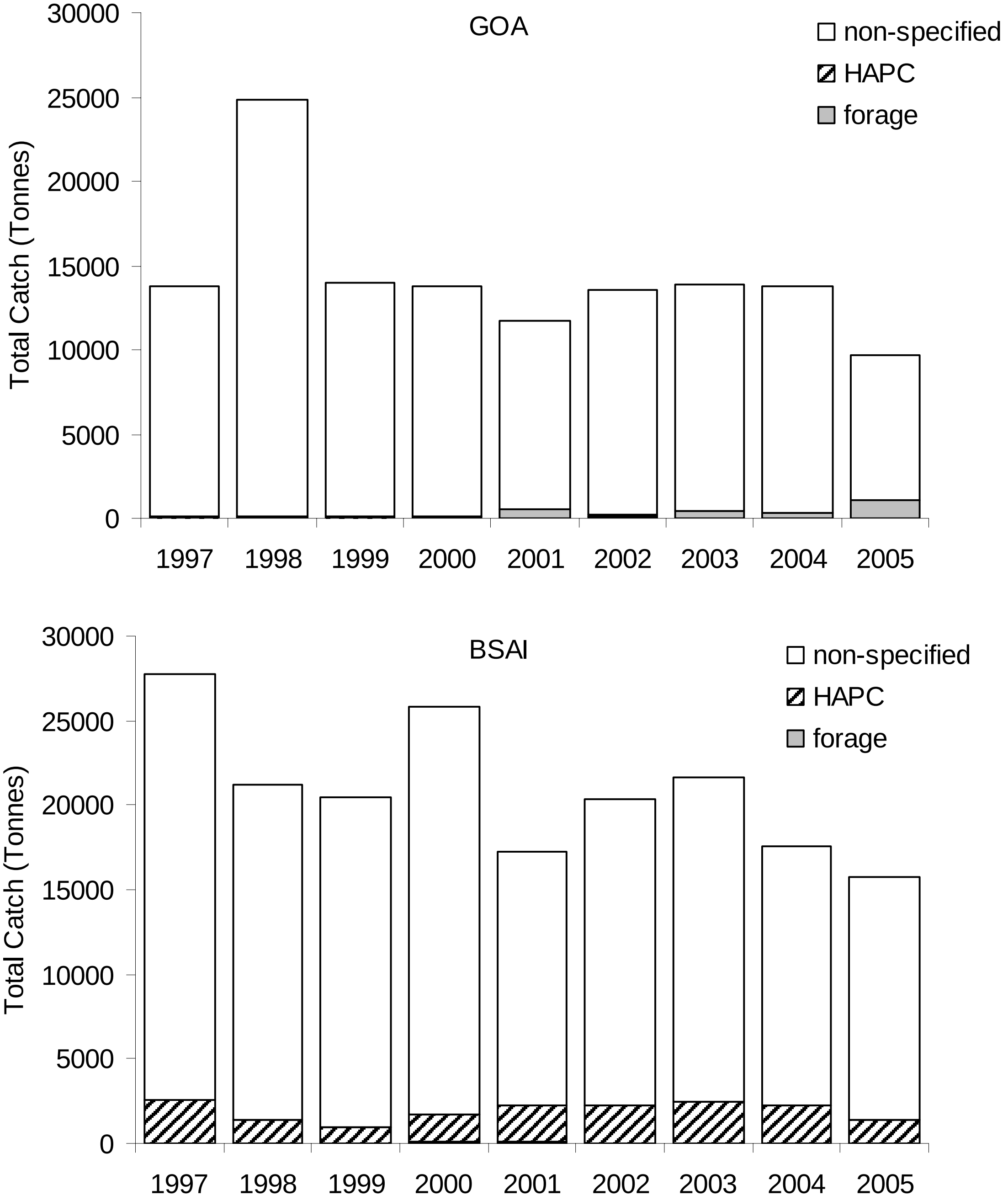

Figure 134. Total catch of non-target species (tonnes) in the BSAI and GOA areas by groundfish fisheries.

Ecosystem Goal: Maintain and Restore Fish Habitats

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

Contributed by Cathy Coon, NPFMC
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Last updated: August 2006

Many trawl closures have been implemented to protect benthic habitat or reduce bycatch of prohibited species (i.e., salmon, crab, herring, and halibut) (Table 33 and Figure 135). Some of the trawl closures are in effect year-round while others are seasonal. A review of trawl closures implemented since 1995 is provided in Table 33. In general, year-round trawl closures have been implemented to protect vulnerable benthic habitat. Seasonal closures are used to reduce bycatch by closing areas where and when bycatch rates had historically been high. Additional measures to protect the declining western stocks of the Steller sea lion began in 1991 with some simple restrictions based on rookery and haulout locations, to specific fishery restrictions in 2000 and 2001. For 2001, over 90,000 nmi of the EEZ off Alaska was closed to trawling year-round. Additionally 40,000 nmi were closed on a seasonal basis. State waters (0-3nmi) are also closed to bottom trawling in most areas.

New closures implemented in 2006 as part of protection for Essential Fish Habitat encompasses a large portion of the Aleutian Islands (Figure 135). The largest of these closures is called the Aleutian Islands Habitat Conservation area and closes 279,000 nmi to bottom trawling year round. By implementing this closure, 41% of Alaska's EEZ is closed to bottom trawling.

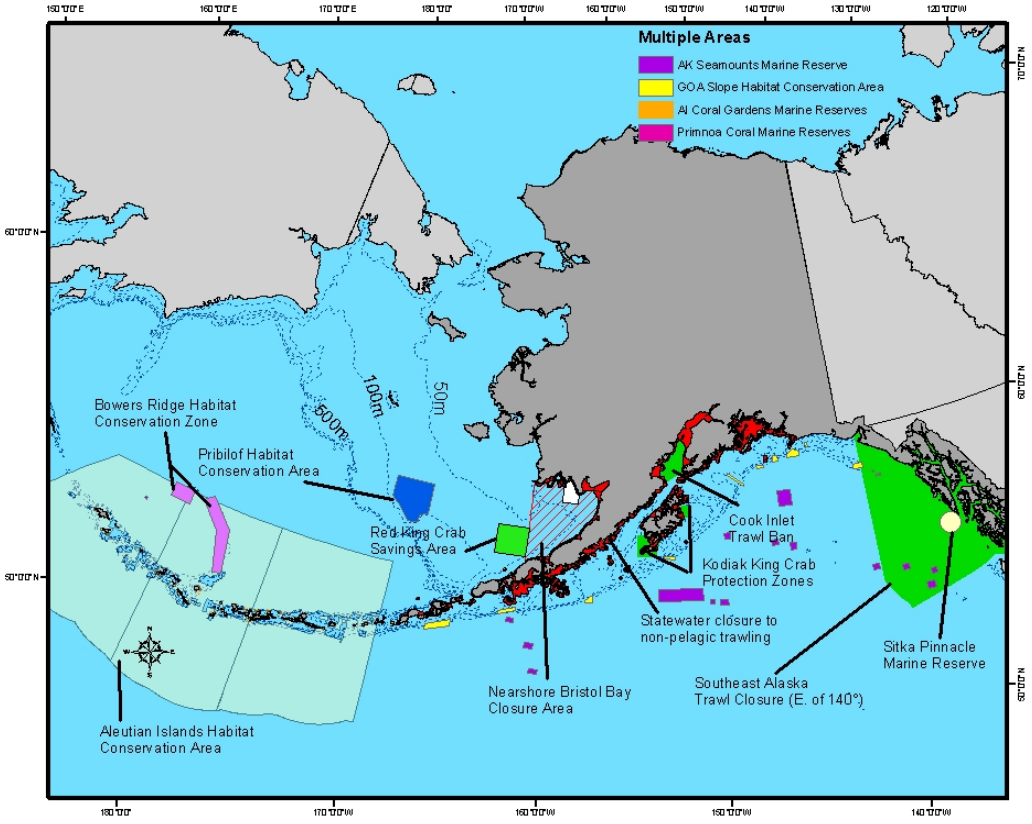

Figure 135. Year-round groundfish closures in Alaska's Exclusive Economic Zone

Table 33. Time series of groundfish trawl closure areas in the BSAI and GOA, 1995-2005.

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 in bycatch
	CHSSA	trigger	9,000 nm^2	closed if 48,000 Chinook salmon bycatch
	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	seasonal ext.	5,100 nm^2	20 mile extensions around 8 rookeries
1996	Same closures in effect as 1995			
1997	Same closure in effect as 1995 and 1996, with two additions:			
	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	same closure in effect as in 1995, 1996, 1997 and 1998			
2000	same closure in effect as in 1995, 1996, 1997 ,1998 and 1999			
	with additions of Steller Sea Lion protections			
	Pollock haulout trawl exclusion zones for EBS, AI **** areas include GOA***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
		No Trawl Atka Mackerel Restrictions	29,000 nm^2	
2001	same closure in effect as in 1995, 1996, 1997 ,1998 and 1999, 2000			
	with additions of Steller Sea Lion protections			
	Pollock haulout trawl exclusion zones for EBS, AI **** areas include GOA***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
		No Trawl Atka Mackerel Restrictions	29,000 nm^2	
2002	same closure in effect as in 1995, 1996, 1997 ,1998 and 1999, 2000, 2001			
	with additions of Steller Sea Lion protections			
	Pollock haulout trawl exclusion zones for EBS, AI **** areas include GOA***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
		No Trawl Atka Mackerel Restrictions	29,000 nm^2	
2003	same closure in effect as in 1995, 1996, 1997 ,1998 and 1999, 2000, 2001,2002			
	including 2002 additions of Steller Sea Lion protections			
2004	same closure in effect as in 1995, 1996, 1997 ,1998 and 1999, 2000, 2001,2002, 2003			
2005	same closure in effect as in 1995-2004			
2006	same closure in effect as in 1995-2005 with the addition of Essential Fish Habitat Areas			
	Aleutian Island Habitat Conservation Area			
	No bottom trawl all year		279,114 nm^2	
	6 coral garden areas		110nm^2	

Gulf of Alaska

Year	Location	Season	Area size	Notes
1995	Kodiak	year-round	1,000 nm^2	red king crab closures, 1987
	Kodiak	2/15-6/15	500 nm^2	red king crab closures, 1987
	SSL Rookeries	year-round	3,000 nm^2	10 mile no-trawl zones around 14 rookeries
	SSL Rookeries	seasonal ext,	1900 nm^2	20 mile extensions around 3 rookeries
1996	same closures in effect as in 1995			
1997	same closures as in 1995 and 1996			
1998	same closures as in 1995, 1996 and 1997, with one addition:			
	Southeast trawl	year-round	52,600 nm^2	adopted as part of the license limitation
	program		(11,929 nm2 area on the shelf)	
1999	same closures as in 1995, 1996, 1997 and 1998, with two additions:			
	Sitka Pinnacles			
	Marine reserve	year-round	3.1 nm^2	Closure to all commercial gear
	Sea Lion haulouts			
2000	same closures as in 1995, 1996, 1997, 1998 and 1999			
	Pollock haulout trawl exclusion zones for GOA**** areas include EBS, AI***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
2001	same closures as in 1995, 1996, 1997, 1998 and 1999, 2000			
	Pollock haulout trawl exclusion zones for GOA**** areas include EBS, AI***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
2002	same closures as in 1995, 1996, 1997, 1998 and 1999, 2000, 2001			
	Pollock haulout trawl exclusion zones for GOA**** areas include EBS, AI***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
	Cook Inlet trawl closure: non-pelagic trawl exclusion to address crab bycatch avoidance			
		Year round	nm^2	
2003	same closures as in 1995, 1996, 1997, 1998 and 1999, 2000, 2001,2002			
2004	same closure in effect as in 1995, 1996, 1997, 1998 and 1999, 2000, 2001,2002, 2003			
2005	same closure in effect as in 1995-2004			
2006	same closure in effect as in 1995-2005 with the addition of Essential Fish Habitat Areas			
		Gulf of Alaska Slope Habitat Conservation Area**		
		No bottom trawl all year	2,100nm^2	

**- May be modified in 5 years.

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

Hook and Line (Longline) fishing effort in the Gulf of Alaska, Bering, Sea and Aleutian Islands

Contributed by Cathy Coon, NPFMC
Contact: Cathy.Coon@noaa.gov

Last updated: August 2006

The amount of effort (as measured by the number of days fished) in hook and line fisheries is used as an indicator for habitat effects. Effort in the hook and line fisheries in the Bering Sea, Aleutian Islands, and Gulf of Alaska is shown in Figure 136. This fishery is prosecuted with stationary lines, onto which baited hooks are attached. Gear components include the anchors, groundline, gangions, and hooks. The fishery is prosecuted with both catcher vessels and freezer longliners. The amount of effort (as measured by the number of sets) in longline fisheries is used as an indicator for target species distribution as well as for understanding habitat effects. Figures 137-142 show the spatial patterns and intensity of longline effort, based on observed data as well as anomalies based on year 2005. Spatial changes in fisheries effort may in part be affected by fishing closure areas (i.e., Steller sea lion protection measures) as well as changes in markets and increased bycatch rates of non-target species. Changes in fishing effort are shown in the anomaly plots that look at current effort relative to previous effort.

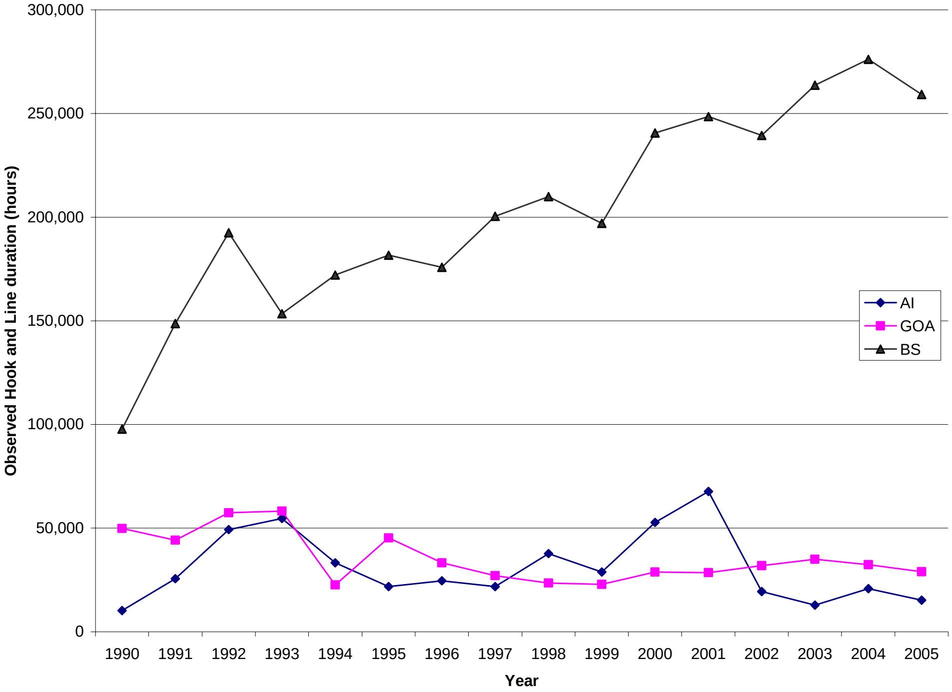

Figure 136. Estimated hook and line duration in the Gulf of Alaska, Bering Sea, and Aleutian Islands during 1990-2005.

Bering Sea

For the period 1990-2005, there were a total of 187,351 observed longline sets in the Bering Sea fisheries. Spatial patterns of fishing effort were summarized on a 5km^2 grid (Figure 137). Areas of high fishing effort are north of False Pass (Unimak Island) as well as the shelf edge represented by the boundary of report areas 513 and 517, as well as areas 521-533. This fishery occurs mainly for Pacific cod, Greenland turbot, and sablefish. In 2005, fishing effort was anomalously high in a small area northwest of the Pribilof Islands and north of the Alaska Peninsula (Figure 138).

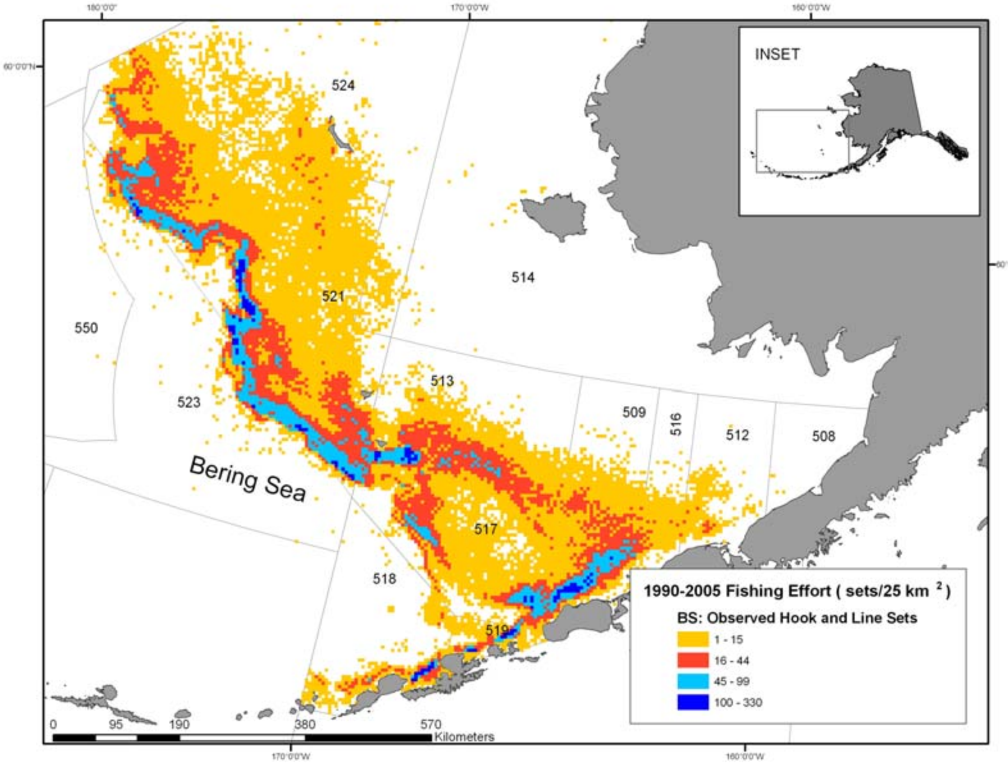

Figure 137. Spatial location and density of hook & line (longline) effort in the Bering Sea 1990-2005.

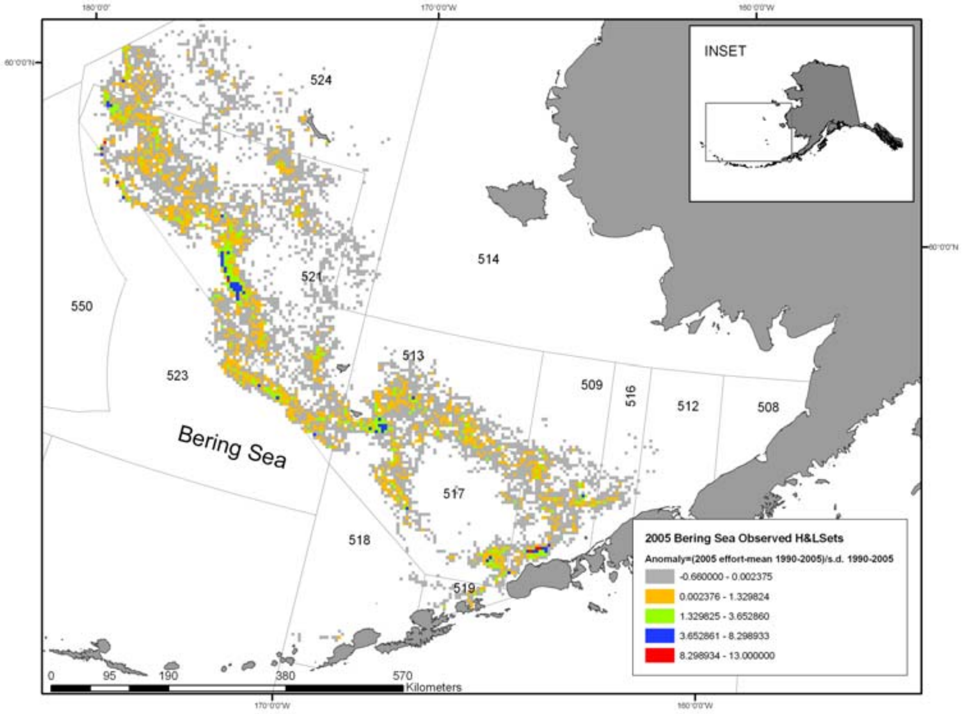

Figure 138. Anomaly plot for Bering Sea observed hook and line (longline) effort in 2005 relative to the average effort during 1990-2005 ((estimated effort for 2005 - average effort from 1990-2005)/stdev(effort from 1990-2005)).

Aleutian Islands

For the period 1990-2005 there were 37,328 observed hook and line sets in the Aleutian Islands. The spatial pattern of this effort was dispersed over a wide area. Patterns of high fishing effort were dispersed along the shelf edge (Figures 139 and 140). This fishery occurs mainly on Pacific cod, Greenland turbot, and sablefish. The catcher vessel longline fishery occurs over mud bottoms. In the summer, the fish are found in shallow (150-250 ft) waters, but are deeper (300-800 ft) in the winter. Catcher-processors fish over more rocky bottoms in the Aleutian Islands. The sablefish/Greenland turbot fishery occurs over silt, mud, and gravel bottom at depths of 150 to 600 fm.

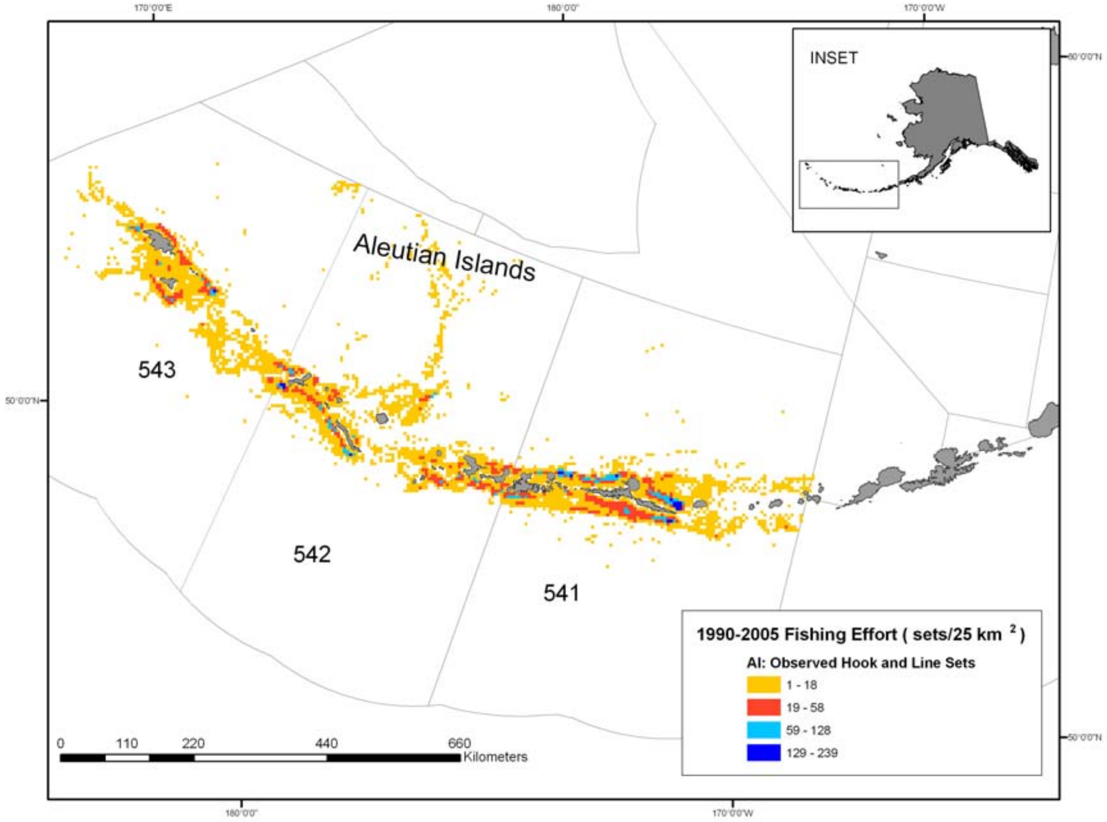

Figure 139. Spatial location and density of hook & line effort in the Aleutian Islands, 1990-2005.

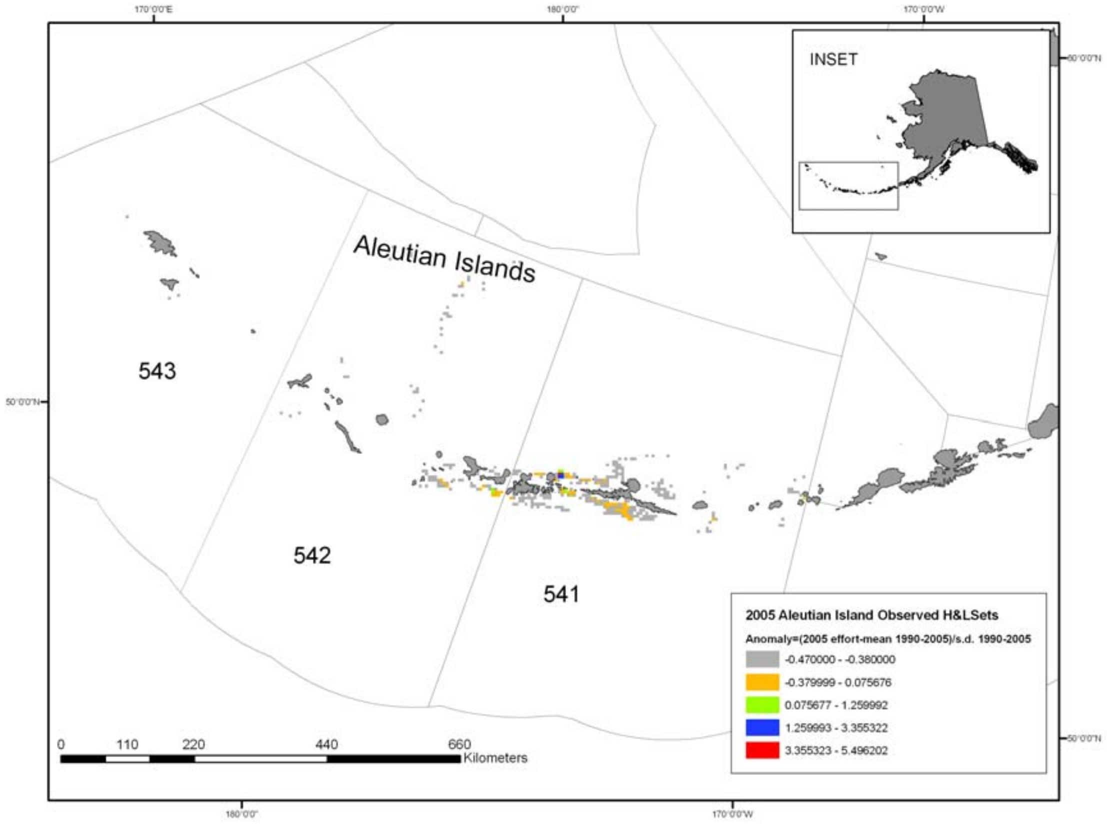

Figure 140. Anomaly plot for Aleutian Islands observed hook and line (longline) effort in 2005, relative to the average effort during 1990-2005 ((estimated effort for 2005 - average effort from 1990-2005)/stdev(effort from 1990-2005)).

Gulf of Alaska

For the period 1990-2005 there were 36,708 observed hook and line sets in the Gulf of Alaska. Patterns of high fishing effort were dispersed along the shelf (Figures 141 and 142). The predominant hook and line fisheries in the Gulf of Alaska are composed of sablefish and Pacific cod. In southeast Alaska, there is a demersal rockfish fishery dominant species include yelloweye rockfish (90%), with lesser catches of quillback rockfish. The demersal shelf rockfish fishery occurs over bedrock and rocky bottoms at depths of 75 m to >200 m. The sablefish longline fishery occurs over mud bottoms at depths of 400 to >1000 m. This fishery is often a mixed halibut/sablefish fishery, with shortraker, rougheye, and thornyhead rockfish also taken. Sablefish has been an IFQ fishery since 1995, which has reduced the number of vessels, crowding, gear conflicts and gear loss, and increased efficiency. The cod longline fishery generally occurs in the western and central Gulf of Alaska, opening on January 1st and lasting until early March. Halibut prohibited species catch sometimes curtails the fishery. The cod fishery occurs over gravel, cobble, mud, sand, and rocky bottom, in depths of 25 fathoms to 140 fathoms.

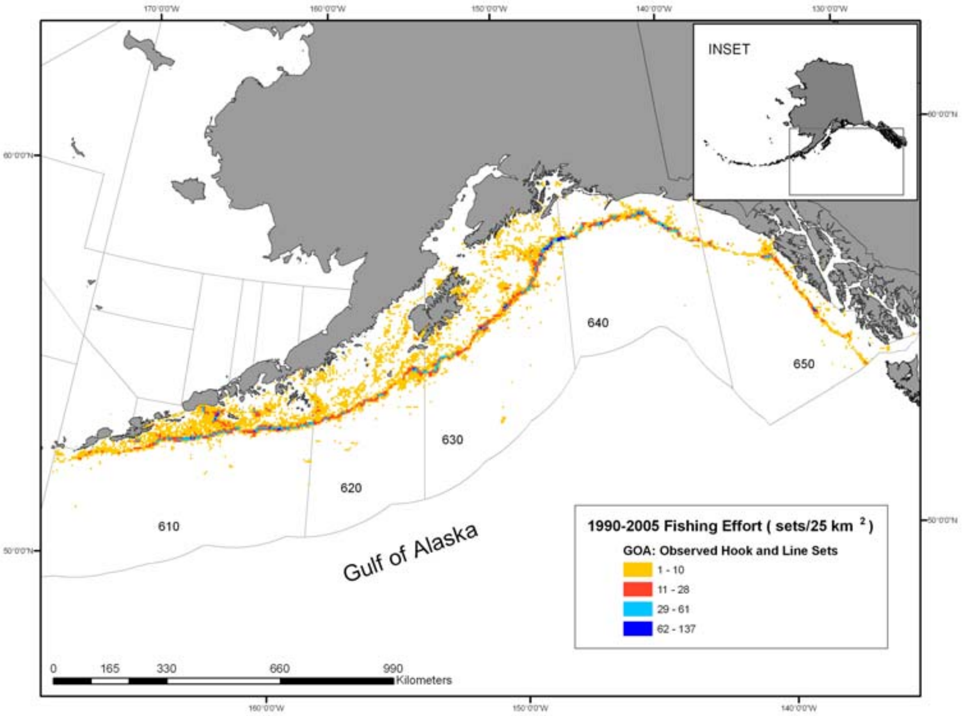

Figure 141. Spatial location and density of hook & line effort in the Gulf of Alaska, 1998-2005.

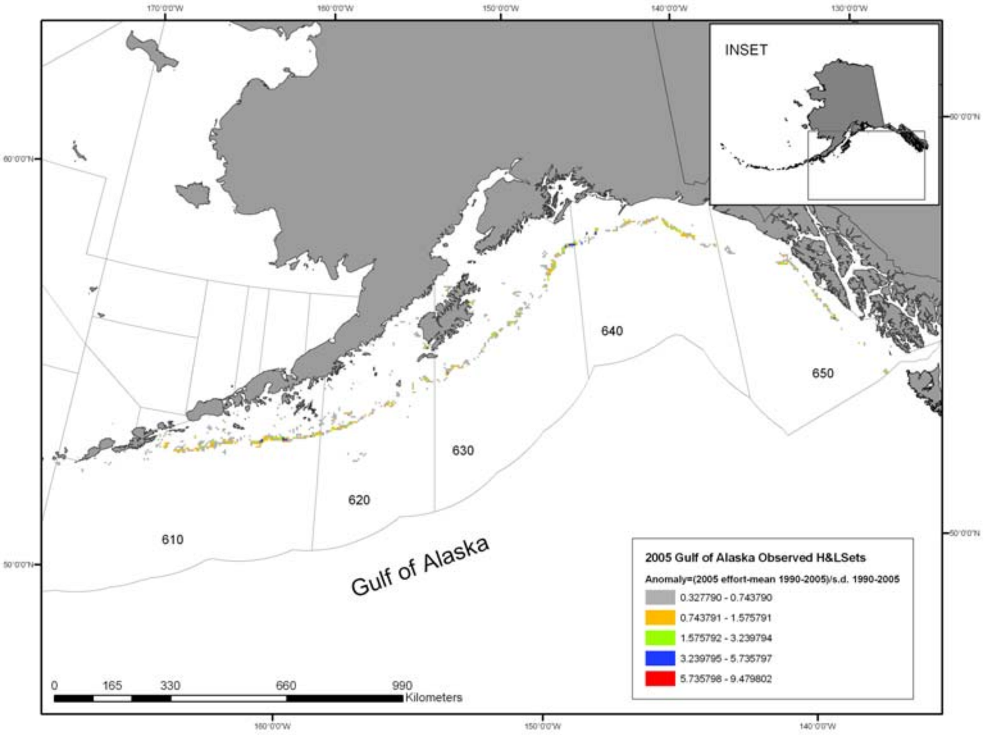

Figure 142. Anomaly plot for the Gulf of Alaska observed hook and line (longline) effort in 2005, relative to the average effort during 1990-2005 ((estimated effort for 2005 - average effort from 1990-2005)/stdev(effort from 1990-2005)).

Groundfish bottom trawl fishing effort in the Gulf of Alaska, Bering Sea and Aleutian Islands

Contributed by Cathy Coon, NPFMC
Contact: Cathy.Coon@noaa.gov
Last updated: August 2006

The amount of effort (as measured by the number of days fished) in bottom trawl fisheries is used as an indicator of the effects of trawling on habitat. In general, bottom trawl effort in the Gulf of Alaska and Aleutian Islands has declined as pollock and Pacific cod TACs have been reduced (Figure 143). Effort in the Bering Sea remained relatively stable from 1991 through 1997, peaked in 1997, then declined (Figure 143). The magnitude of the Bering Sea trawl fisheries is twice as large in terms of effort than both the Aleutian Islands and Gulf of Alaska combined. Fluctuations in fishing effort track well with overall landings of primary bottom trawl target species, such as flatfish and to a lesser extent pollock and cod. As of 1999, only pelagic trawls can be used in the Bering Sea pollock fisheries.

The locations where bottom trawls have been used are of interest for understanding habitat effects. The following figures show the spatial patterns and intensity of bottom trawl effort, based on observed data. Spatial changes in fisheries effort may in part be affected by fishing closure areas (i.e., Steller sea lion protection measures) as well as changes in markets and increased bycatch rates of non-target species. These changes in effort can be observed by examining effort for the current year relative to the average effort in prior years of fishing (effort anomalies).

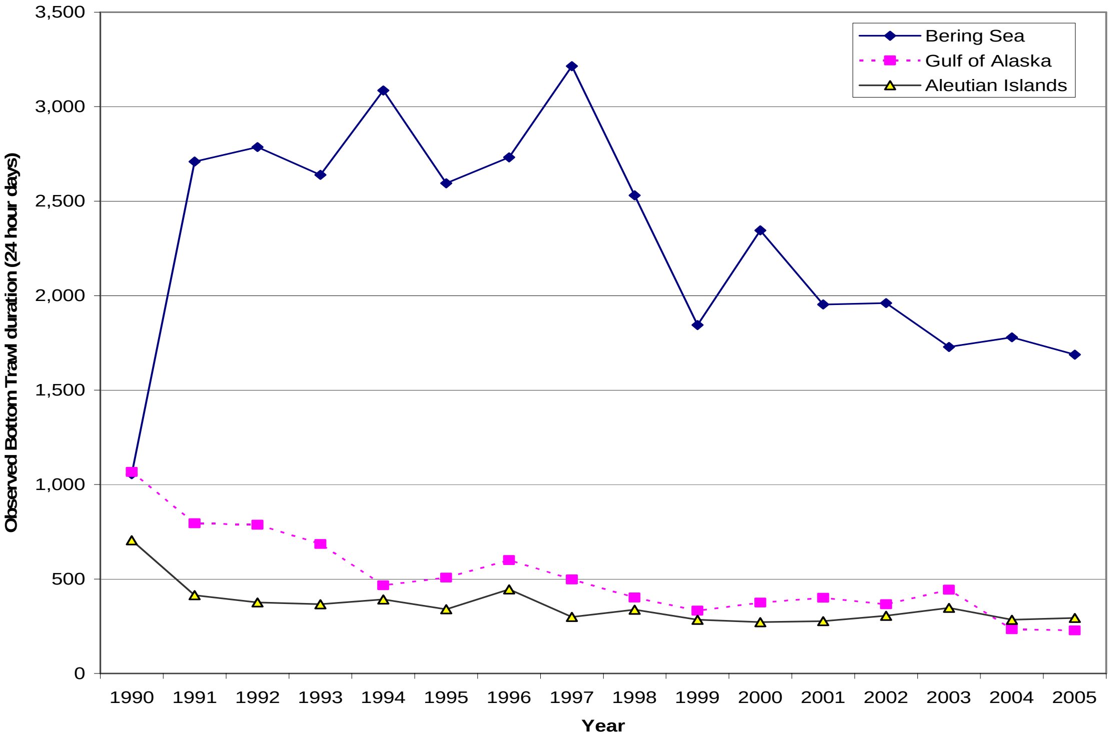

Figure 143. Estimated bottom trawl time in the Gulf of Alaska, Bering Sea, and Aleutian Islands during 1990-2005.

Bering Sea

For the period 1990-2005, there were a total of 282,442 observed bottom trawl sets in the Bering Sea fisheries. During 2003, trawl effort consisted of 111,777 sets which was the low for the 10 year period. Spatial patterns of fishing effort were summarized on a 5km^2 grid (Figure 144). Areas of high fishing effort were north of False Pass (Unimak Island) as well as the shelf edge represented by the boundary of report areas 513 and 517. The primary catch in these areas was Pacific cod and yellowfin sole. In 2005, fishing effort was anomalously high in area 509 (Figure 144) where there were catches of Pacific cod, pollock and rockfish.

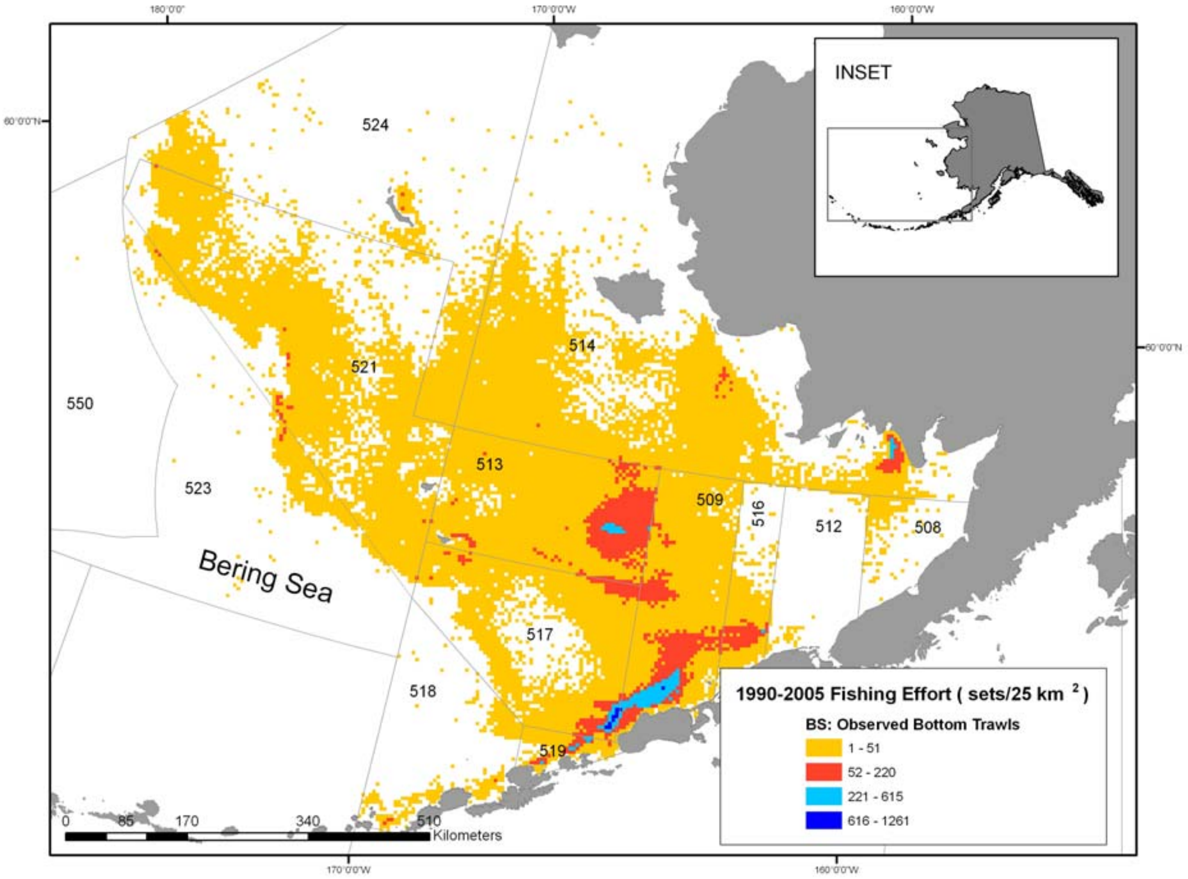

Figure 144. Spatial location and density of bottom trawling in the Bering Sea, 1990-2005.

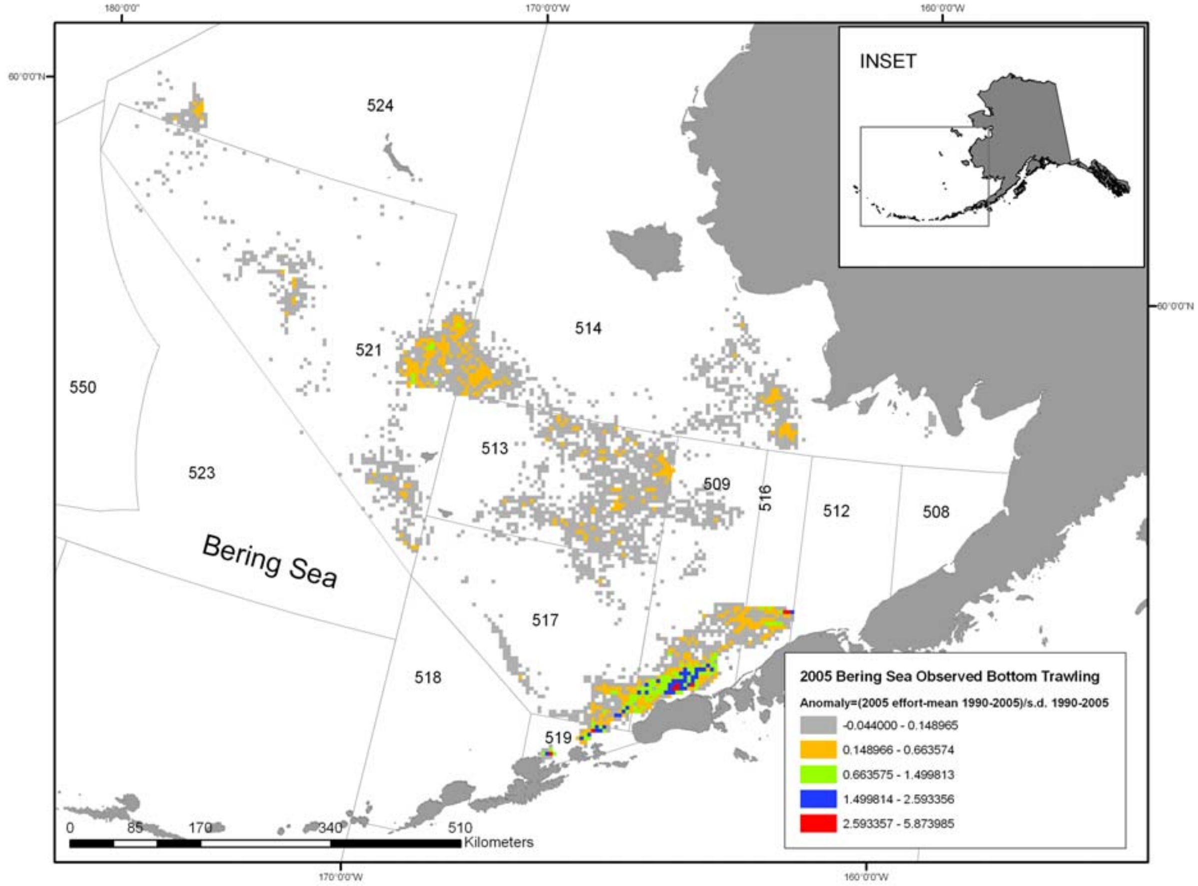

Figure 145. Fishing effort in 2005 shown as an anomaly relative to previous years of fishing effort (1990-2005) for Bering Sea observed bottom trawls ((estimated effort for 2005 minus average effort from 1990-2005)/stdev(effort from 1990-2005)).

Aleutian Islands

For the period 1990-2005 there were 45,653 observed bottom trawl sets in the Aleutian Islands. The spatial pattern of this effort was dispersed over a wide area. During 2005, the amount of trawl effort was 2,188 sets, which was the low for the 15 year period. Patterns of high fishing effort were dispersed along the shelf edge (Figure 146). The primary catches in these areas were pollock, Pacific cod, and Atka mackerel. Catch of Pacific ocean perch by bottom trawls was also high in earlier years. In 2005, fishing effort was anomalously high in some locations in areas 541 and 543 and fisheries in these areas targeted Atka mackerel, Pacific cod and rockfish (Figure 147).

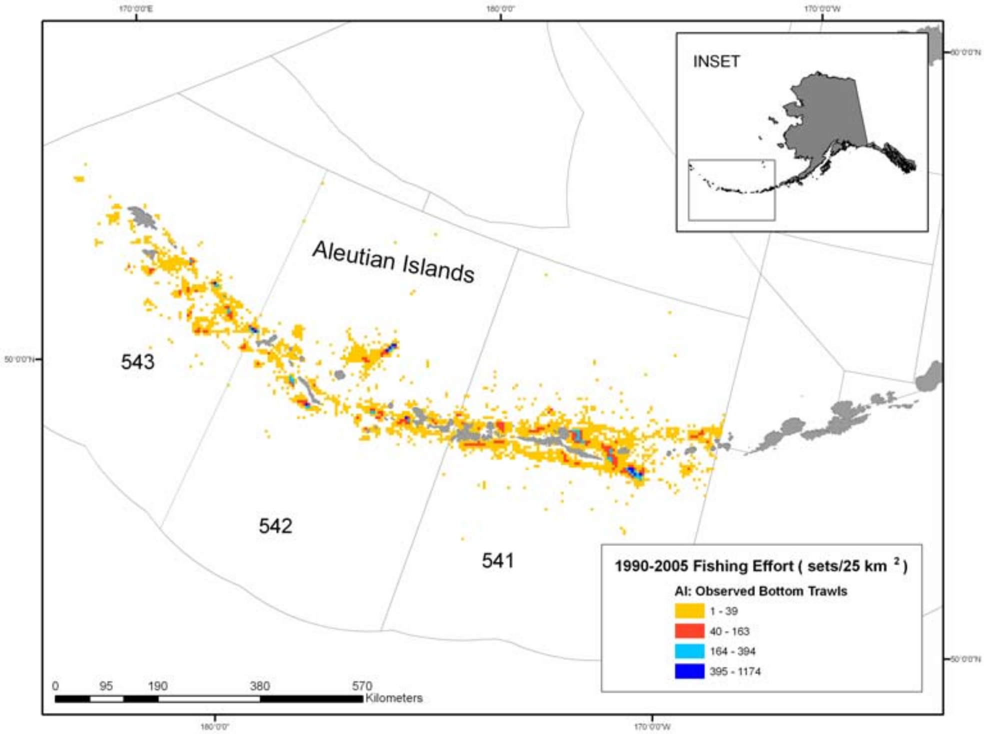

Figure 146. Spatial location and density of bottom trawl effort in the Aleutian Islands, 1990-2005.

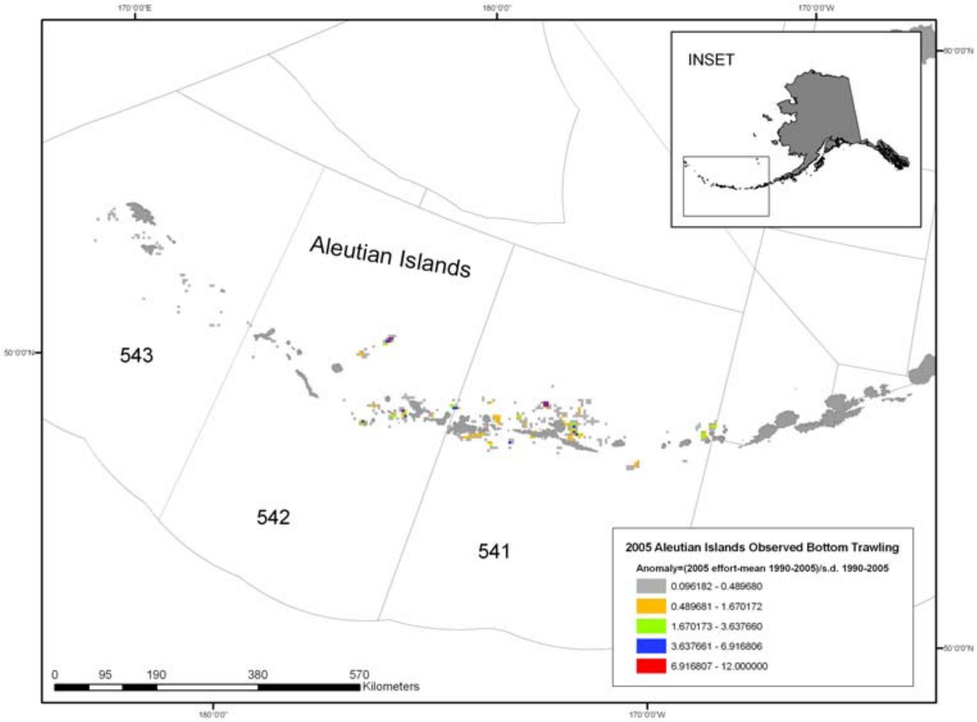

Figure 147. Fishing effort in 2005 shown as an anomaly relative to previous years of fishing effort (1990-2005) for Aleutian Islands observed bottom trawls ((estimated effort for 2005 minus average effort from 1990-2005)/stdev(effort from 1990-2005)).

Gulf of Alaska

For the period 1990-2005 there were 78,842 observed bottom trawl sets in the Gulf of Alaska. The spatial pattern of this effort was much more dispersed than in the Bering Sea region. During 2005, the amount of trawl effort was 2,090 sets, which was the low for the 15 year period. Patterns of high fishing effort were dispersed along the shelf edge with high pockets of effort near Chirkoff, Cape Barnabus, Cape Chiniak and Marmot Flats (Figure 148). Primary catches in these areas were pollock, Pacific cod, flatfish and rockfish. A larger portion of the trawl fleet in Kodiak is comprised of smaller catcher vessels that require 30% observer coverage, indicating that the actual amount of trawl effort would be much higher since a large portion is unobserved.

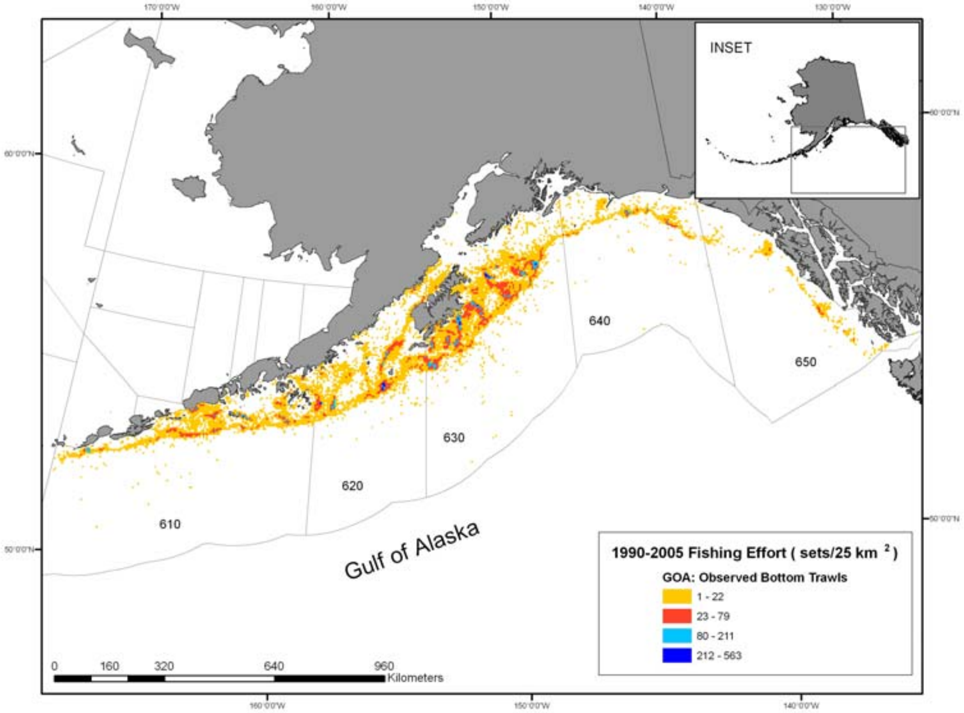

Figure 148. Spatial location and density of bottom trawl effort in the Gulf of Alaska, 1990-2005.

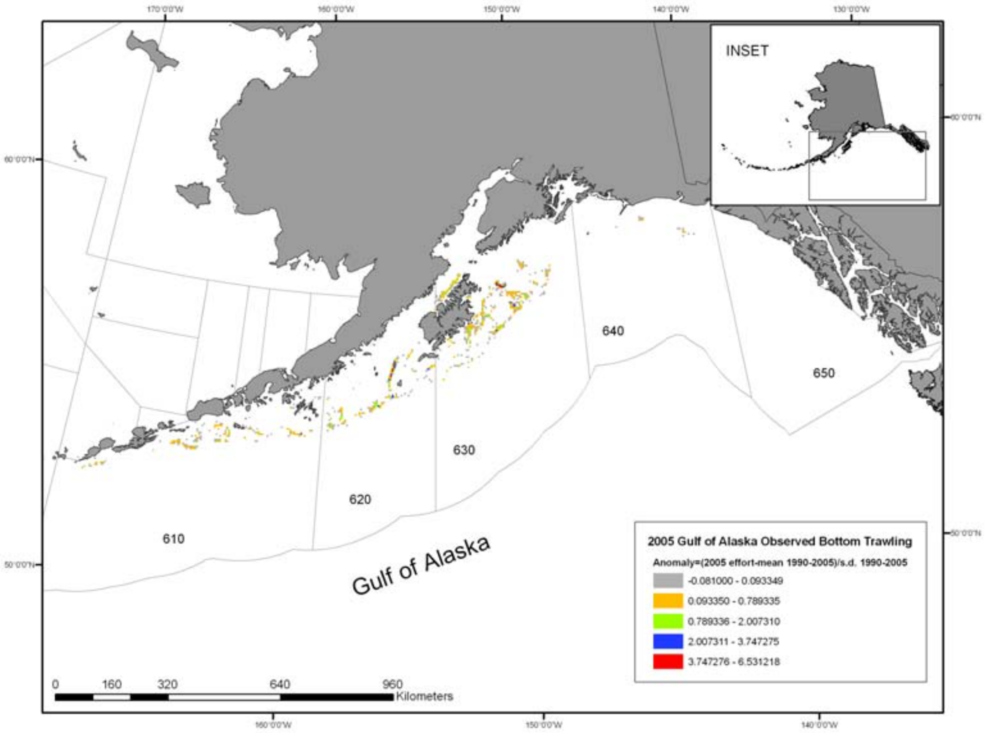

Figure 149. Fishing effort in 2005 shown as an anomaly relative to previous years of fishing effort (1990-2005 for Gulf of Alaska observed bottom trawls ((estimated effort for 2005 minus average effort from 1990-2005)/stdev(effort from 1990-2005)).

Groundfish pelagic trawl fishing effort in the Eastern Bering Sea

Contributed by Cathy Coon, NPFMC
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Last updated: August 2006

Fishing intensity in the pelagic trawl fishery in the eastern Bering Sea can be described in either effort (number of hauls) or duration (amount of time net is in the water). Observed duration for the pelagic trawl fisheries is shown in Figure 150. The spatial pattern of fishing effort was summarized on a $5km^2$ grid (Figure 151). Areas of high fishing effort are north of the Aleutian Islands near Bogoslof Island along the shelf edge represented by the boundary of report areas 509 and 519. The predominant fish harvested within the eastern Bering Sea is walleye pollock (*Theragra chalcogramma*). Pollock occur on the sea bottom but are also found in the water column to the surface. Most catch of pollock is taken at 50-300 m.

In 1990, concerns about bycatch and seafloor habitats affected by this large fishery led the North Pacific Fishery Management Council to apportion 88% of the TAC to the pelagic trawl fishery and 12% to the nonpelagic trawl fishery (NPFMC 1999). For practical purposes, nonpelagic trawl gear is defined as trawl gear that results in the vessel having 20 or more crabs (*Chionecetes bairdi*, *C. opilio*, and *Paralithodes camstschaticus*) larger than 1.5 inches carapace width on board at any time. Crabs were chosen as the standard because they live only on the seabed and they provide proof that the trawl has been in contact with the bottom.

Figure 152 shows the pelagic trawl fishing effort in 2005 relative to the long term average fishing effort in the Bering Sea. Slightly positive anomalies in effort were located in the area north of the Alaska Peninsula. Some changes in fleet movement may be attributed to the AFA fishing cooperative structure and voluntary rolling hotspot closures to reduce the incidental take of chinook salmon and "other salmon" bycatch.

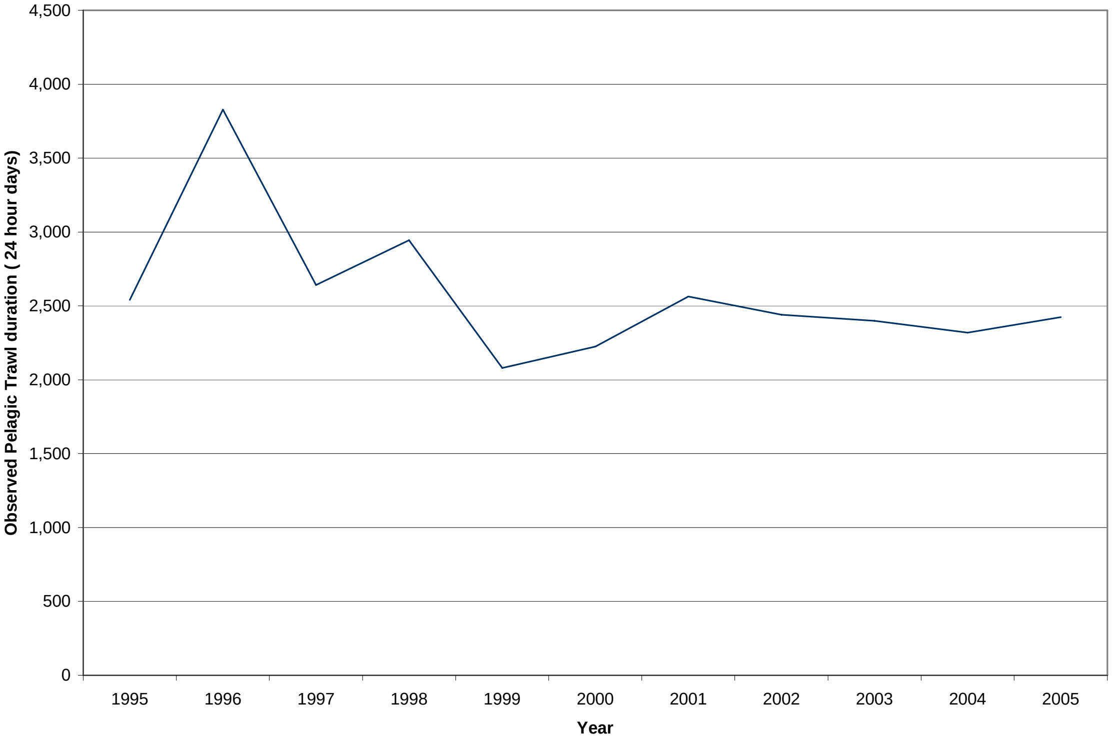

Figure 150. Observed pelagic trawl time in the eastern Bering Sea during 1990-2005.

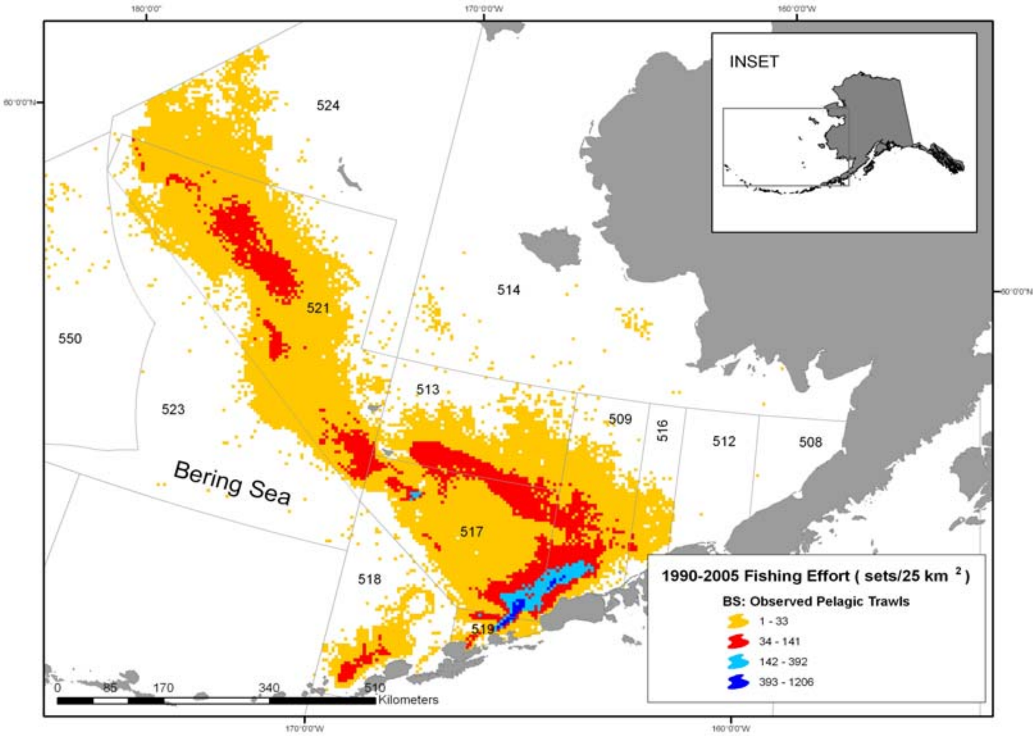

Figure 151. Spatial location and density of pelagic trawl effort in the eastern Bering Sea 1990-2005.

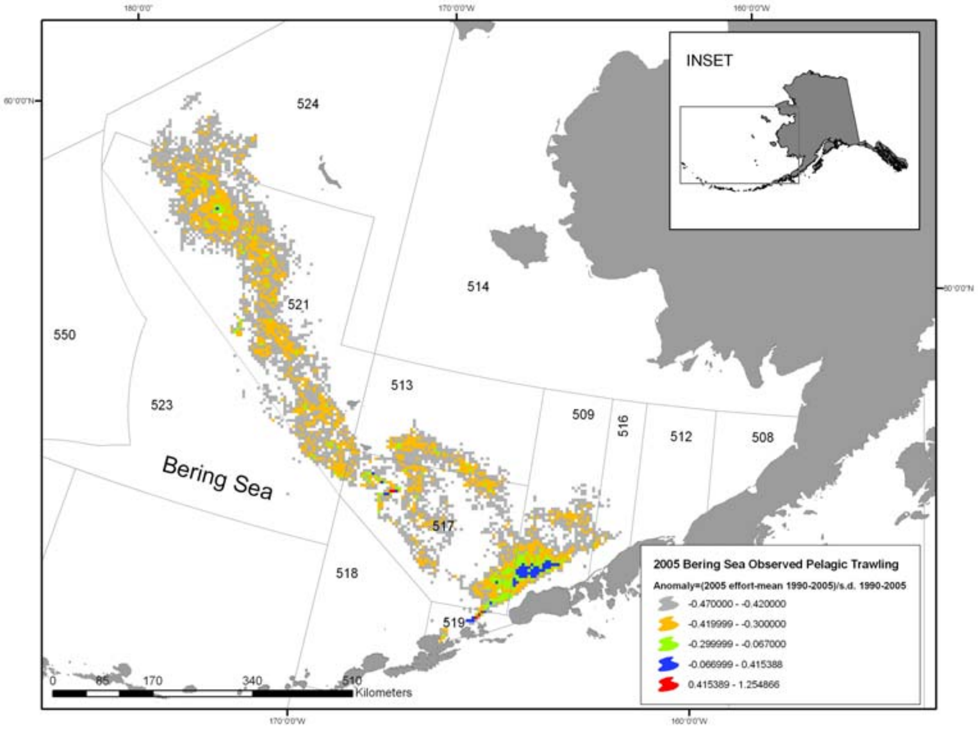

Figure 152. Anomaly plot for Bering Sea observed pelagic trawling effort in 2005 relative to the average effort during 1990-2005 ((estimated effort for 20045 - average effort from 1990-2005)/stdev(effort from 1990-2005)).

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

Trophic level of the catch

Contributed by Pat Livingston, Alaska Fisheries Science Center and Jennifer Boldt, University of Washington
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Last updated: August 2006

To determine whether North Pacific fisheries were "fishing-down" the food web, the total catch, trophic level of the catch, and the Pauly et al. (2000) Fishery In Balance (FIB) Index in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska areas were determined. To estimate the trophic level of the catch, the catch of each species in a given year was multiplied by the trophic level of that species; products were summed across all species in a given year and divided by the total catch in that year. To calculate the FIB index (Pauly et al. 2000):

$\mathrm{FIB}=\log(Y_i \cdot (1/TE)^{TL_i})-\log(Y_0 \cdot (1/TE)^{TL_0})$,

where Y_i is the catch in year i, TL_i the mean trophic level in the catch in year i, TE the transfer efficiency (assumed to be 0.1), and 0 refers to a year used as a baseline (first year in the time series).

Total catch levels and composition for the three regions show the dominance of walleye pollock in the catch from around the 1970s to at least the early 1990s (Figure 153). Other dominant species groups in the catch were rockfish prior to the 1970s in the Aleutian Islands and the Gulf of Alaska, and Atka mackerel in the 1990s in the Aleutian Islands. All these species are primarily zooplankton consumers and thus show alternation of similar trophic level species in the catch rather than a removal of a top-level predator and subsequent targetting of a lower trophic level prey.

Stability in the trophic level of the total fish and invertebrate catches in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska (Figure 154) are another indication that the "fishing-down" effect is not occurring in these regions. Although there has been a general increase in the amount of catch since the late 1960s in all areas, the trophic level of the catch has been high and stable over the last 25 years.

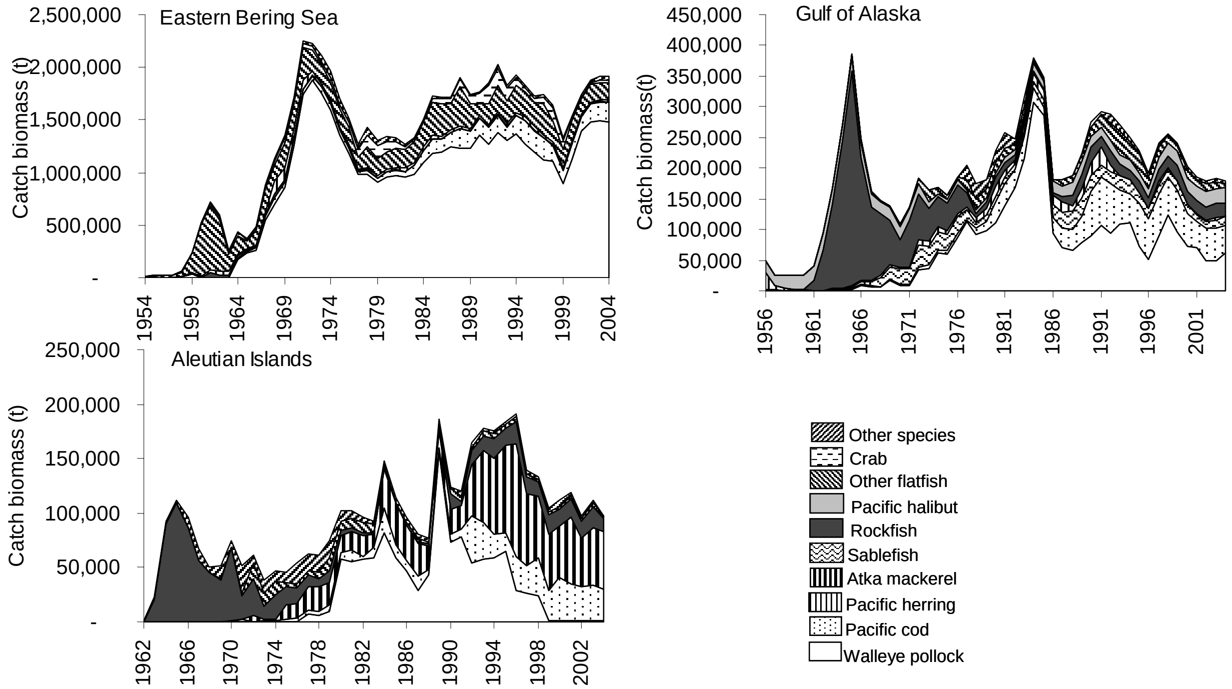

Figure 153. Total catch biomass (except salmon) in the EBS, GOA, and AI through 2004.

The Fishery in Balance Index (FIB) of Pauly et al. (2000) was developed to ascertain whether trophic level catch trends are a reflection of deliberate choice or of a fishing down the food web effect. This index declines only when catches do not increase as expected when moving down the food web, relative to an initial baseline year. The FIB index for each Alaskan region was calculated (Figure 154) to allow an assessment of the ecological balance of the fisheries. Unlike other regions in which this index has been calculated, such as the Northwest Atlantic, catches and trophic level of the catch in the EBS, AI, and GOA have been relatively constant and suggest an ecological balance in the catch patterns.

The single metrics of TL or FIB indices, however, may hide details about fishing events. We, therefore, plotted the trophic level of catches in the BS, AI, and GOA in a similar style to that recently published by Essington et al. (2006; see Ecosystem Assessment, this report). This further examination supports the idea that fishing-down the food web is not occurring in Alaska, and there does not appear to be a serial addition of lower-trophic-level fisheries in the BS or GOA. In general, it appears that fishing events are episodic in the AI and GOA, and pollock dominate catches in the BS.

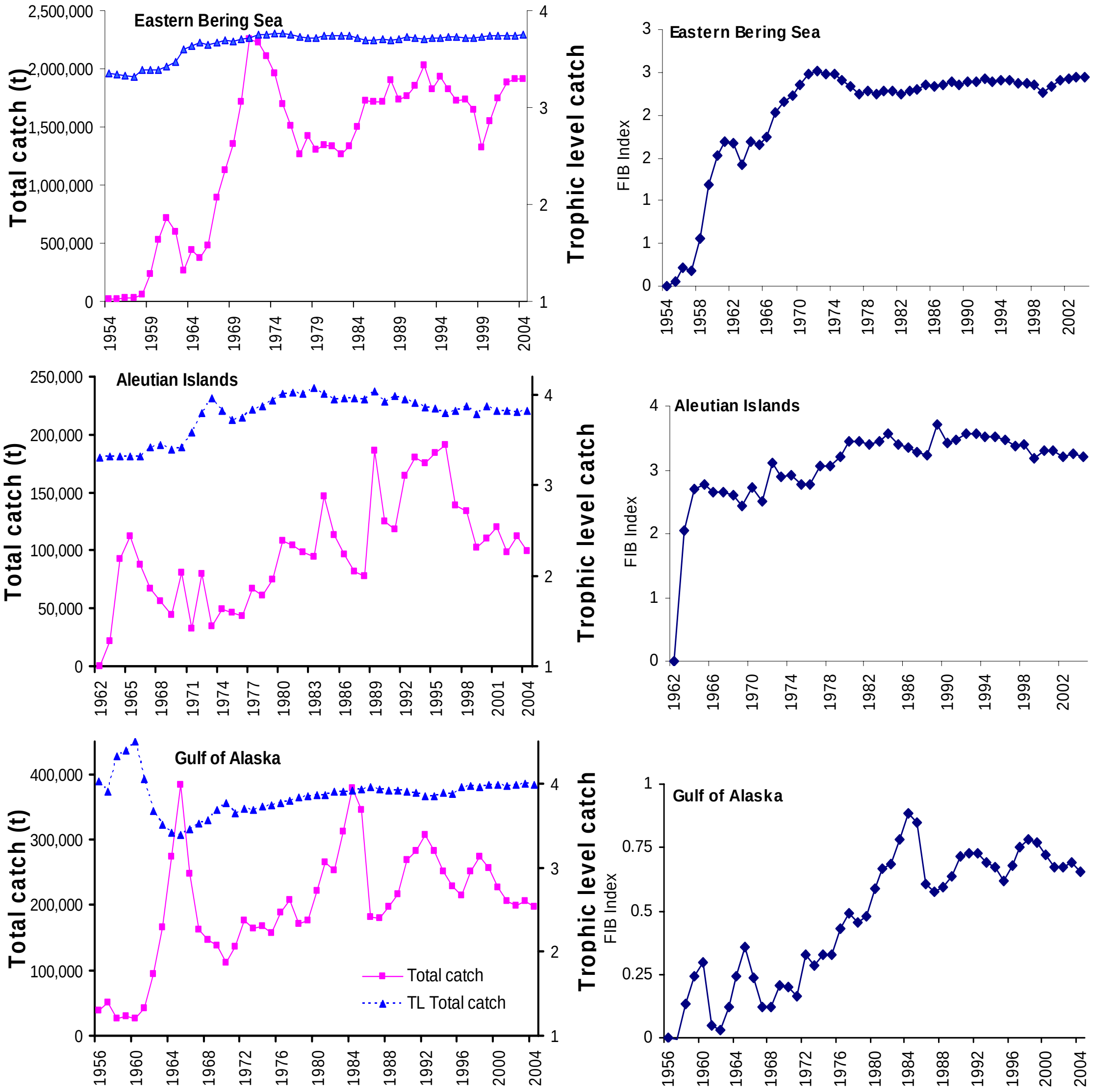

Figure 154. Total catch (groundfish, herring shellfish, and halibut) and trophic level of total catch in the EBS/AI and GOA through 2004 (left column). Right column shows FIB index values for the EBS, AI and GOA through 2004.

Fish Stock Sustainability Index and status of groundfish, crab, salmon and scallop stocks

Updated by Jennifer Boldt, University of Washington
Contact: Jennifer.Boldt@noaa.gov

Last Updated: August 2006

Description of index: The Fish Stock Sustainability Index (FSSI) is a performance measure for the sustainability of fish stocks selected for their importance to commercial and recreational fisheries (http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm). The FSSI will increase as overfishing is ended and stocks rebuild to the level that provides maximum sustainable yield. The FSSI is calculated by assigning a score for each fish stock based on the following rules:

1. Stock has known status determinations:
    a) overfishing 0.5
    b) overfished 0.5
2. Fishing mortality rate is below the "overfishing" level defined for the stock 1.0
3. Biomass is above the "overfished" level defined for the stock 1.0
4. Biomass is at or above 80% of maximum sustainable yield (MSY) 1.0
(this point is in addition to the point awarded for being above the "overfished" level)

The maximum score for each stock is 4. The value of the FSSI is the sum of the individual stock scores. Since there are 230 stocks in the U.S, an overall FSSI score of 920 would be achieved if every stock scored a 4. In the Alaska Region, there are 35 FSSI stocks and an overall FSSI of 140 would be achieved if every stock scored the maximum value, 4.

Many species in Alaska are monitored as part of a group or complex, but are considered individually for the purposes of the report. The overfishing determination for the individual species is listed as "unknown", but the species' complex is determined to be "not subject to overfishing" based on the abundance estimates for the entire complex. This determination is applicable for some sharks, skates, sculpins, octopus, and squid complexes in the GOA Groundfish FMP. In the BSAI Groundfish FMP, similar determinations are made for some stocks in the sharks, skates, sculpins, octopus, rockfish, and flatfish complexes.

Status and trends:
No BSAI or GOA groundfish stock or stock complex is overfished and no BSAI or GOA groundfish stock or stock complex is being subjected to overfishing. Halibut is a major stock (not included in Table 34, since it is jointly managed with the West Coast) that is not considered subject to overfishing. Two stocks are considered overfished: Pribilof Island blue king crab and St. Matthew Island blue king crab (Table 34). Four stocks of crabs are under continuing rebuilding plans: BS snow crab, EBS tanner crab, Pribilof Island blue king crab, and St. Matthew Island blue king crab. Table 34 summarizes the status of Alaskan groundfish, crab, salmon and scallop stocks or stock complexes managed under federal fishery plans in 2006 from the Annual Report on Status of Stocks available on the web at: http://www.nmfs.noaa.gov/sfa/reports.htm

The current value of the FSSI for the U.S. is 500.5 of a possible 920, based on updates through August 18, 2006. The current overall Alaska FSSI is 112 of a possible 140, based on updates through August 18, 2006 (Table 35). The overall Bering Sea score is 65 of a possible maximum score of 88. The BSAI groundfish score is 47 of a maximum possible 52 and BSAI king and tanner crabs score 18 of a possible score of 36. The Gulf of Alaska groundfish score is 43 of a maximum possible 48. The sablefish, which are managed as a BSAI/GOA complex, score is 4.

Since January 2006, changes in overfished status and/or score of FSSI stocks as of August 18, 2006 in the Alaska Region include:

1. Snow Crab – Bering Sea is no longer overfished, but is still rebuilding (biomass is below 100% of maximum sustainable yield) – score increased from 2 to 3.

2. Tanner Crab – Eastern Bering Sea is no longer overfished, but is still rebuilding (biomass is below 100% of maximum sustainable yield) – score increased from 2 to 3.

Factors causing trends: The groundfish stocks that had low scores in the BSAI include AI pollock (1.5) and rougheye rockfish (1.5). The reasons for these low scores are: it is undefined whether these species are overfished and unknown if they are approaching an overfished condition.

The stocks that scored low in the GOA are shortspine thornyhead rockfish (indicator species for thornyhead rockfish complex) and yelloweye rockfish (indicator species for demersal shelf rockfish complex), which both scored 1.5. The reasons for these low scores are: it is undefined whether these species are overfished and unknown if they are approaching an overfished condition.

Table 34. Description of major and minor stocks managed under federal fishery management plans off Alaska, 2006. (Major stocks have landings of 200 thousand pounds or greater.)

		Overfishing?					Overfished?					
Stock Group	Number of Stocks and Stock Complexes	Yes	No	Not Known	Not Defined	NA	Yes	No	Not Known	Not Defined	NA	Approaching Overfished Condition
FSSI	35	0	32	3	0	0	2	26	0	7	0	0
Non-FSSI	34	0	25	8	1	0	0	6	0	28	0	0
Total	69	0	57	11	1	0	2	32	0	35	0	0

Table 35. This table was adapted from the Status of U.S. Fisheries website, which is updated quarterly: http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm The information presented in this table was updated as of August 18, 2006.

Fishery Management Plan	Stock	Overfishing? (Is Fishing Mortality above Threshold?) Post SFA	Overfished? (Is Biomass below Threshold?) Post SFA	Approaching Overfished Condition?	Management Action Required	Rebuilding Program Progress	FSSI
GOA Groundfish	Walleye Pollock - Western/Central	No	No	No	N/A	N/A	4
GOA Groundfish	Pacific Cod	No	No	No	N/A	N/A	4
GOA Groundfish	Arrowtooth Flounder	No	No	No	N/A	N/A	4
GOA Groundfish	Pacific Ocean Perch [46]	No	No	No	N/A	N/A	4
GOA Groundfish	Northern Rockfish - Western / Central	No	No	No	N/A	N/A	4
GOA Groundfish	Flathead Sole	No	No	No	N/A	N/A	4
GOA Groundfish	Dusky Rockfish[47]	No	No	No	N/A	N/A	4
GOA Groundfish	Dover Sole[48]	No	No	No	N/A	N/A	4
GOA Groundfish	Rex Sole	No	No	No	N/A	N/A	4
GOA Groundfish	Shortspine Thornyhead [49]	No	Undefined	Unknown	N/A	N/A	1.5
GOA Groundfish	Yelloweye Rockfish [50]	No	Undefined	Unknown	N/A	N/A	1.5
GOA Groundfish	Rougheye Rockfish[51]	No	No	No	N/A	N/A	4
BSAI Groundfish	Walleye Pollock - EBS	No	No	No	N/A	N/A	4
BSAI Groundfish	Walleye Pollock - AI	No	Undefined	Unknown	N/A	N/A	1.5
BSAI Groundfish	Pacific Cod	No	No	No	N/A	N/A	4
BSAI Groundfish	Yellowfin Sole	No	No	No	N/A	N/A	4
BSAI Groundfish	Greenland Turbot	No	No	No	N/A	N/A	4
BSAI Groundfish	Arrowtooth Flounder[52]	No	No	No	N/A	N/A	4
BSAI Groundfish	Rock Sole[53]	No	No	No	N/A	N/A	4
BSAI Groundfish	Flathead Sole[54]	No	No	No	N/A	N/A	4
BSAI Groundfish	Pacific Ocean Perch	No	No	No	N/A	N/A	4
BSAI Groundfish	Atka Mackerel	No	No	No	N/A	N/A	4
BSAI Groundfish	Alaska Plaice	No	No	No	N/A	N/A	4
BSAI Groundfish	Northern Rockfish	No	No	No	N/A	N/A	4
BSAI Groundfish	Rougheye Rockfish	No	Undefined	Unknown	N/A	N/A	1.5
BSAI/GOAGroundfish	Sablefish[55]	No	No	No	N/A	N/A	4
BSAI Crabs	Blue King Crab - Pribilof Is.	No[56]	Yes	N/A	continue rebuilding	3/10-year plan	2

BSAI Crabs	Blue King Crab - Saint Matthews Is.	No[56]	Yes	N/A	continue rebuilding	6/10-year plan	2
BSAI Crabs	Golden King Crab -AI	Unknown	Undefined	Unknown	N/A	N/A	0
BSAI Crabs	Red King Crab - AI, Adak	Unknown	Undefined	Unknown	N/A	N/A	0
BSAI Crabs	Red King Crab - Bristol Bay	No	No	No	N/A	N/A	4
BSAI Crabs	Red King Crab - Norton Sound	Unknown	Undefined	Unknown	N/A	N/A	0
BSAI Crabs	Red King Crab - Pribilof Is.	No[56]	No	Unknown[3]	N/A	N/A	4
BSAI Crabs	Snow Crab - BS	No	No - rebuilding	No	continue rebuilding	6/10-year plan	3
BSAI Crabs	Tanner Crab - EBS	No[56]	No - rebuilding	N/A	continue rebuilding	7/10-year plan	3

[3] This stock was assessed using pre-SFA criteria, but its status should be regarded as unknown. The stock assessment used static spawning potential ratio (SPR) to determine the overfished status, but static SPR is not an appropriate measure to determine overfished status; it is useful for measuring the overfishing status. Measures are being developed to list the correct status by the end of 2006.

[46] Although Pacific ocean perch is managed separately in the Western, Central, and Eastern areas, with separate overfishing levels, ABCs, and TACs based on the proportion of biomass in each respective area, separate assessments are not conducted for each of these three regions; the assessment is based on aggregated data from throughout the Gulf of Alaska. Therefore, it is not appropriate to list separate status determinations for these three areas.

[47] The Pelagic Shelf Rockfish Complex consists of the following stocks: Dark Rockfish, Dusky Rockfish, Widow Rockfish, and Yellowtail Rockfish. The overfished determination is based on Dusky Rockfish as an indicator species; the overfishing determination is based on the OFL, which is computed by using the dusky rockfish assessment combined with abundance estimates for the remainder of the complex.

[48] The Deep Water Flatfish Complex consists of the following stocks: Deepsea Sole, Dover Sole, and Greenland Turbot. The overfished determination is based on Dover Sole as an indicator species; the overfishing determination is based on the OFL, which is computed by using the dover sole assessment combined with abundance estimates for the remainder of the complex.

[49] The Thornyhead Rockfish Complex consists of the following stocks: Longspine Thornyhead and Shortspine Thornyhead. The overfishing determination is based on the OFL, which is computed using abundance estimates of Shortspine Thornyhead.

[50] The Demersal Shelf Rockfish Complex consists of the following stocks: Canary Rockfish, China Rockfish, Copper Rockfish, Quillback Rockfish, Rosethorn Rockfish, Tiger Rockfish, and Yelloweye Rockfish. The overfishing determination is based on the OFL, which is computed by using estimates of Yelloweye Rockfish

[51] Rougheye Rockfish was previously part of the Shortraker / Rougheye Rockfish Complex, which consisted of the following stocks: Rougheye Rockfish and Shortraker Rockfish. It is now assessed as a single stock and is no longer part of this complex.

[52] Arrowtooth Flounder consists of Arrowtooth Flounder and Kamchatka Flounder. Arrowtooth Flounder accounts for the overwhelming majority of the biomass and is regarded as the indicator species for the complex. The overfished determination is based on the combined abundance estimates for the two species; the overfishing determination is based on the OFL, which is computed from the combined abundance estimates for the two species.

[53] Rock Sole consists of Northern Rock Sole and Southern Rock Sole (NOTE: These are two distinct species, not two separate stocks of the same species). Northern Rock Sole accounts for the overwhelming majority of the biomass and is regarded as the indicator species for the complex. The overfished determination is based on the combined abundance estimates for the two species; the overfishing determination is based on the OFL, which is computed from the combined abundance estimates for the two species.

[54] Flathead Sole consists of Flathead Sole and Bering Flounder. Flathead Sole accounts for the overwhelming majority of the biomass and is regarded as the indicator species for the complex. The overfished determination is based on the combined abundance estimates for the two species; the overfishing determination is based on the OFL, which is computed from the combined abundance estimates for the two species.

[55] Although sablefish is managed separately in the Gulf of Alaska, Bering Sea, and Aleutian Islands, with separate overfishing levels, ABCs, and TACs based on the proportion of biomass in each respective region, separate assessments are not conducted for each of these three regions; the assessment is based on aggregated data from the Gulf of Alaska, Bering Sea, and Aleutian Islands regions. Therefore, it is not appropriate to list separate status determinations for these three regions.

[56] Fishery in the EEZ is closed; therefore, fishing mortality is very low.

Total annual surplus production and overall exploitation rate of groundfish

Contributed by Franz Mueter, Sigma Plus Statistical Consulting, Fairbanks, Alaska
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Last updated: August 2006

Description of indices: Total annual surplus production (ASP) of groundfish on the Eastern Bering Sea (EBS) and Gulf of Alaska (GOA) shelfs was estimated by summing annual production across all commercial groundfish stocks for which assessments were available. These species represent at least 70-80% of the total catch retained in bottom trawl surveys. Assuming that all biomass estimates correspond to beginning of year estimates (prior to when the fishery occurs), annual surplus production in year t can be estimated as the change in total adult groundfish biomass across species from year t (B_t) to year t+1 (B_{t+1}) plus total catches in year t (C_t, All estimates of B and C are based on 2005 stock assessments):

$$ASP_t = \Delta B_t + C_t = B_{t+1} - B_t + C_t$$

An index of total exploitation rate within each region was estimated by dividing the total groundfish catch across the major commercial species by the combined biomass at the beginning of the year:
$u_t = C_t / B_t$

For details, see Mueter and Megrey (in press).

Status and trends: The resulting indices suggest high variability in groundfish production in the EBS (Figure 155) and a non-significant decrease in production between 1977 and 2004 (slope = - 52,300 mt / year, t = -1.18, p = 0.248). Production in the GOA was much lower on average, less variable, and decreased slightly over the same time period (slope = - 9,800 mt/ year, t = -1.30, p = 0.204).

Total exploitation rates were generally much higher in the EBS than in the GOA and were highest in the early part of the time series due to high exploitation rates of walleye pollock (Figure 156). Total exploitation has remained relatively constant in both systems from the mid-1980s to the present. Exploitation rates in the EBS reached a low in 1999 and have increased since, while they are near their long-term minimum in the GOA.

Because trends in annual surplus production in the Eastern Bering Sea are almost entirely driven by variability in walleye pollock in the EBS, I computed ASP_t without this stock included (Figure 157). The results suggest a strong, significant decrease in aggregate surplus production of all non-pollock species from 1977 – 2004 in the Bering Sea (slope = -28,000 mt / year, t = -5.49, p < 0.0001). These trends reflect decreases across many species and are not driven by the next dominant species alone. In the Bering Sea, surplus production of all species except Atka mackerel and northern rockfish has decreased from 1977-2004.

Factors causing trends: Annual Surplus Production is an estimate of the sum of new growth and recruitment minus deaths from natural mortality (i.e. mortality from all non-fishery sources) during a given year. It was highest during periods of increasing total biomass (e.g. 1977-1985 in the EBS) and lowest during periods of decreasing biomass (e.g. 1992-2000 in the GOA). In the absence of a long-term trend in total biomass, ASP is equal to the long-term average catch. Theory suggests that surplus production will decrease as biomass increases above B_{MSY}, which has been the case for a number of flatfish species (arrowtooth flounder, rock sole, flathead sole) and rockfish species (Pacific ocean perch, northern rockfish). Therefore the declines in production may be a density-dependent response to observed increases in biomass.

Exploitation rates are primarily determined by management and reflect a relatively precautionary management regime with rates that have averaged less than 10% across species over the last decade. Exploitation rates are much lower in the GOA because of the very limited exploitation of arrowtooth flounder, which currently make up the majority of the biomass in the GOA. If arrowtooth flounder is excluded, rates are comparable to those in the EBS.

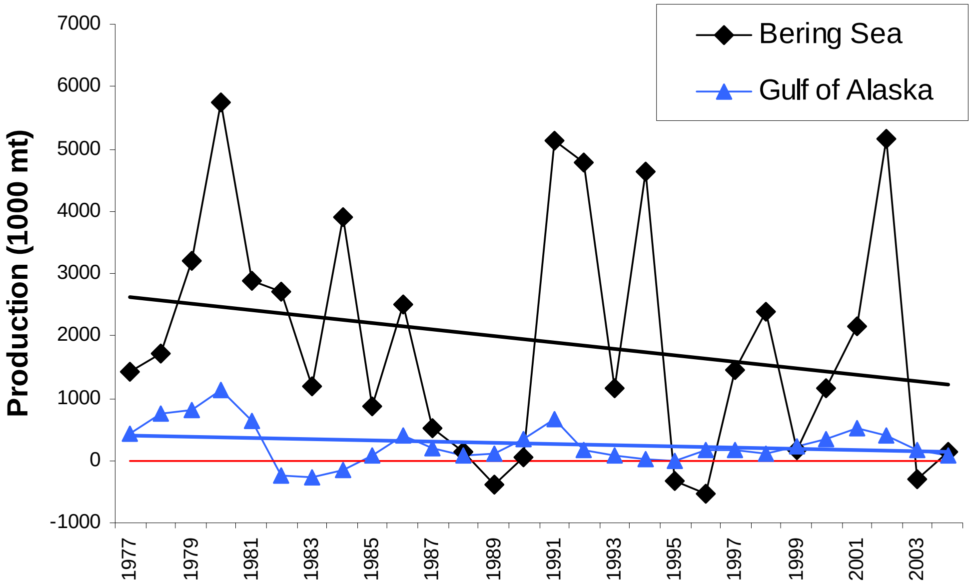

Figure 155. Total annual surplus production (change in biomass plus catch) across all major groundfish species in the Gulf of Alaska and Bering Sea with estimated linear trends (solid lines) and long-term means (red).

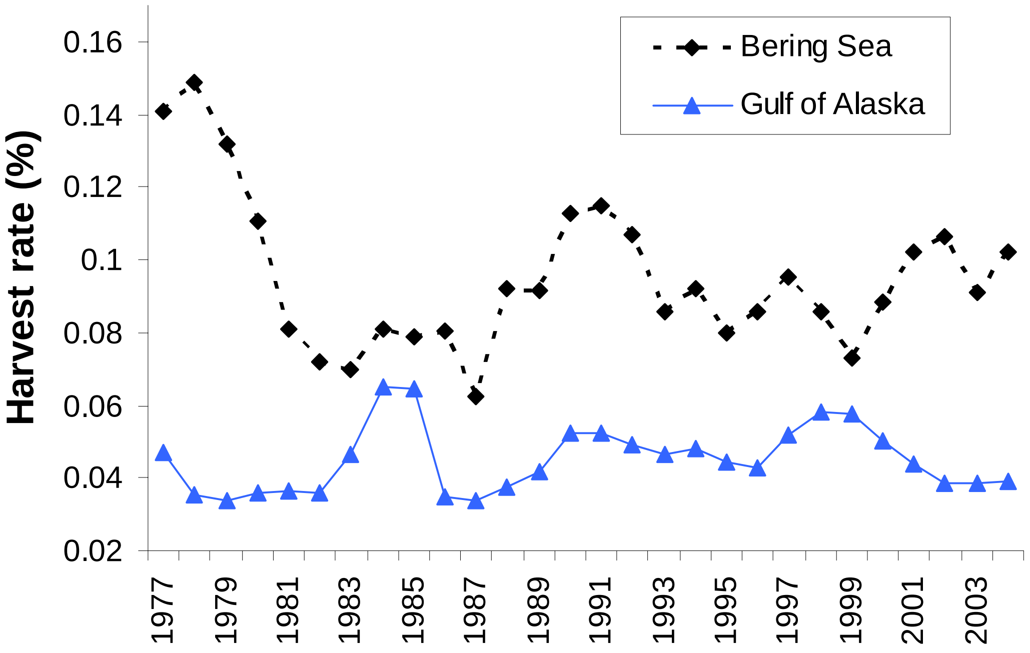

Figure 156. Total exploitation rate (total catch / total biomass) across all major groundfish species in the Gulf of Alaska and Bering Sea.

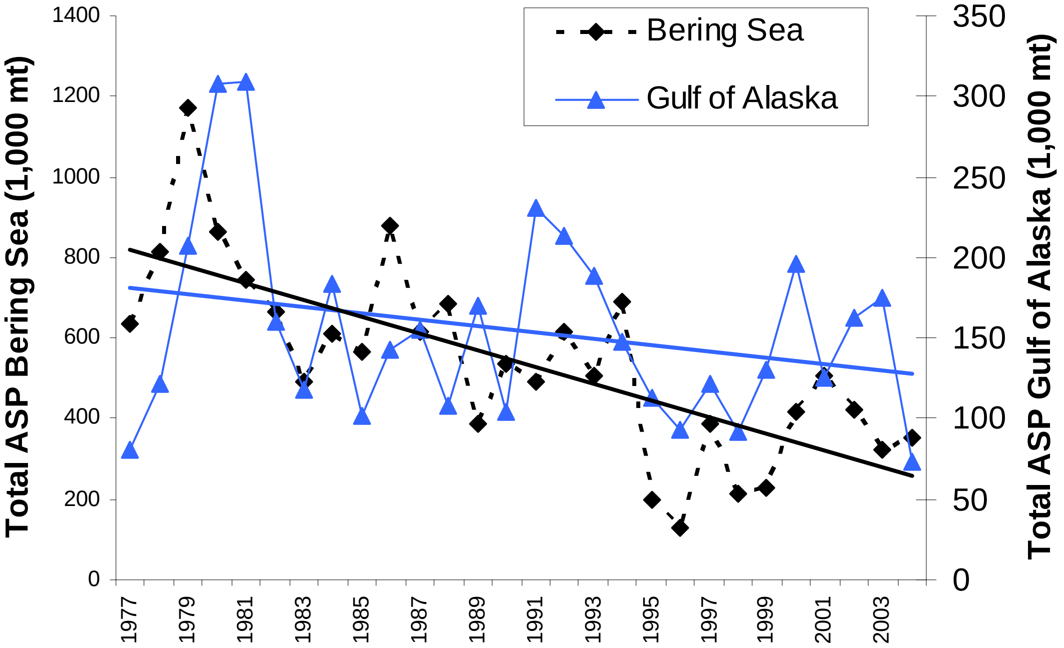

Figure 157. Total annual surplus production (change in biomass plus catch) across all major groundfish species excluding walleye pollock in the Bering Sea and excluding both walleye pollock and arrowthooth flounder in the Gulf of Alaska, with estimated linear trends (solid lines).

Ecosystem indicators for the bottom trawl fish community of the eastern Bering Sea
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Ecosystem-based fisheries management requires analyses beyond assessments of species that are targets of fisheries. The ICES working group on "Ecosystem Effects of Fishing Activities" has provided some ideas for developing additional ecosystem management indicators that measure more system-wide properties that might change due to fishing. Two indicators that have been found to be relatively explanatory of fishing induced changes at a more system-wide level are community size spectrum (CSS) and k-dominance curves. These indicators have been derived for several systems (Greenstreet and Hall 1996, Rice & Gislason 1996, Duplisea et al. 1997, Greenstreet et al. 1999, Bianchi et al. 2000, Zwanenburg 2000) using time series of survey information. Size spectrum involves the relationship between numbers by size interval across the sampled size range of the whole community. Some factors, such as fishing, may change the abundance of organisms of different size classes, particularly the amount of larger animals, affecting the slope of the descending limb of the size spectrum. For example, in an exploited fish assemblage, larger fish generally suffer higher fishing mortality than smaller individuals and this may be one factor causing the size distribution to become skewed toward the smaller end of the spectrum (Zwanenburg 2000), and leading to a decrease in the slope of the size relationship over time with increasing fishing pressure. Similarly, k-dominance curves, which measure the combined dominance of the k most dominant species (Lambshead et al. 1983), of disturbed communities will differ from those in unperturbed communities (Rice 2000, Bianchi et al. 2000). These indicators were derived for the eastern Bering Sea to ascertain the degree of influence fishing may have had on the characteristics of the size spectrum and k-dominance patterns and how those compare with other exploited marine systems. The k-dominance curves will be presented in the October 2004 draft.

The bottom trawl fish community appears to have fewer small individuals and more large individuals through time (Figure 158a). The slope and intercept of the CSS decreased from 1982-1987, primarily due to non-target fish. Since 2002 the both slope and intercept values have been relatively stable (Figure 158b and c). Factors other than fishing, such as the regime shift in 1988/89, may have had an influence on the community size spectrum.

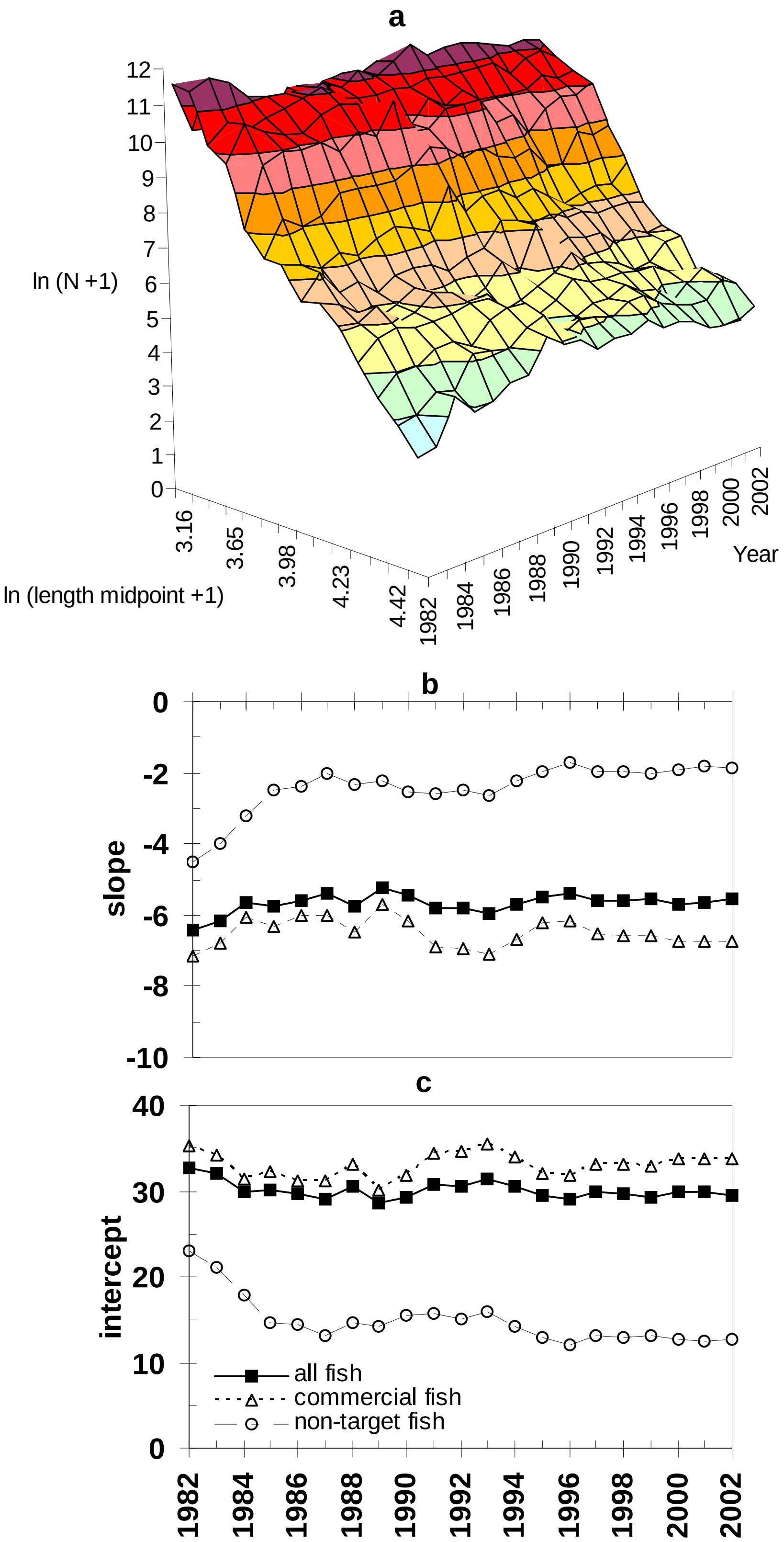

Figure 158. Eastern Bering Sea demersal fish (20-90 cm) community size spectrum (CSS), 1982-2002 (a); changes in slope (b) and intercept (c) of the CSS 1982 to 2002.

Ecosystem Goal: Humans are part of ecosystems

Fishing overcapacity programs

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Overview

Overcapacity, wherein there is an excessive level of investment or effort relative to the available fisheries resources, is considered a problem in fisheries throughout the world. The problem is often manifested in short fishing seasons, increased enforcement and safety 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 (Council) has developed several programs to address overcapacity in the Alaskan fisheries. Moratorium programs were implemented in the crab and groundfish fisheries to limit the number of harvesting vessels that may be deployed off Alaska, and access has since been limited further by replacing the moratoria with license limitation programs (LLP). However, rights-based management is increasingly being used to “rationalize” fisheries.

An Individual Fishing Quota (IFQ) program has been used to manage the halibut and fixed gear sablefish fisheries since 1995. Rather than explicitly limiting the number of harvesting vessels, this program grants quota holders the privilege of harvesting a specified percentage of the Total Allowable Catch (TAC) each year. A similar program developed by the Council, beginning in 2005, placed management of most crab fisheries of the Bering Sea and Aleutian Islands (BSAI) under a quota system, in which quota shares were issued to harvesters (including vessel captains) and processors. The program also includes community protection measures (hence the term “three-pie” program), and provides for voluntary harvesting cooperatives. Some features of this crab program had to be authorized by Congressional action. The Council also is considering comprehensive rationalization of Gulf of Alaska (GOA) groundfish fisheries and sector allocations of groundfish in the BSAI. Congress has provided additional statutory tools to help relieve overcapacity. The American Fisheries Act (AFA) retired nine catcher-processors, limited entry of additional harvesting vessels, authorizes harvesting cooperatives to which a portion of the total allowable catch of BSAI pollock is granted, prevents pollock fishery participants from expanding historical activities to other fisheries, and stabilized deliveries to shoreside processors. Congress later authorized a BSAI crab “buyback” program that, if approved by industry, will retire crab licenses, vessels, and vessel histories prior to implementation of the crab quota program. And, as a prelude to the more complex GOA rationalization program, the National Marine Fisheries Service (NMFS), in response to a Congressional mandate and in consultation with the Council, is developing a two-year demonstration quota program for Central Gulf of Alaska rockfishes.

Moratorium on New Vessels

A moratorium on new vessel entry into the federally managed groundfish and crab fisheries was implemented in 1996. The program was considered a place holder while more comprehensive management measures were developed. The owners of 1,864 groundfish and 653 crab vessels held moratorium fishing rights at the time the program was sunsetted (December 31, 1999). In addition to limiting the number of vessels the moratorium also restricted the lengths of vessels that could be deployed under moratorium permits. Qualifying vessels that were less than 125' in length overall received licenses that had a maximum length overall of 120 percent of the qualifying vessel’s length on June 24, 1992, or up to 125', whichever is less; vessels that were 125' or longer could not increase their length. The concern over increasing vessel length arises because such actions can increase harvesting capacity even though additional vessels are prohibited from entering a fishery, thus undermining the effectiveness of the moratorium.

License Limitation Program for Groundfish and Crab

The LLP for groundfish and crab vessels was implemented on January 1, 2000 to 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 recommended by the Council in 1998 and April 2000 tightened the LLP program and included additional restrictions on crab vessel numbers and on fishery crossovers. The amendments also limited participation in the non-trawl BSAI Pacific cod fisheries. The LLP reduced the number of vessels eligible to participate in the BSAI crab fisheries by more than 50% relative to the vessel moratorium (down to about 347 licenses, of which an estimated 306 are currently being used). The number of current LLP groundfish licenses (1,819) is similar to the number that held moratorium permits and some of both types of licenses were or are not actively used. At present, only 1,446 groundfish LLP licenses name vessels. However, the LLP is more restrictive in terms of the crab fisheries in which a license holder may participate, the groundfish areas in which a license holder can fish, and the types of gear that may be deployed. Also important to note is that the vast majority of the vessels that can be deployed under the LLP are longline vessels less than 60' (and are only eligible to participate in Gulf of Alaska fisheries). These vessels have typically had relatively small catch histories in past years. The LLP Program is being modified to accommodate changes implemented under the Crab Rationalization Program (CR Crab). In addition to crab endorsement changes resulting from new quota fisheries, some groundfish licenses were modified to incorporate “sideboard” restrictions, as they have become known, on GOA groundfish activities to avoid “spillover” effects of excess crab capital on groundfish fisheries.

License Limitation Program for Scallops (LLPS)

The LLPS was implemented in 2001 to replace a 1997 temporary vessel moratorium program for this fishery. Under the LLPS, nine persons were issued transferable licenses authorizing them to deploy vessels in the scallop fishery off Alaska. The licenses restrict the lengths of vessels and the size and amount of gear that may be used.

Bering Sea and Aleutian Islands Crab Rationalization and Buyback

The North Pacific Fishery Management Council developed, and NMFS has implemented, a plan to rationalize the BSAI crab fishery.

A statutory change to the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) authorized an industry-funded buyback program for the crab fisheries. This program permanently retired the fishery endorsements of 25 vessels, and LLP crab licenses and vessel histories; as well as 15 limited entry licenses for groundfish (and some halibut quota share) associated with those histories. The program was approved by an industry referendum in which a majority of participants approved the proposed effort reduction and a debt retirement burden of $97.4 million.

The Council also developed, and NOAA Fisheries Service, has implemented, the Crab Rationalization Program (CR Crab). This program includes allocations to Community Development Quota Groups, an allocation of one species of king crab to the community of Adak, and a complex quota system for harvesters and processors called the “three-pie voluntary cooperative program“. CR Crab program attempts to balance the interests of several identifiable groups that depend on these fisheries. Allocations of harvest shares are made to harvesters, including captains. Processors are allocated processing shares. Community protection measures are designed to help provide economic viability of fishery-dependent communities. Designated regions are allocated landings and processing activity to preserve their historic interests in the fisheries. Harvesters are permitted to form cooperatives to realize efficiencies through fleet coordination. The novelty of the program has compelled the Council to include several safeguards into the program, including a binding arbitration program for the resolution of price disputes and extensive economic data collection and review programs to assess the success of the rationalization program. These safeguards, together with the Council's continuing development of the program through a series of ongoing amendments and clarifications, demonstrate the Council's commitment to a fair and equitable rationalization program that protects the interests of those dependent on the BSAI crab fisheries.

As of May 2006, NOAA Fisheries Service has initially issued one or more types of harvesting quota to 490 distinct persons; and processing quota to 25 persons. For harvesters, NOAA Fisheries initially issued quota to 270 applicants who qualified based on holding a transferable LLP crab license; and to 232 individuals who qualified for "Captain" (also known as "crew") shares by virtue of both historic and recent participation in these crab fisheries. Fishing under Crab Rationalization began with two Aleutian Islands golden king crab fisheries, in August 2005.

Sablefish and Halibut Individual Fishing Quotas

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 recommended an IFQ program for both the halibut and fixed gear sablefish fisheries. These programs were initiated in 1995. After implementation, the traditional short, pulse fisheries were extended to more than eight months long. IFQs have allowed participants to better match fishing capacity with the amount of fish they are allowed to harvest during a year, improving economic efficiency for harvesters and decreasing gear conflicts on fishing grounds, among other salutary effects. In recent years the numbers of vessels and persons have declined, even as the TACs have been increasing. A total of 4,829 persons were initially issued halibut quota share (QS) and 1,054 were initially issued sablefish QS. At the end of 2005, 3,286 persons held halibut QS and 875 held sablefish QS. The number of vessels landing halibut in the IFQ fishery declined from 3,450 in 1994 to 1,276 at the end of 2005; the number landing sablefish in the IFQ fishery declined from 1,191 in 1994 to 378 in 2005.

American Fisheries Act

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 are eligible to harvest BSAI pollock. At the inception of the AFA, 21 catcher/processors and 112 catcher vessels qualified, or were specifically identified, as eligible to participate under the AFA guidelines. Nine other catcher/processors were bought out at a cost of $90 million.

Specific provisions in the AFA allow for the formation of cooperatives among catcher/processors, among the catcher vessels that deliver to the catcher-processors, among eligible motherships and catcher vessels in the mothership sector, and among the eligible catcher vessels in the inshore sector of the BSAI pollock fishery. Within each cooperative, each member company is then contractually allocated a percentage share of the total cooperative allocation based on its historical catch (or processing) levels. The catcher-processor cooperative is called the Pollock Conservation Cooperative (PCC) and is made up of eight companies that own 19 of the 20 catcher-processors currently eligible to fish in the pollock fishery (the fishing privileges of the 21st eligible vessel were purchased by the PCC in 2000, and one eligible vessel has not joined the PCC). The catcher vessel cooperative is called the High Seas Catchers' Cooperative (HSCC), and comprises seven catcher vessels authorized under the AFA to deliver to the eligible catcher/processors (these vessels had traditionally delivered the majority of their pollock to catcher/processors).

Under the AFA, the PCC is currently allocated 91.5% of the total offshore pollock allocation (the rest is allocated to members of the HSCC). When the new fishery cooperative structure was adopted in 1999, not all of the eligible catcher/processors fished during the 1999 late winter and early spring pollock seasons; four catcher/processors opted not to fish during the winter season and six chose not to fish during the summer season. This pattern continued in 2000 and 2001 when four and three catcher/processors were idle in the winter season, respectively. Five of the catcher/processors were idle in both 2000 and 2001 for the summer season. In 2002, three vessels were idle in the winter season and four were idle in the summer season. For 2003 to 2005, three vessels were idle during the winter and 5 vessels were idle in the summer season. The varations in vessel participation can probably be attributed to the variations in the pollock TAC.

The HSCC is allocated 8.5% of the offshore pollock allocation. However, since the formation of the cooperative, they have leased much of their TAC allocation for pollock to catcher/processors. In fact, since 1999, none of the seven HSCC vessels have engaged in directed fishing for pollock, choosing instead to lease their catch to the AFA catcher/processor fleet.

The AFA also authorizes three motherships to participate in the BSAI pollock fishery. In 1998, 31 vessels landed greater than 10 mt of pollock to be processed by offshore motherships. In 1999, this number decreased to 27. In 2000, the first year in which a cooperative was operating in the mothership sector, 19 of the 20 catcher vessels eligible to deliver pollock to these motherships actually did so. The same number of vessels made deliveries to motherships in 2001, dropped to 17 vessels annually in 2002 and 2003, increased to 18 in 2004, and dropped to 17 in 2005.

In 1998 107 inshore catcher vessels each delivered more than 10 mt of pollock to inshore processors (including stationary floating processors). That number decreased slightly in 1999 (100 vessels), again decreased in the 2000 roe fishery (91 vessels), remained at that level in 2001, and dropped to 85 in 2002. Although the number of vessels delivering at least 10 mt of pollock to inshore processors dropped to 83 vessels in 2003, the number increased back up to 85 vessels in 2004, and fell to 84 in 2005..

Finally, it should be noted that the AFA also restricts eligible vessels from shifting their effort into other fisheries. “Sideboard” measures 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 spill over and compete in other fisheries.

Two recent acts of Congress provided additional authority and guidance to the Council and NMFS for developing and implementing dedicated access privilege (DAP) programs. Under these authorities, the Rockfish Pilot Program, a BSAI groundfish capacity reduction (“buyback”) program, and Amendment 80 to the FMP for the BSAI are in various stages of development by the Council and/or NMFS.

Rockfish Pilot Program

Congress granted NMFS specific statutory authority to manage Central GOA rockfish fisheries in Section 802 of the Consolidated Appropriations Act of 2004 (Pub. L. 108-199; Section 802). The North Pacific Fishery Management (Council) was required to establish the Rockfish Pilot Program, to provide exclusive harvesting and processing privileges for a specific set of rockfish species and for associated species harvested incidentally to those rockfish in the Central GOA, an area from 147E W. long. to 159E W. long. The Program is intended to increase resource and improve economic efficiency for harvesters and processors who participate in the fishery. For the two year period through December, 2008, exclusive harvesting and processing privileges would be allocated for three primary rockfish species and for five incidentally harvested secondary species in the Central GOA. NMFS would also allocate a portion of the total GOA halibut mortality limit to participants based on historic halibut mortality rates in the primary rockfish species fisheries.

Under the Rockfish Program NMFS would:

1. Assign quota share (QS) for primary rockfish species to an LLP license with a trawl gear designation in the Central GOA.
2. Establish eligibility criteria for processors to have an exclusive privilege to receive and process primary rockfish species and secondary species allocated to harvesters in this Program. 3. Allow a person holding a LLP license with QS to form a rockfish cooperative with other persons (i.e., harvesters) on an annual basis.
4. Allow rockfish cooperatives to transfer all or part of their CFQ to other rockfish cooperatives, with some restrictions.
5. Provide an opportunity for a person not in a rockfish cooperative, but who holds an LLP license with QS, to fish in a limited access fishery.
6. Establish a small entry level fishery for Central GOA rockfish for harvesters and processors not eligible to receive QS under this Program.
7. Allow holders of catcher/processor LLP licenses to opt-out of the Program, with certain limitations.
8. Limit the ability of processors to process catch outside the communities in which they have traditionally processed primary rockfish species and associated secondary species.
9. Establish catch limits, commonly called “sideboards”, to limit the ability of participants eligible for this Program to harvest fish in fisheries other than the Central GOA rockfish fisheries.
10. Create a monitoring and enforcement mechanism to ensure that harvesters maintain catches within their annual allocations and would not exceed sideboard limits.

Capacity Reduction in Non-Pollock Groundfish Fisheries of the Bering Sea and Aleutian Islands

Under the Consolidated Appropriations Act of 2005 (Public Law 108-447) and Consolidated Appropriations Act of 2004 (Public Law 108-199); NMFS will implement a capacity reduction program pursuant to applicable provisions of the MSA (15 U.S.C. 1861a(b-e)). The program will reduce current and future effort in the non-pollock groundfish fisheries in the Bering Sea and Aleutian Islands through a “buyback” program to retire vessels, licenses, and vessel histories. The legislation provides for a total loan of up to $75 million and authorizes specific amounts for four subsectors in the fishery: longline catcher processors, AFA trawl catcher processors, non-AFA catcher processors, and pot catcher processors. A separate program will be developed for each subsector, with the first, for longline catcher processors, currently in regulatory development. The objective of the program is to achieve a permanent reduction of capacity to: increase post-reduction harvester’s productivity, help financially stabilize the fishery, and help conserve and manage fishery resources.

Amendment 80

In response to requirements of the Consolidated Appropriations Act of 2005 (Public Law 108-447) the Council is developing Amendment 80 to the FMP for the Bering Sea and Aleutian Islands (BSAI). Amendment 80 pertains to the non-AFA trawl catcher processor participant subsector. Under this Amendment, vessels owned, and/or LLP licenses held, by eligible participants would be allocated quota for target groundfish species, based on historic participation. Including combinations of allocated species and fishing areas, there would be a total of 11 quota categories. Quota holders would annually receive pound allocations based on quota holdings, and could elect to form harvesting cooperatives or participate in a limited access fishery. Cooperatives and the limited access fishery would each be allocated amounts of bycatch of Pacific halibut and crab, which are prohibited species in groundfish fisheries. Caps would limit the amounts of quota a person could hold at any time. Sideboard provisions would limit “spillover” effects of this program on other fisheries and required reporting would allow NMFS and the Council to monitor the efficacy of the program over time.

Amendment 85
At its April, 2006 meeting, the Council took final action on Amendment 85 to the FMP for the BSAI, which would modify the current annual allocations of BSAI Pacific cod (after deductions for the CDQ fishery) among jig, trawl, and fixed gear (hook-and-line and pot) subsectors. The recommended allocations were determined based on a set of historic participation criteria, with consideration for small boats and coastal communities dependent on the Pacific cod resource. The Council also recommended seasonal apportionments for jig and trawl gear and a hierarchy for reallocating projected unused allocations among the various sectors. The number of eligible persons subject to this Amendment would be reduced to the extent that prior capacity reduction programs first reduce the size of the fleet.

Groundfish fleet composition

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Last updated: August 2006

Fishing vessels participating in federally-managed groundfish fisheries off Alaska principally use trawl, hook and line, and pot gear. The pattern of changes in the total number of vessels harvesting groundfish and the number of vessels using hook and line gear have been very similar since 1994. They both were high in 1994 and then decreased annually through 1998 before increasing in 2000. The total number of vessels was about 1,453 in 1994, decreased to 1,170 in 1998, and was 937 in 2005, the most recent year for which we have complete data (Figure 159). Hook and line vessels accounted for about 1,161 and 625 of these vessels in 1994 and 2005, respectively. The number of vessels using trawl gear has tended to decrease; during this twelve-year period it decreased from 255 to 189 vessels. During the same period, the number of vessels using pot gear peaked in 2000 at 341, but decreased to 199 in 2005. Vessel counts in these tables were compiled from blend and Catch-Accounting System estimates and from fish ticket and observer data. Vessel counts in this report are slightly higher than in previous reports because we've refined our estimation method to include vessels that deliver to other vessels, as reported in fish tickets, that don't appear in our other data sources.

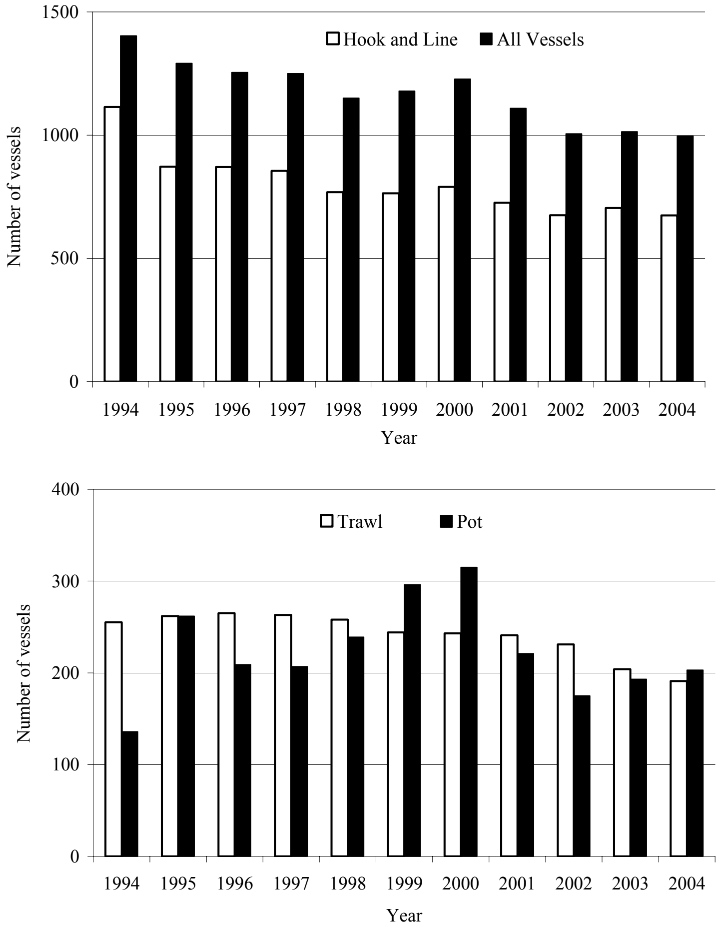

Figure 159. Number of vessels participating in the groundfish fisheries off Alaska by gear type, 1994-2005.

Distribution and abundance trends in the human population of the Bering Sea/Aleutian Islands

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Description of Indices: This report describes the distribution and abundance over time of human populations in Bering Sea/Aleutian Island (BSAI) fishing communities. Population was calculated by aggregating Census values for selected Bering Sea communities into Census Areas for each decade between 1920- 2000 (data from U.S. Census Bureau), and yearly between 1990- 2005 (data from the Alaska Department of Labor and Workforce Development (ADLWD 2005)). This approach is concordant with research on arctic communities that uses crude population growth or loss as a general index of community viability (Aarsaether and Baerenholdt 2004). A more detailed discussion of these and other demographic issues is contained in the Economics Appendix of 2006 SAFE.

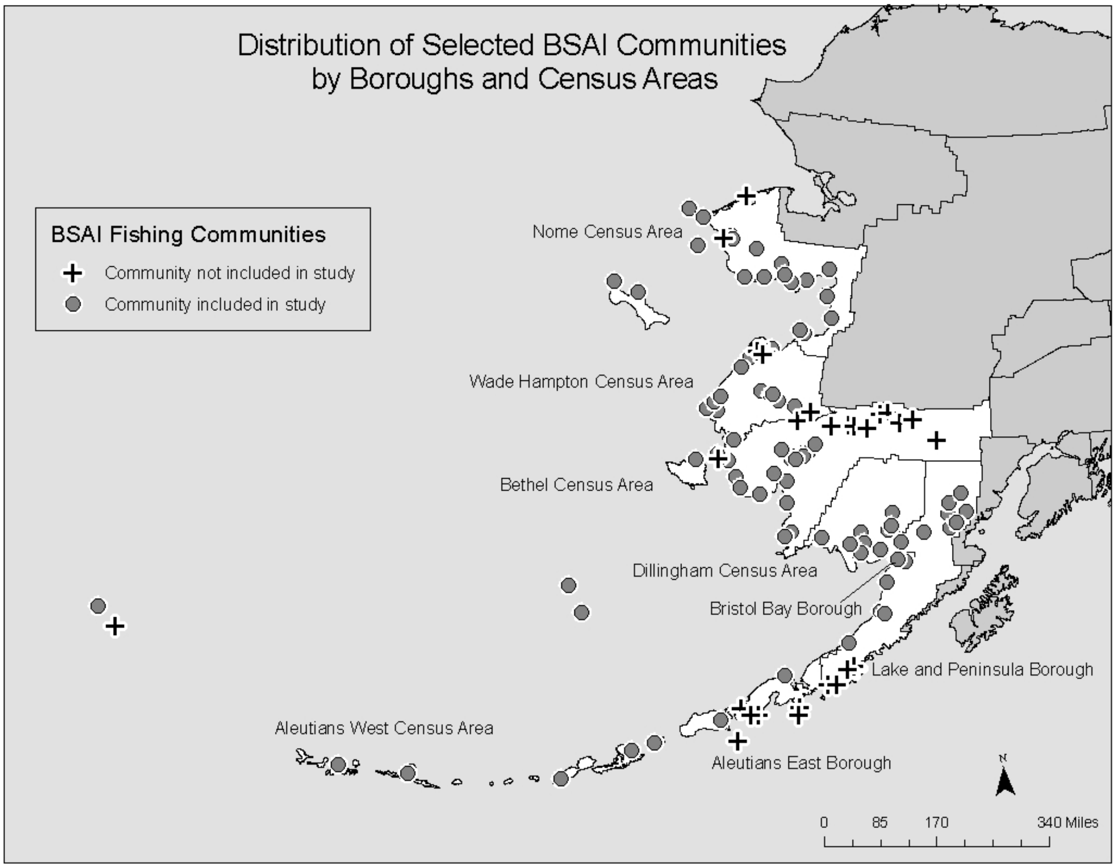

Figure 160. Distribution of selected BSAI communities by boroughs and census areas.

The 94 BSAI fishing communities selected for use in this report comprise most of the population in each of these Census Areas (between 79% for Aleutians East and West and 99% for Dillingham Census Area) and were chosen due to their proximity and historical involvement in Bering Sea subsistence or industrial fisheries (Figure 160). Following CDQ community selection parameters however, towns near the Bering Sea but located on the Gulf of Alaska Large Marine Ecosystem (LME) or Arctic LME were excluded.

The US Census counts populations based on place of residence on April 1 of the Census year. In many fishing communities in Alaska, the population fluctuates greatly during the year according to the fishing season. Due to an influx of processing workers, salmon communities may have much higher populations in the summer, crab and groundfish communities in the winter. Census data does not differentiate between long-term residents and transient residents, and does not capture seasonal population fluctuations.

Status and Trends:

The overall population of BSAI fishing communities in 2000 was almost seven times larger than its 1920 population - growing from 6,215 to 43,237. The proportion of people living in BSAI communities relative to the total Alaskan population has declined from around 11% of the state total of 55,036 in 1920 to around 6.8% of the total Alaska population of 626,932 in 2000.

Nearly all of Alaska’s rural areas, including BSAI, have had a positive average population growth rate since 1990 (Figures 161 and 162). Seventy-nine BSAI fishing communities (or 84%) have had a positive average annual percent change during the period between 1990 and 2000. Three communities showed zero percent average annual change over the same time period and 14 had a negative average annual percent change. Communities with a negative annual percent change during this time period appear to be concentrated in Aleutians East and West along with Lake and Peninsula and Bristol Bay Boroughs. The sharp decrease (Figure 161) in the Aleutians East and West area is largely due to the military base closure in Adak.

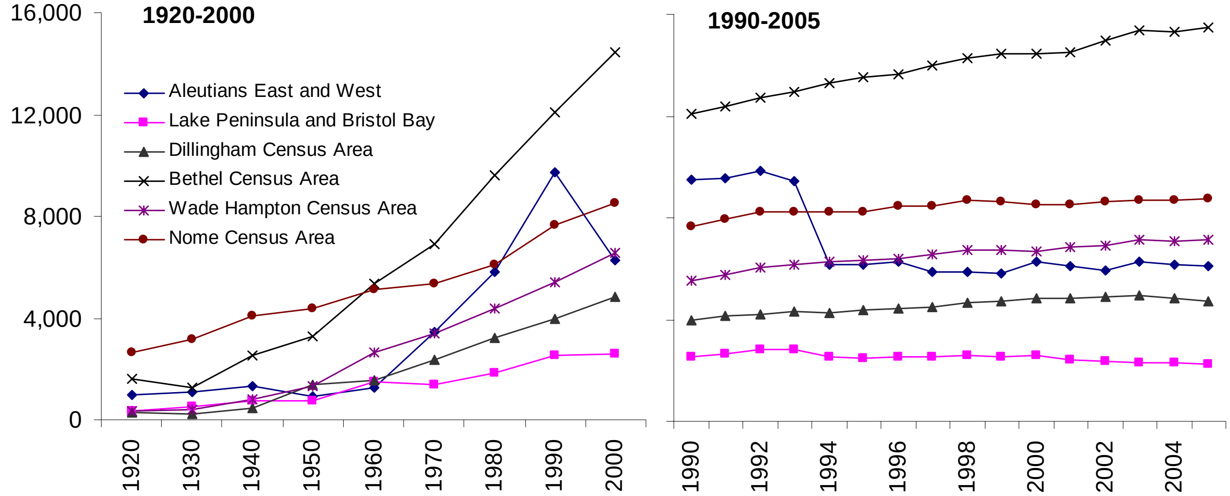

Figure 161. Population of BSAI communities per census areas: a.) every 10 years during 1920-2000 (data source: US Census Bureau) and b.) every year during 1990-2005 (data source: ADLWD).

Overall, Alaska has one of the highest intra- and interstate migration levels of any US state (Williams 2004b). However, these figures differ dramatically across BSAI communities. Based on ADLWD 2004 statistics, Lake and Peninsula and Aleutians East and West exhibit some of the highest gross migration rates in Alaska (21 to 30% of the population) compared to the lowest rates of gross migration (9.5 – 11.9%) in Nome, Wade Hampton, and Bethel (Williams 2004a). In Aleutians West, which includes the region’s major fishing hub in Unalaska/Dutch Harbor, only 25% of the residents were born in Alaska, compared to 94.1% in Wade Hampton.

Alaska has the highest share of indigenous Americans of any US state (one person in five), and Alaska Natives make up 82% of the population in remote rural census areas, 90% when excluding regional hubs (Goldsmith et al. 2004). In the BSAI, the percent Native population is lowest among the Aleutians East (38.6%) and Aleutians West (22.5%) and highest in Wade Hampton (94.9%) and Bethel (85.5%), though there is significant variation between communities.

Factors Causing Trends: The overall population growth in the BSAI region since 1920 reflects state and national trends, although the BSAI growth rate lags behind both. The two key factors affecting population growth rates are natural increase (birthrates subtracting mortality), and migration. Both factors affect the BSAI region.

High birth rates among Alaska Natives (50% higher than that of non-Natives) account for steady natural increase in many BSAI area populations (particularly Wade Hampton and Bethel), which serves to off-set out-migration from these areas. The Alaska version of the Todaro Paradox (Huskey et al. 2004) describes the out-migration of young Alaska Natives to urban centers for education and work opportunities, and the return migration to remote rural areas despite the high levels of unemployment there. This return migration is partly due to the social benefit of family networks, and the sustenance and income from subsistence activities which are most successful in natal villages where traditional environmental knowledge is an asset (Huskey et al. 2004).

Swift and dramatic changes in residency and migration patterns account for some of the region's population trends and anomalies. The military base closure in Adak accounts for Aleutians West population decline between 1992 and 1994. Historically, the gold mining industry accounted for community growth, decline, and in some cases abandonment (e.g., Council and Mary's Igloo) in the Nome area, while the fishing industry accounts for similar boom-bust dynamics in the Aleutians and Bethel, Dillingham, and Lake and Peninsula areas. An acute drop in ex-vessel prices for salmon has been the most significant driver of negative population growth in the latter two Census Areas in the last decade. Unlike many other parts of the state, the oil and gas industry has not been a direct factor in BSAI population dynamics.

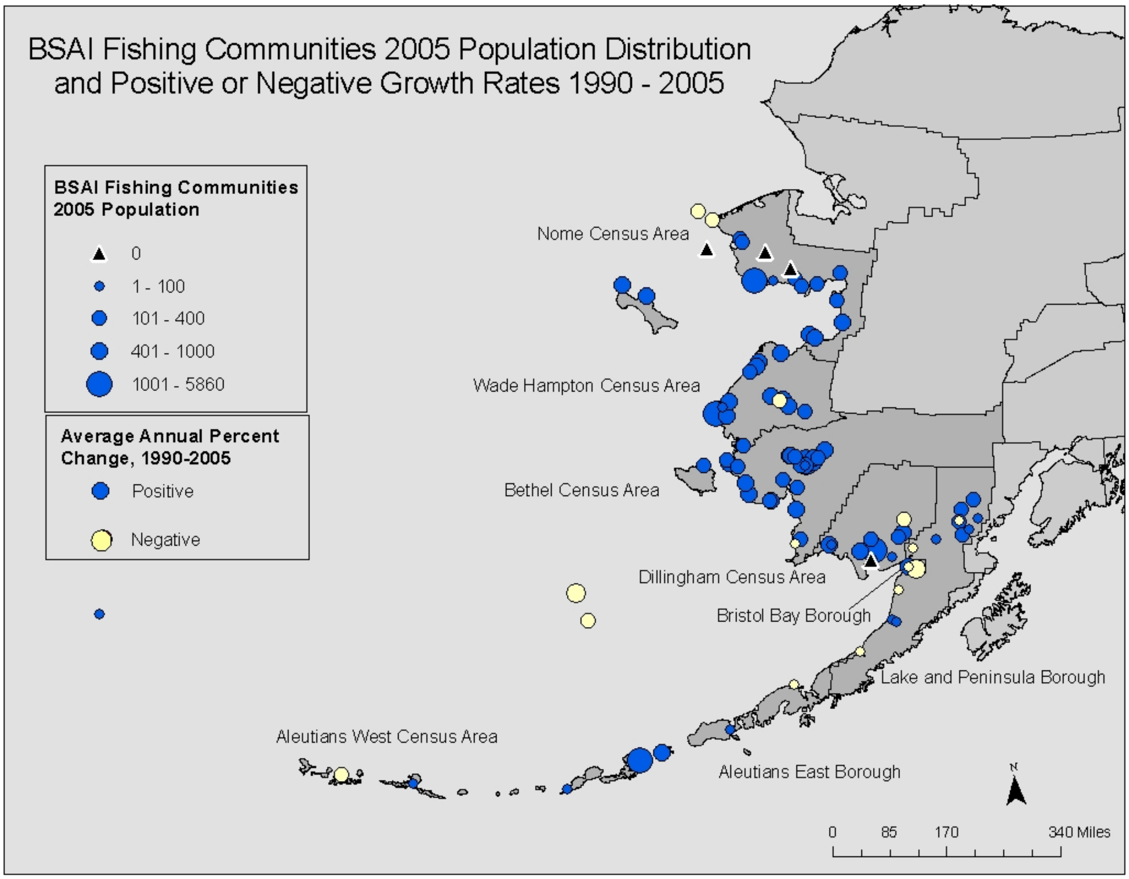

Figure 162. BSAI fishing communities 2005 population distribution and positive or negative growth rates, 1990-2005.

Impacts: Population decline or growth in small communities can factor into health care provision, education, land use, environmental impacts, transportation, and other social services (Williams 2004a). Over 36% of federal dollars allocated to Alaska depend in some way on population, State programs attach many services to population, and CDQ quota shares are also provisioned in relation to population numbers.

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APPENDIX 2

Essential Fish Habitat Research by AFSC

Fish Habitat Assessment and Classification of Alaska Estuaries

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Last updated: November 2005

NMFS Alaska Region (AKRO) is currently mapping coastal resources in Alaska to assist in the inventory, understanding and monitoring of nearshore marine resources. The ShoreZone method (Morris et al. 1995) of resource inventory in use by AKRO uses low speed aerial surveys to classify biological and geomorphic conditions along the coast and then links those classifications geospatially to a linear shoreline model through a GIS. That classification system has already been applied along the entire Washington state coast and throughout British Columbia. Our project focuses on resolving some of the technical and systematic issues with that inventory.

A technical deficiency of linear classification systems such as ShoreZone is an inability to reliably inventory resources in expansive areas such as estuaries and intertidal wetlands. In intertidal wetlands, for example, aerial classification units like those used in National Wetlands Inventory mapping (Cowardin et al. 1979) provide a much better inventory. The developers of the ShoreZone mapping system are aware of that issue and are working with us and other regional scientists to resolve it. In terms of resource management, a systematic problem with ShoreZone mapping is that it does little to relate functional values to the classifications. By developing a baseline inventory of estuarine resources that can be explored for correlations with ShoreZone classification data we hope to help resolve some of the aerial classification issues and also find ways to better associate functional values with ShoreZone classes.

To provide that baseline we are sampling at least 10 estuaries in each of six biogeographic strata in southeast Alaska. The strata are based on trends in biotic distribution noted by O’Clair and O’Clair (1998). The six strata generally divide southeast Alaska into northern and southern sections with divisions in each section for mainland coast, island, and outer coast strata. Estuaries within each stratum are selected to include a range of possible classification characteristics including exposure, watershed size and geomorphology, and adjacent land-use.

Twenty-five estuaries in southeast Alaska were sampled in 2005, bringing the total number sampled to 53. In addition, annual surveys are conducted in two additional estuaries to provide a time-series that is being used to assess temporal variability and habitat change. Sampling involves netting for fish and macroinvertebrates, vertically stratified water quality sampling, and foot surveys using ShoreZone field verification protocols. To date, sampling of three strata is complete and only one stratum has not been sampled at all. More than 200 animal taxa and more than 70 plant taxa have been identified. The identified taxa include more than ten percent of those in the RACE taxonomic database and many that are not in the Resource Assessment and Conservation Engineering (RACE) database.

Data on resource distribution and habitat use by life stage will be explored for correlations with ShoreZone classifications and other environmental variables such as salinity and turbidity. The majority of fish captured during estuary sampling are juvenile forage fish such as herring and sandlance, however juvenile salmon often dominate spring catches. Seasonal spawning aggregations of herring, sandlance, smelt, yellowfin sole, pricklebacks, cottids, and crab have been documented during the surveys. Shiner perch make up much of the summer catch in southern strata, but are nearly absent from northern strata and several northern range extensions have been documented for fish and invertebrate species. In protected bays, flatfish such as yellowfin sole and starry flounder are often abundant. Species diversity appears to be greatest in estuaries adjacent to large deep-water bays and least in those adjacent to fjords, however species assemblages in those two estuary types are generally very different. Distribution of marine algae, kelp, and eelgrass are dependant on environmental variables such as salinity, turbidity, and exposure.

Relationships between the distribution of marine resources and environmental variables will be used to help develop a classification system for estuaries that is compatible with ShoreZone inventories. Better understanding of the functional values of estuaries will improve resource inventories and also provide a template to help describe ecosystem functions for other habitat classifications.

Mapping and Monitoring Eelgrass Beds in the City and Borough of Juneau, Alaska.

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Last updated: November 2005

Project Need: Nearshore areas within the City and Borough of Juneau (CBJ), Alaska, continue to be under development pressure from shore-based facilities and intertidal projects. Since our 2004 field effort, a fish processing plant has become operational in Auke Bay within a few meters of a large eelgrass bed and another bed was subjected to a 61,000-68,000 liter diesel spill. Pending proposals would allow additional fill placed in these two eelgrass beds. These events highlight the need for continued assessment and monitoring of CBJ eelgrass beds to determine their value as fish habitat and the effects of development over time.

Eelgrass supports high fish diversity and abundance, and is especially important for juvenile fishes. Reductions in bed size and eelgrass biomass have occurred in other locations due to increased nutrient loads from outfalls, increased sedimentation, and increased propeller or anchor scour.

Research Objectives: Measurements of eelgrass bed size and fish use in 2005 will be added to a *ShoreZone* GIS database so that the changes over time can be tracked. Eelgrass disturbance can result from climate change or local development impacts. This study will serve a NOAA strategic goal: to protect, restore, and manage the use of coastal and ocean resources by increasing understanding of ecosystems through mapping and characterization of coastal areas.

Progress in 2004 and 2005: In the first two years of this project, we mapped 17 eelgrass beds with GPS, and determined plant density, biomass, percent cover, and canopy height in 7 beds. Eelgrass sampling occurred in late June through late August. Thermographs recorded seawater temperatures in two beds where development has occurred or will soon occur, and in two beds that may not experience development for some years. Eleven eelgrass beds were sampled for fish and marcroinvertebrates with a beach seine from late June through late July.

Eelgrass: Preliminary data analysis indicates high variability among eelgrass beds in area and biological parameters. Bed areas ranged from less than a square meter to 5.7 hectares; biomass (dry weight/ m^2) ranged from 1.1 to 306g/m^2; stem densities ranged from 32 to 1,408 stems/m^2; range of canopy heights was 150 to 1,000 mm, and percent cover ranged from 1 to 100%. Eelgrass was often patchy within a bed; approximately 10% of randomly chosen quadrats sampled were bare.

Fauna: A total of 28 fish species were caught at 11 seine sites. The most widely distributed species were crescent gunnel (*Pholis laeta*), tubesnout (*Aulorhynchus flavidus*), threespine stickleback (*Gasterosteus aculeatus*), and Pacific staghorn sculpin (*Leptocottus armatus*). Coho salmon (*Oncorhynchus kisutch*), chum salmon (*O. keta*), Starry flounder (*Platichthys stellatus*), bay pipefish (*Syngnathus leptorhynchus*), snake prickleback (*Lumpenus sagitta*), tubenose poacher (*Pallasina barbata aix*), frog sculpin (*Myoxocephalus stelleri*), silverspotted sculpin (*Blepsias cirrhosus*), and northern sculpin (*Icelinus borealis*) were found at more than half of the sites. Less widely distributed were Pacific herring (*Clupea pallasii*), Pacific sand lance (*Ammodytes hexapterus*), walleye pollock (*Theragra chalcogramma*), pink salmon (*O. gorbuscha*) and chinook salmon (*O. tshawytscha*). The most widely distributed invertebrates sampled were hermit crabs (*Pagurus* sp.) and unidentified juvenile shrimp (*Pandalus* and *Heptacarpus* spp.). Dungeness crab (*Cancer magister*) were captured at five sites.

A total of 5,313 fish were caught; the most abundant species were crescent gunnels (1,709), juvenile tubesnouts (1,490), and larval herring (989). Several hundred chum salmon, coho salmon, threespine stickleback, and staghorn sculpin were also caught.

Most fish caught were larvae or juveniles. Most notable was the large number of herring larvae caught at four sites. Similarly all Dungeness crab and shrimp caught were juveniles.

Products: This project will provide GIS maps and baseline data to the Alaska Regional Office (AKRO) NOAA Fisheries and other agencies, such as the CBJ. Data will also be available in a web-accessible GIS database maintained by AKRO that includes nearshore vegetation, geomorphology, and fish use. After three years of baseline data collection, a NOAA Technical Memorandum or a journal article will be published to analyze trends in area and physical characteristics of eelgrass beds and fish use.

Investigations of Skate Nurseries in the Eastern Bering Sea - Principal Investigator: Gerald R. Hoff, NMFS Alaska Fisheries Science Center, RACE Division
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Last updated: November 2004

The goal of this study is to verify skate nurseries in the eastern Bering Sea, determine the temporal aspect of skate reproduction and skate embryo development, and to identify interaction of predatory species in the skate nurseries.

Bottom trawling was conducted at each of three sites to establish the species utilizing the area, egg spatial densities and extent of the nursery areas in July-August of 2004. The investigations identified three species specific nurseries including the Alaska skate *Bathyraja parmifera,* The Aleutian skate *B. aleutica*, and The Bering skate *B. interrupta.* Data collected at each site included skate egg developmental state, egg predation rate, egg densities and distribution, skate predation rate, and reproductive status of mature skates in the nursery.

The data collected to date verifies the location, extent, and species at three locations in the eastern Bering Sea. Each site is species specific and evidence suggests these sites are used for many years as nurseries. Each site will be sampled periodically throughout the year to track skate reproductive state and the development of the embryo population.

Atka mackerel natural history studies

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Atka mackerel (*Pleurogrammus monopterygius*) spawn demersally in rocky areas and nests comprised of egg clutches are defended by guardian males. Reproductively mature male Atka mackerel aggregate at specific nesting sites along the Alaskan continental shelf. Aggregations of nesting males, the developing embryos in the nests that males guard, and the nesting habitat itself are all vulnerable to the effects of bottom trawling. The potential impact of trawl fishing on Atka mackerel populations cannot be assessed without first understanding how the spatial and temporal aspects of their reproduction overlap with the commercial fishery.

The geographic distribution, depth range, and description of Atka mackerel nesting and spawning habitat were investigated in Alaskan waters from 1998 to 2004. Scuba diving and in situ towed underwater video cameras were used to locate and document Atka mackerel nesting sites and reproductive behavior. Results from this study extended the geographic range of nesting sites from the Kamchatka Peninsula to the Gulf of Alaska, and extended the lower depth limit for nesting and spawning from 32 m to 143 m. There was no apparent concentration of nesting sites in nearshore coastal areas as was surmised by other investigations. Nesting sites were widespread on the continental shelf across the Aleutian archipelago and into the western Gulf of Alaska. Nesting habitat invariably had rocky substrate and current, and water temperatures for nesting sites ranged from 3.9-10.5°C. Water temperatures within nesting sites varied little and did not appear to be limiting the upper or lower depth boundaries of nesting.

The temporality of the Atka mackerel spawning and nesting season in Alaska is currently being investigated using a towed video camera, time lapse camera, archival tags, and egg samples brought up in trawls. Using the time lapse camera and data from one archival tag, it was established that male Atka mackerel begin to aggregate at nesting sites in mid-June. In Kamchatka, Zolotov (1993) found that nesting started at the same time and spawning lasted until September. Gorbunova (1962) determined that the incubation for Atka mackerel eggs was 40-45 days; hence it was inferred that nesting season off Kamchatka lasted until early October.

Histological analysis of Atka mackerel ovaries by McDermott and Lowe (1997) and Cooper and McDermott (unpublished data) indicate spawning lasts through October in Alaskan waters, however, the ending time for nesting season remains unclear. As late as October, aggregations of nest guarding males were observed in Alaskan waters with a towed video camera, and egg masses were brought up in trawls tows done through a nesting site. No effort has been made later into the year to see if aggregations of males or egg masses are present in November and December.

Recent laboratory incubation experiments of fertilized eggs obtained from the field (Lauth, unpublished data) and from fish in captivity at the Alaska Sealife Center in Seward (Guthridge and Hillgruber, unpublished data) indicate that incubation of eggs lasts from about 1 to 3 months depending on temperature (at 10°C and 4°C, respectively). If eggs are being deposited in nests in October, it is likely that males are still guarding incubating eggs at nesting sites through November or December. The towed video camera will be used at a known nesting site near Dutch Harbor, Alaska, in late November or early December 2005 to see if aggregations of males are still guarding incubating eggs.

Other means besides histology and underwater video are being used to determine the end of the spawning and hatching periods. Incubation rates from laboratory experiments will be used to stage over 100 egg clutches brought up from trawl tows made through nesting sites. Eggs will be staged according to their embryological development. Historical temperature data from the areas near the nesting site where eggs were collected will be used to estimate the range of spawn and hatch dates for the egg samples.

Effects of Fishing Gear on Seafloor Habitat

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Last updated: November 2004

In 1996, the Alaska Fisheries Science Center (AFSC) initiated a number of seafloor habitat studies directed at investigating the effects of fishing on seafloor habitat. Each year a progress report for each of the projects is completed. 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 web page http://www.afsc.noaa.gov/abl/MarFish/geareffects.htm has been developed that highlights these research efforts. Included in this web page are a research plan, previous progress reports, and a searchable bibliography on the effects of mobile fishing gear on benthic habitats.

> **Determining the value of habitat to juvenile rockfish in the Aleutian Islands.** Principal Investigators - Chris Rooper and Mark Zimmermann (AFSC – RACE), and Jennifer Boldt (University of Washington)
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> **Last updated: November 2004**

Linking the specific benefits of habitats to fish is important to determining Essential Fish Habitat for species. The objective of this study is to assess the value of Aleutian Islands habitat to juvenile (< 250 mm fork length) Pacific ocean perch (POP) by examining abundance, condition and growth in five study areas. The initial phase of habitat mapping was completed during a research cruise beginning and ending in Dutch Harbor, Alaska from May 28 to June 9, 2004. Video transects and sediment samples were completed in a cruise from August 13-24, 2004. Each of five study areas surrounding the Islands of Four Mountains was mapped using a towed side scan sonar (Klein 3000) and a multibeam system (Simrad SM2000), to collect bathymetry and backscatter data. Much of the data processing was completed aboard the F/V *Ocean Explorer* and side scan sonar mosaics were produced (Figure 163). In total, 25 km^2 were mapped using side scan sonar, and multibeam data was collected over almost twice that area. Video and sediment samples were collected to groundtruth the acoustic data. Preliminary results indicate habitats at each area varied widely, from bare sand fields to rocky ledges, ridges and pinnacles. Sponge and coral were the dominant epibenthic invertebrates observed in the video and trawl collections. Juvenile POP were collected from 4 of the 5 study areas for laboratory analyses. Sponge and coral were observed at most sites where juvenile POP were collected. During the fall and winter of 2004-05 sediment samples, zooplankton, and fish collections will be analyzed in the laboratory, and data analyses will begin later. The approach presented here will provide information to determine the value of habitats to their inhabitants, as well as insight into the processes controlling fish-habitat relationships. This project was supported by a grant from the North Pacific Research Board.

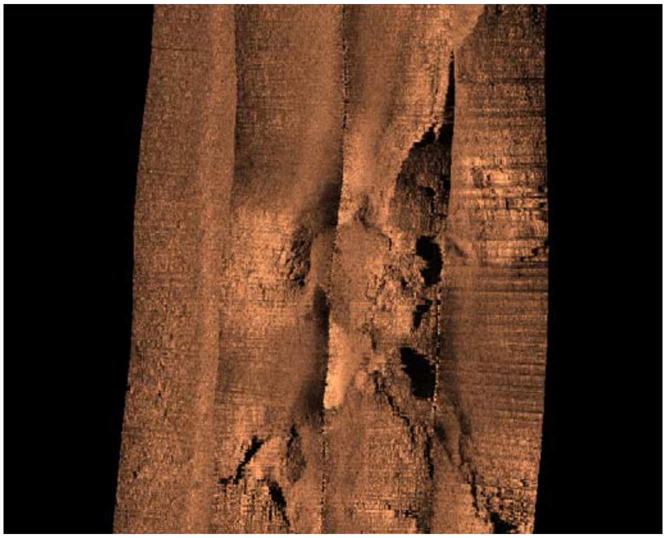

Figure 163. Side scan sonar mosaic from the Islands of Four Mountains west study location, showing interesting geological features on the seafloor.

Distribution of deep-water corals and associated communities in the Aleutian Islands.

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During July 24 – August 8, 2004 the ROV *Jason II* (Woods Hole Oceanographic Institute) and support vessel RV *Roger Revelle* were used to study deep-sea coral and sponge habitat in the central Aleutian Islands. The dives made with the *Jason II* were at ten sites from 131 m to 2948 m in depth. Video footage of the seafloor was collected along strip transects from 2.4 to 13.2 km in length. Corals and sponges were widely distributed at the study sites with an apparent change in density, diversity, and species composition at a depth of approximately 1400 m. Samples were collected at stations along transects and included 260 corals, 45 sponges, 165 miscellaneous invertebrates, and 82 rocks. Preliminary results indicate that representatives from all seven coral families known to occur in the North Pacific were collected and that several of the collected sponges represent species new to science.

NOAA's Undersea Research Program funded the cruise and this was the final component of a comprehensive study initiated in 2003 and funded by the AFSC and the North Pacific Research Board. Coupled with detailed multibeam mapping and previous in-situ observations in shallow water (< 365 m) these findings will be used to construct a model to predict where coral habitat is located in the Aleutian Islands. The model will provide fisheries managers with a powerful tool to conserve coral habitat. Results from this cruise will provide information on the distribution of corals and sponges in the Aleutian Islands that will aid in fisheries management decisions. Our findings will greatly add to the understanding of the role of corals and sponges in seafloor ecology and their susceptibility to disturbance. An overview of the coral research can be seen at http://www.alaskascienceoutreach.com/

Bogoslof Island mapping and colonization. Principal Investigators - Mark Zimmermann (AFSC - RACE), Jennifer Reynolds (U. Alaska Fairbanks), and Chris Rooper (AFSC - RACE)
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We are studying the colonization process of benthic invertebrates at hard-bottom sites about 10-200 years old on Bogoslof Volcano to provide estimates of habitat recovery rates from benthic fishing activities. Bogoslof provides a natural laboratory for our study because lava and tephra (fragments of volcanic rock and lava) from historical eruptions (since 1796) have resurfaced different areas of the shallow seafloor around the island. The results will provide information needed for fisheries management by defining an upper bound on the time needed for recovery. Currently there are no reliable estimates of habitat recovery time from field work, and recovery rates on hard-bottom areas have been estimated as 1-9% per year whereas gorgonian coral recovery rates were estimated as 0.5-2% per year (or 50-200 years) for use in the Fujioka habitat impacts model.

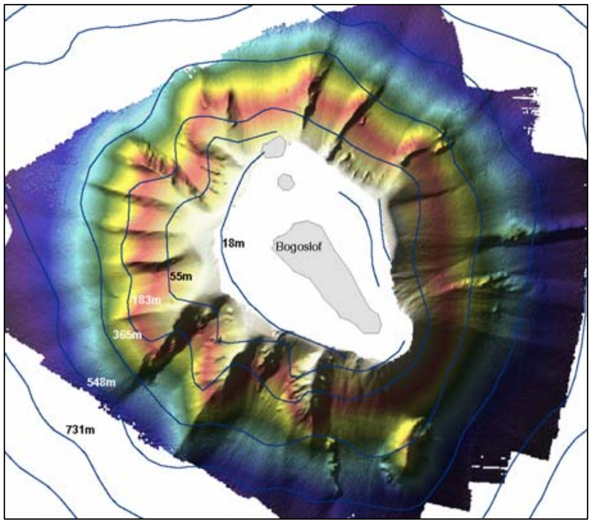

Figure 164. Preliminary multibeam map of the seafloor surrounding Bogoslof Island. Relief is artificially shaded from the northwest.

The project involves three separate stages of research: mapping the seafloor, matching seafloor areas to specific eruptions (dates), and conducting an ROV census of benthic invertebrates within seafloor areas of known ages. The first phase of the project was completed in July 2004 when a contract survey company successfully mapped the seafloor surrounding Bogoslof with a 100 kHz Reson SeaBat 8111 multibeam at depths from 20 to 750 m (Figure 164). After the final multibeam maps are delivered, the second phase will be completed this winter, and we will develop a census plan for studying the invertebrates. In summer 2005 we plan to conduct ROV transects within selected seafloor patches. We anticipate that there may be three possible levels of resolution for the video census: 1) presence/absence of species or taxa groups, 2) density or percent horizontal coverage, and 3) age estimates of individuals.

A model for evaluating fishery impacts on habitat. Principal investigator - Jeffrey Fujioka (AFSC - ABL)
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Last updated: November 2004

A mathematical model to evaluate the effects of fishing on benthic habitat was developed within the context of the Programatic and Essential Fish Habitat (EFH) supplemental environmental impact statements (EIS). The initial formulation of the model was comprised of equations that incorporate the basic factors determining impacts of fishing on habitat. Given values, either estimated or assumed, of 1) fishing intensity, 2) sensitivity of habitat to fishing effort, and 3) habitat recovery rate, the model predicts a value of equilibrium (i.e., long term) habitat level, as a proportion of the unfished level.

In 2004 new equations were formulated to expand on application of the model. In addition, model properties and new examples were developed which provide guidance in evaluating or designing mitigation strategies. The equations in the initial development of the model dealt with constant fishing effort situations and the EIS habitat impact analyses compared hypothetical equilibrium levels. During review of the EFH EIS concerns were raised about the current status of habitat impact. One new equation provides a simple way to determine the time it takes to approach equilibrium habitat reduction. Another equation was derived to extend model application to non-constant fishing effort so that if actual fishing effort history exists, habitat reduction over time can be modeled.

Distribution of juvenile Pacific ocean perch (*Sebastes alutus*) in the Aleutian Islands.

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Last updated: November 2004

The objective of this research was to identify juvenile (< 250 mm fork length) Pacific ocean perch (POP) habitat, using data from trawl surveys conducted by NMFS. Analyses were carried out to evaluate the POP CPUE relationship to depth, temperature, and sponge and coral CPUE. A principal component analysis indicated that sponge and coral CPUE were tightly linked, and depth and temperature were negatively correlated. The survey data indicate that juvenile POP were present at depths from 76 to 225 m (Figure 165). Juvenile POP CPUE increased with depth from 76 to 140 m, and decreased with increasing temperature from 3 to 5.5 ºC. Juvenile POP CPUE also increased with increasing sponge and coral catch rates (Figure 166). A statistical model predicting juvenile CPUE at stations where POP were caught explained 34% of the CPUE variability using bottom temperature, depth, and combined sponge and coral CPUE. Juvenile POP were most abundant at sites in the western Aleutians (beyond 170º W longitude), on large underwater banks (Stalemate and Petrel banks), and in passes between islands where currents are strong and production may be higher than surrounding areas. These results suggest sponge and coral have an important role in the early life history of juvenile POP.

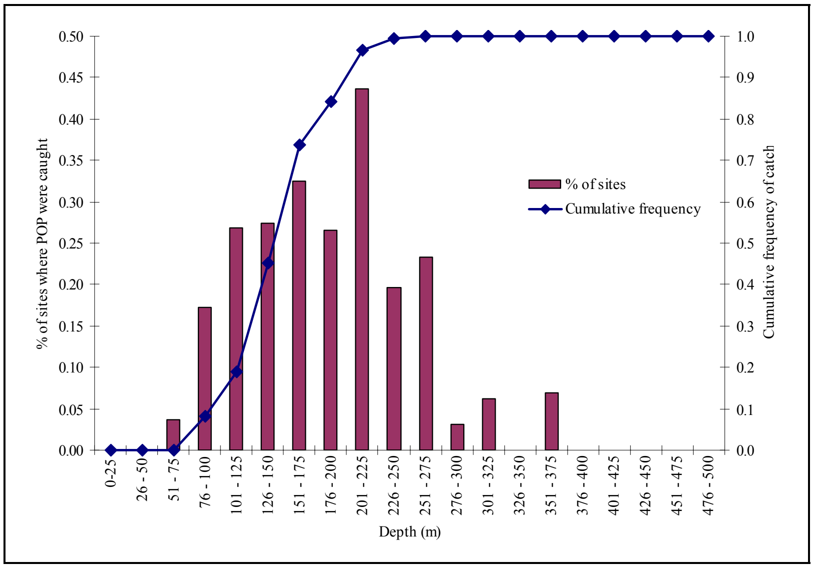

Figure 165. Cumulative frequency distribution of juvenile POP catch and proportion of trawl survey sites with rockfish present. Data are presented in 25-m depth bins.

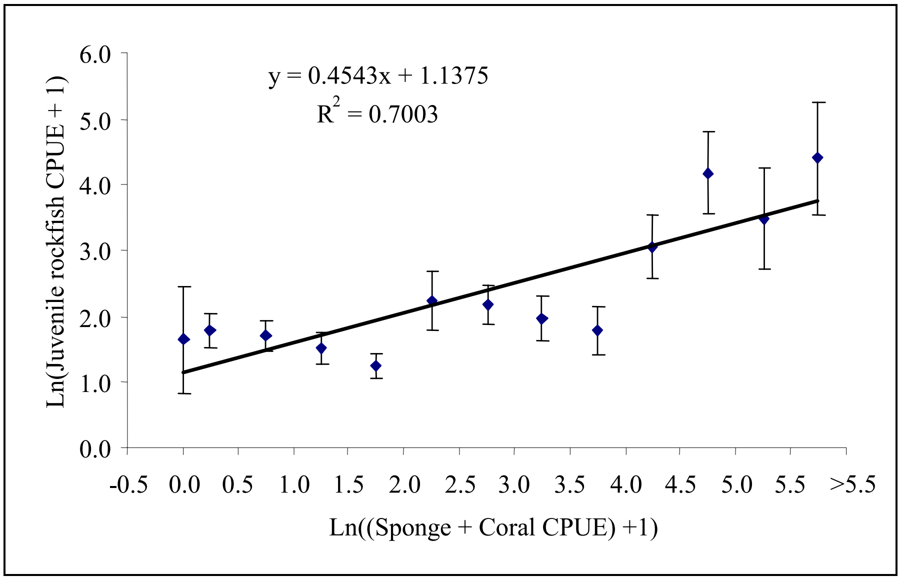

Figure 166. Relationship between sponge and coral CPUE (kg/ha) and juvenile POP CPUE (no./ha) at sites where juvenile POP were caught. Data are divided into 0.5 CPUE bins and each data point is plotted in the center of its bin.

Effects of experimental bottom trawling on soft-sediment sea whip habitat in the Gulf of Alaska. Principal Investigator - Robert Stone (AFSC - ABL)
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Last updated: November 2004

In June 2001 a study was initiated to investigate the immediate effects of intensive bottom trawling on soft-bottom habitat and in particular an area colonized by sea whips. Sea whip biological characteristics and their resistance to two levels of trawling were studied. Sea whips are highly visible and changes in their abundance can be readily quantified. Within the study site, at least two species of sea whips (*Halipterus willemoesi* and *Protoptilum* sp.) are present with densities up to 10 individuals per m^2. Sea whip beds provide vertical relief to this otherwise homogeneous, low relief habitat. This habitat may be particularly vulnerable since sea whips can be removed, dislodged, or broken by bottom fishing gear. Furthermore, since sea whips are believed to be long-lived, recolonization rates may be very slow.

The study plan consisted of three phases. In *Phase 1*, baseline data was collected. The *Delta* submersible was used to collect *in situ* videographic documentation of the seafloor along 20 predetermined transects within the study area. Additionally, a bottom sampler was deployed from the submersible tender vessel to collect sediment samples (n=42) from the seafloor. During *Phase 2*, a commercial trawler outfitted with a Bering Sea combination 107/138 net, mud gear, and two NETS High Lift trawl doors made a single trawl pass in one corridor of the study area and repetitively trawled (six trawl passes) a second corridor. A third corridor was the control and was not trawled. *Phase 3* repeated the videographic and sediment sampling (n= 42) following the trawling phase. A scientist on board the *Delta* observed the seafloor and verbally identified biota and evidence of trawling including damaged or dislodged biota and marks on the seafloor from the various components of the bottom trawl (e.g., trawl door furrows, and ground gear striations) in synchrony with the external cameras. Analyses of sediment, chemical, and infauna abundance and diversity was completed in 2002. Video analysis of epifauna data was completed in spring 2003 and data analyses are underway.

Growth and recruitment of an Alaskan shallow-water gorgonian coral. Principal Investigator - Robert Stone (AFSC - ABL)
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Last updated: November 2004

Little is known about the growth rates and lifespan of cold-water gorgonian coral. Some evidence exists that growth rates for these habitat-forming corals are low and that they are long-lived. Consequently, recovery rates from disturbance are likely slow. A study was initiated in 1999 to examine the growth and recruitment of *Calcigorgia spiculifera*, the most common and abundant species of shallow-water gorgonian in Alaskan waters. During June and July 2004 two sites established in July 1999 were revisited and 36 of 38 tagged colonies were relocated and video images recorded. These images will be digitized and growth determined from baseline images collected during the five previous years. A third study site was established in Kelp Bay, Baranof Island in 2000 where 30 colonies were tagged and images recorded. This site was unique in that it contained more than 1000 colonies, many of which were young (i.e., non-arborescent). At this site 18 of 30 colonies were relocated in July 2004 and video images were recorded. Additionally, branch samples were collected from untagged colonies at all three locations in 2002 and 2003 and will be examined microscopically to determine the gonadal morphology, gametogenesis, and reproductive schedule for this species. This research on reproductive biology should provide insights into the capability of cold-water gorgonians to recolonize areas set aside as mitigative measures, such as Marine Protected Areas.

Age validation and growth of three species of Pennatulaceans. Principal Investigator - Robert Stone (AFSC - ABL)
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Last updated: November 2004

Pennatulaceans (sea whips and sea pens) are locally abundant in Alaskan waters, susceptible to disturbance by bottom fishing activities, and are an important structural component to benthic ecosystems. Furthermore, research on one species (*Halipterus willemoesi*), indicates that they are long-lived and have low growth rates. This research was based on ring couplet (growth rings) counts but the periodicity of the couplets was not verified. To determine if the couplets are indeed annuli, 14 *Halipterus willemoesi* colonies were immersed in calcein solution and tethered to the seafloor where they were collected at 25 m depth. Preliminary results indicated that the calcein produced clear detectible marks on the axial rods. The 14 tethered specimens were retrieved between March and September 2004. Examination of these specimens is currently underway and may provide verification of the periodicity of ring couplets.

Axial rods from approximately 20 specimens each of the sea whips *Halipterus willemoesi* and *Protoptilum* sp. and the sea pen, *Ptilosarcus gurneyi*, are being examined for ring couplet counts. Examination of a wide size range for each species will provide estimates of growth rate, asymptotic size, and life span. One species (*Halipterus willemoesi*) will be collected from two populations subjected to different temperature regimes (Southeast Alaska and Bering Sea) and will allow us to examine the effects of temperature on growth rates. These data will allow us to estimate the growth rates of pennatulaceans throughout their geographical range and depth distribution.

Effects of bottom trawling on soft-sediment epibenthic communities in the Gulf of Alaska.
Principal Investigator - Robert Stone (AFSC - ABL)
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Last updated: November 2004

In April 1987 the North Pacific Fishery Management Council closed two areas around Kodiak Island, Alaska to bottom trawling and scallop dredging (Type 1 Areas). These areas were designated as important rearing habitat and migratory corridors for juvenile and molting crabs. The closures are intended to assist rebuilding severely depressed Tanner and red king crab stocks. In addition to crab resources, the closed areas and areas immediately adjacent to them, have rich stocks of groundfish including flathead sole, butter sole, Pacific halibut, arrowtooth flounder, Pacific cod, walleye pollock, and several species of rockfish.

These closures provide a rare opportunity to study the effects of an active bottom trawl fishery on soft-bottom, low-relief marine habitat because bottom trawling occurs immediately adjacent to the closed areas. In 1998 and 1999 studies were initiated to determine the effects of bottom trawling on these soft-bottom habitats. The goal of these studies was to determine if bottom trawling in some of the more heavily trawled areas of the Gulf of Alaska, has chronically altered soft-bottom marine communities. Direct comparisons were possible between areas that were consistently trawled each year and areas where bottom trawling had been prohibited for 11 to 12 years. The proximity of the closed and open areas allowed for comparison of fine-scale infauna and epifauna diversity and abundance and microhabitat and community structure. Continuous video footage of the sea floor was collected with an occupied submersible at two sites that were bisected by the boundary demarcating open and closed areas.

The positions of 155,939 megafauna were determined along 89 km of seafloor. At both sites we detected general and site-specific differences in epifaunal abundance and species diversity between open and closed areas that indicate the communities in the open areas had been subjected to increased disturbance. Species richness was lower in open areas. Species dominance was greater in one open area, while the other site had significantly fewer epifauna in open areas. Both sites had decreased abundance of low-mobility taxa and prey taxa in the open areas. Site-specific responses were likely due to site differences in fishing intensity, sediment composition, and near bottom current patterns. Prey taxa were highly associated with biogenic and biotic structures; biogenic structures were significantly less abundant in open areas. In addition a relationship between epifaunal biomass and sea whip abundance was apparent. This relationship indicates that sea whip habitat may have increased productivity. Recent studies in the Bering Sea have shown a similar functional relationship for sea whip habitat. Evidence exists that bottom trawling has produced changes to the seafloor and associated fauna, affecting the availability of prey for economically important groundfish. These changes should serve as a “red flag” to managers since prey taxa are a critical component of essential fish habitat. Results from the epifauna component of this study were presented at Effects of Fishing Activities on Benthic Habitats symposium held in Tampa during November 2002 and will be published in the American Fisheries Society Symposium 41 planned for publication in October 2004.

Ecological value of physical habitat structure for juvenile flatfishes. Principal Investigator – Allan W. Stoner (AFSC - RACE)
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Last updated: November 2004

Our previous field and laboratory studies have shown that some juvenile flatfishes have strong preferences for habitats with physical structure created by large epibenthic invertebrates, biogenic structures in the sediment, and sand waves. New experiments in large laboratory pools revealed that predation vulnerability of age-0 rock sole and Pacific halibut decreases substantially in the presence of habitat complexity presented by sponges. Predator-prey encounter rates decreased with habitat structure as predator swim speed and search behavior was impeded. Physical structure in the environment also impeded pursuit of prey. Young halibut were more likely to flee from predators than rock sole, but once flight was initiated halibut were more likely to escape than rock sole because of greater speed and agility. Subsequent experiments have shown that mortality decreases with amount of structural complexity, but the function is not linear. These experiments support an accumulating body of evidence that emergent structure in otherwise low-relief benthic habitats may play a critical role in the survival and recruitment of juvenile flatfishes.

During 2003 and 2004, field experiments were conducted near Kodiak to increase the structural complexity of large bare sand plots within flatfish nurseries. Bivalve shells were added (5 shells/m^2) to replicated plots. The modified plots and reference plots were then monitored with a towed camera sled at several intervals over the following month to characterize changes in the fish fauna occupying those plots. Unexpectedly, numbers of age-0 flatfishes decreased inside the structurally enhanced plots, but older flatfishes increased in abundance. Subsequent laboratory experiments showed that both large and small flatfishes are attracted to structurally complex habitats, but disturbance by the larger flatfishes resulted in the smallest fishes moving away. This illustrates the complexity of mechanisms behind fish/habitat associations.

Camera sled surveys for juvenile flatfishes were continued in three key nursery grounds near Kodiak during 2004, with the purpose of quantifying flatfish/habitat associations. Surveys were expanded to include a seasonal component during the early summer to fall recruitment season. Surveys have now been conducted for three years, yielding ~150 hours of video tape. Analysis of the video is currently underway. Statistical and spatially-explicit analyses of the distribution patterns will begin during FY-05. A new manuscript shows that densities of age-0 flatfishes recorded with our small camera sled are equivalent to the values provided in diver surveys and with small beam trawls. The camera gear, integrated with navigational data, provides a permanent record of the habitat, can be used for large spatial coverage, and has been a very effective way to explore fish/habitat associations.

Mapping marine benthic habitat in the Gulf of Alaska: geological habitat, fish assemblages, and fishing intensity. Principal Investigators - Jon Heifetz (AFSC – ABL), Kalei Shotwell (AFSC – ABL), Dean Courtney (AFSC – ABL), and Gary Greene (Moss Landing Marine Labs)
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Last updated: November 2004

Since 2001 we have mapped about 4,000 km^2 of seafloor in the Gulf of Alaska using a high-resolution multibeam echosounder that includes coregistered backscatter data. The mapping has mainly focused on areas in the vicinity of major groundfish fisheries such as Portlock Bank, Albatross Bank, Pamplona Spur, and Yakutat slope. This past year we focused our analyses on the 790 km^2 mapped area on Portlock Bank northeast of Kodiak. We evaluated the utility of integrating various sources of biological data with high resolution bathymetry and backscatter for describing benthic habitat, fish/habitat associations, and habitat specific fishing intensity. The biological information evaluated included data acquired from programs external to our study such as fishery observer data and trawl survey data and new data from the multibeam mapping and submersible dive transects. Habitat classification derived from mapping data indicated the presence of twenty-two different benthic habitats. Although biological data were limited on the mapped site for identifying fish/habitat associations and habitat specific fishing intensity, we were able to determine general and habitat specific fish distributions over the surveyed area through occurrence measurements and density calculations. We also created a density surface of the commercial fishing trawls in the mapped area that enabled basic patterns in fishing intensity by habitat type. We recommend a directed survey that collects biological samples in each of the established benthic habitats for more quantitative measurements of fish-habitat preference. Other properties within the area, such as oceanography and predator/prey fields, may also influence fish distributions and should be considered during benthic habitat classification.

Red king crab and bottom trawl interactions in Bristol Bay. Principal Investigators - C. Braxton Dew and Robert A. McConnaughey (AFSC - RACE)
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Last updated: November 2004

The 1976 U.S. Magnuson-Stevens Fishery Conservation and Management Act effectively eliminated the no-trawl zone known as the Bristol Bay Pot Sanctuary, located in the southeastern Bering Sea, Alaska. Implemented by the Japanese in 1959, the boundaries of the Pot Sanctuary closely matched the well-defined distribution of the red king crab (*Paralithodes camtschaticus*) population's mature-female brood stock, thus affording a measure of protection to the reproductive potential of the stock. In 1980, the point at which the commercial harvest of Bristol Bay legal-male red king crab reached an all-time high after a decade-long increase, domestic bottom trawling in the brood-stock sanctuary began in earnest with the advent of a U.S.-Soviet, joint-venture, yellowfin sole fishery. In the first year of trawling in the Pot Sanctuary, the Bering Sea/Aleutian Islands (BSAI) red king crab bycatch increased by 371% over the 1977-79 average; in 1981 the BSAI bycatch increased another 235% over that in 1980, most of which were mature females. As the number of unmonitored domestic trawls in the brood-stock area increased rapidly after 1979 and anecdotal reports of "red bags" (trawl cod-ends plugged with red king crab) began to circulate, the proportion of males in the mature population (0.25 in 1981 and 0.16 in 1982) jumped to 0.54 in 1985 and 0.65 in 1986. It is unlikely that normal demographics caused this sudden reversal in sex ratio. Our hypothesis is that sequential, sex-specific sources of fishing mortality were at work. Initially there were ten years (1970-1980) of increasing, male-only exploitation in the directed pot fishery, followed by a drastic reduction in the male harvest after 1980 (to zero in 1983). Then, beginning around 1980, there was an increase in bottom trawling among the highly aggregated, sexually mature female brood stock concentrated near the western end of the Alaska Peninsula, an area documented by previous investigators to be the most productive spawning, incubation, and hatching ground for Bristol Bay red king crab. There has been considerable discussion about possible natural causes (e. g., meteorological regime shifts, increased groundfish predation, epizootic diseases) of the abrupt collapse of the Bristol Bay red king crab population in the early 1980s. Our research focused on the association between record harvests of male crab in the directed fishery, the onset of large-scale commercial trawling within the population's primary reproductive refuge, and the population's collapse.

Short-term trawling effects and recovery monitoring in the eastern Bering Sea (2001-present). Principal Investigator - Robert A. McConnaughey (AFSC - RACE Division)
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Last updated: November 2004

Whereas our earlier work focused on chronic effects of trawling this ongoing multi-year study is a process-oriented investigation of short-term effects and recovery using a BACI experimental design. The study area is located within the Crab and Halibut Protection Zone 1 closed area, approximately 25-50 mi south and west of the chronic effects site. During a 35-day cruise in 2001, 6 pairs of predesignated 10-mi long research corridors were sampled before and after a trawling disturbance with commercial gear (NETS 91/140 Aleutian cod combination). Biological sampling consisted of 15 min research trawls for epifauna (n=72 total) and 0.1 m^2 van Veen grab samples for infauna (n=144 total at 2 per epifauna site). At each infauna-sampling site, a second grab sample (n=144 total) was collected for characterizing carbon and nitrogen levels in surficial sediments, as well as grain size properties. The experimental and control corridors were also surveyed before and after trawling using a Klein 5410 side scan sonar system, to evaluate possible changes in sediment characteristics and bedforms. Taken together, the 2001 data quantify short-term changes in the experimental corridors due to trawling.

To investigate the recovery process, these same corridors were resampled in 2002 during a 21-day cruise aboard the same 155' trawler *F/V Ocean Explorer*. Sampling effort was equally divided between experimental and control corridors and was consistent with the level of effort in 2001. There was no commercial trawling event in 2002. A total of 36 epifauna trawls, 72 infauna grabs, 72 sediment grabs, and one side scan survey per corridor were performed. Combined, these data quantify recovery in the experimental corridors after one year using corrections for temporal variability measured in the control corridors.

The experimental design for this study will accommodate one additional series of epifauna sampling and multiple years of grab sampling after 2002, however the final recovery monitoring event has not yet been scheduled. At present, processing of all 2001 and 2002 samples is complete and analysis is pending. Preliminary observations indicate a very diverse epifaunal community (approximately 90 distinct taxa) on very-fine olive-gray sand at 60 m depth. The seafloor appears to be brushed smooth in the 2001 side scan imagery, probably due to sizable storm waves and strong tidal currents that regularly disturb the area. Occasional video deployments on the trawls indicated somewhat greater complexity. Derelict crab pots are scattered throughout the study area and there is evidence of extensive feeding by walrus.

A systematic framework for assessing mobile fishing gear effects. Principal Investigators
Robert A. McConnaughey and Cynthia Yeung (AFSC – RACE Division)
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Last updated: November 2004

To some degree, our understanding of fishing gear impacts is constrained by the experimental methods being used. In general, the process of understanding mobile gear effects has three distinct phases. It begins with the identification of changes caused by gear contact, followed by controlled studies to determine the ecological effects and, ultimately, decision making based on some form of cost-benefit analysis. Nearly all of the research to date has targeted the specific changes in benthic invertebrate populations that occur when mobile fishing gear, particularly bottom trawls, contact the seabed. This worldwide focus on benthic invertebrates reflects their limited mobility and vulnerability to bottom-tending gear, and observations that structurally complex seabeds are an important element of healthy productive benthic systems. Effects are typically measured as changes in abundance or community structure. However, despite decades of intensive research, the overall impact of mobile fishing gear on marine ecosystems and, in particular, on fish production is largely unknown. This reflects a need for substantially more research on the ecology of the affected invertebrates and their linkages to managed fish stocks, as well as more systematic studies of disturbance effects. Although certain gross generalities are possible, site-specific results are likely given variation in the composition of the benthos as well as the intensity, severity and frequency of both natural and anthropogenic disturbances. Because of the manner in which study areas are typically selected, any application of findings to other geographic areas is extremely tenuous. As such, there is a strong need to examine the issue more systematically so that research can move ahead from “case studies” of effects to the more interpretive (i.e. second) phase of investigation. To this end, we are working to identify areas with distinct invertebrate assemblages within which replicated *experiments* (not samples) could be placed and the aggregate findings applied to the entire area. The approaches being investigated are of two primary types and are detailed in sections that follow: (1) mapping surficial sediments as a physical proxy for invertebrate assemblages, given benthic organisms have demonstrated strong affinities for particular substrates and (2) analyzing spatial patterns of the benthic invertebrates themselves. Whereas the former approach has potential advantages in terms of cost and relatively rapid spatial coverage, the latter has clear advantages related to the direct nature of the measurements since, after all, invertebrates are the *de facto* measure of gear effects.

Evaluating single beam echosounders for synoptic seabed classification. Principal Investigators Robert A. McConnaughey and Stephen Syrjala (AFSC – RACE Division)
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Last updated: November 2004

Acoustic technology is particularly suited to synoptic substrate mapping since quantitative data are collected rapidly and in a cost-effective manner. The QTC View seabed classification system (Quester Tangent Corporation, Sidney, B.C.) is capable of background data acquisition during routine survey operations. Echo returns from the seafloor were simultaneously collected at two frequencies (38 and 120 kHz) along a 9,000 nm trackline in the eastern Bering Sea (EBS) during a 1999 hydroacoustic fishery survey on the *R/V Miller Freeman*.

Acoustic diversity directly represents substrate diversity. Surface roughness, acoustic impedance contrast, and volume homogeneity are characteristic of different seabed types, and these factors influence echo returns from a vertical-incidence echo sounder. The standard QTC method uses a set of algorithms to extract features from individual echoes. These features include cumulative amplitude and ratios of samples of cumulative amplitude, amplitude quantiles, amplitude histogram, power spectrum, and wavelet packet transform. Principal components analysis (PCA) is used to reduce the full set of features to the three linear combinations that explain a large fraction of echo (seabed) variance. A three-factor cluster analysis then groups the echoes into distinct seabed types based on their acoustic diversity. Variation in continuous seabed properties is thus represented in discrete classes of seabed. The optimum classification scheme for any particular data set strikes a balance between high information content (i.e., many acoustic classes) and high confidence in the assigned class (e.g., if only one class). Clustering methods typically require significant user input to decide which class to split next and when to stop splitting. To overcome this subjectivity and develop a fully-automated objective process, a new application of the Bayesian form of the Akaike Information Criterion (BIC) was developed to guide the clustering process. Because of the computational intensity of the Bayesian method, analytical methods based on simulated annealing have been introduced to improve the program's ability to locate the global minimum (rather than a local minimum) of the BIC function. Alternatively, the three principal components may themselves be used to represent acoustic seabed diversity.

Results of this collaborative research with QTC include guidelines for acoustic mapping of seabeds and an optimal classification scheme for the EBS shelf. A total of 14 distinct classes of bottom types (clusters) were identified from the 38 kHz data. These results have now been merged with 22 years of RACE trawl survey data from the EBS shelf (1982-2003). Statistical analyses are being conducted to examine the degree to which acoustic variability corresponds to environmental features that influence the distribution and abundance of groundfish and benthic invertebrates.

Reconnaissance mapping with side scan sonar. Principal Investigator Robert A. McConnaughey (AFSC – RACE Division)
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Last updated: November 2004

Upon completion of the 2002 bottom trawl study in the eastern Bering Sea, a reconnaissance of Bristol Bay seafloor habitats was undertaken using a high-resolution 500 kHz side scan sonar (Klein 5410). The reconnaissance effort was centered on an 800 mi^2 area of central Bristol Bay that has never been surveyed by NOAA hydrographers. The primary research objective is to identify large homeogenous regions that would be the basis for more systematic study of mobile gear effects. Secondary objectives include a study of walrus feeding ecology, a comparison of supervised and unsupervised classification methods for EFH characterization, and potential updates of nautical charts for the area.

A 150 m swath of bathymetric data and imagery were collected along survey lines totaling nearly 600 linear miles. The survey intentionally intersected six of the Bering Sea trawl study corridors currently being studied (above) in order to provide a spatial context for these results. In support of coordinated EFH characterization studies in the area, the reconnaissance survey also crossed 18 RACE Division trawl survey stations and followed 78 mi of seabed previously classified using a *QTC View* single beam acoustic system. Imagery was systematically groundtruthed using an underwater video camera and van Veen grab samples. Overall, a great diversity of complex sand-bedforms and other geological features were encountered in the survey area.

Thus far, a subset of the data has been classified using geological (supervised) and statistical (unsupervised) methods. A new software product, *QTC Sideview*, uses automated processing techniques to read the data on a line by line basis, segment the imagery, extract features based on pixel intensity and image texture, and classify the segments using multivariate statistics. Thirteen distinct acoustic classes were identified. A geologist identified seven major bottom types: (1) degraded bedforms, (2) hummocky seabed, (3) mixed sediments, (4) sand lenses, (5) smooth seabed, (6) sand ribbons, and (7) sand waves, with subdivisions loosely based on scale and shape of features, acoustic reflectivity, and presence or absence of walrus feeding tracks. There was general agreement, albeit with important differences, between the methods. The statistical classification did not seem to identify the differing scales of bedforms identified by the geologist, nor did it distinguish between sand waves and sand ribbons. On the other hand, the statistical classification used information at the scale of the acoustical wavelength (~3 mm) that may not have been considered the geologist. Further experimentation with the image patch size chosen for the statistical classification may improve the correlation between the methods. The Klein 5410 side scan sonar system is co-owned with the NOAA Office of Coast Survey.

Spatial and temporal patterns in eastern Bering Sea invertebrate assemblages. Principal Investigators Cynthia Yeung and Robert A. McConnaughey (AFSC – RACE Division)
Contact: Cynthia.Yeung@noaa.gov
Last updated: November 2004

Invertebrate taxa exhibit highly specific geographical patterns reflecting their environmental requirements and ecological niches. These animals add important vertical complexity to the otherwise flat seabeds of the Bering Sea shelf and are also prey for commercially valuable species. In order to (1) characterize benthic habitats by invertebrate communities, and (2) detect temporal and spatial changes in community structure, invertebrate bycatch recorded during the annual RACE Division groundfish trawl surveys in the eastern Bering Sea (1982-2002) was examined. This study lays the groundwork for identifying the underlying biotic and environmental dependencies that define EFH for the benthic component of the eastern Bering Sea ecosystem. Spatio-temporal variability in the benthic invertebrate community structure is also a measure of natural and anthropogenic disturbance on the benthic environment, and clear, established community patterns could provide a basis for systematic study of fishing gear impact.

Of some 400 invertebrate taxa recorded over all the surveys, twenty-eight taxa were selected as the ‘core’ group for community analysis. They represent the dominant taxa in every survey either by frequency of occurrence (presence) or by biomass (kg/ha). Stations in each survey were grouped by the similarity of their assemblage of core taxa using hierarchical clustering. A persistent, interannual spatial pattern emerged of an “inshore” and an “offshore” group partitioned approximately along either side of the dynamic oceanographic “inner front” that runs mostly along the 50 m isobath (Figure 167). Offshore-type stations are mostly of > 50 m in depth; inshore-type stations are characteristically of < 50 m in depth. Stations extending southwest along the coast of the Alaska Peninsula from Bristol Bay up to about the 100-m isobath near Unimak Pass and some around the Pribilof Islands also typically fall into the inshore category. The key inshore indicator taxon is the sea star, *Asterias amurensis*; the key offshore indicator taxa are Gastropoda, Paguridae, and the snow crab *Chionoecetes opilio*.

The inshore-offshore spatial structure of the epibenthic communities is robust across the 21-year time series. Variations in this typical structure are only evident in 1982-84 and 1998-99 (Figure 167). Both periods saw a shoreward reduction in the domain of the inshore community (shoreward expansion of the domain of the offshore community). These anomalies coincided with significant climate events, namely the extreme El Niños in 1982-83 and 1997-98, and the Pacific Decadal Oscillation circa 1997-98. Multivariate ordination also indicates a trend of movement in the center of biomass of at least some of the core taxa towards the offshore (west). The dampening of these shifts in biomass distribution in the recent decade could signify the establishment of a stable and perhaps new spatial distribution of the taxa.

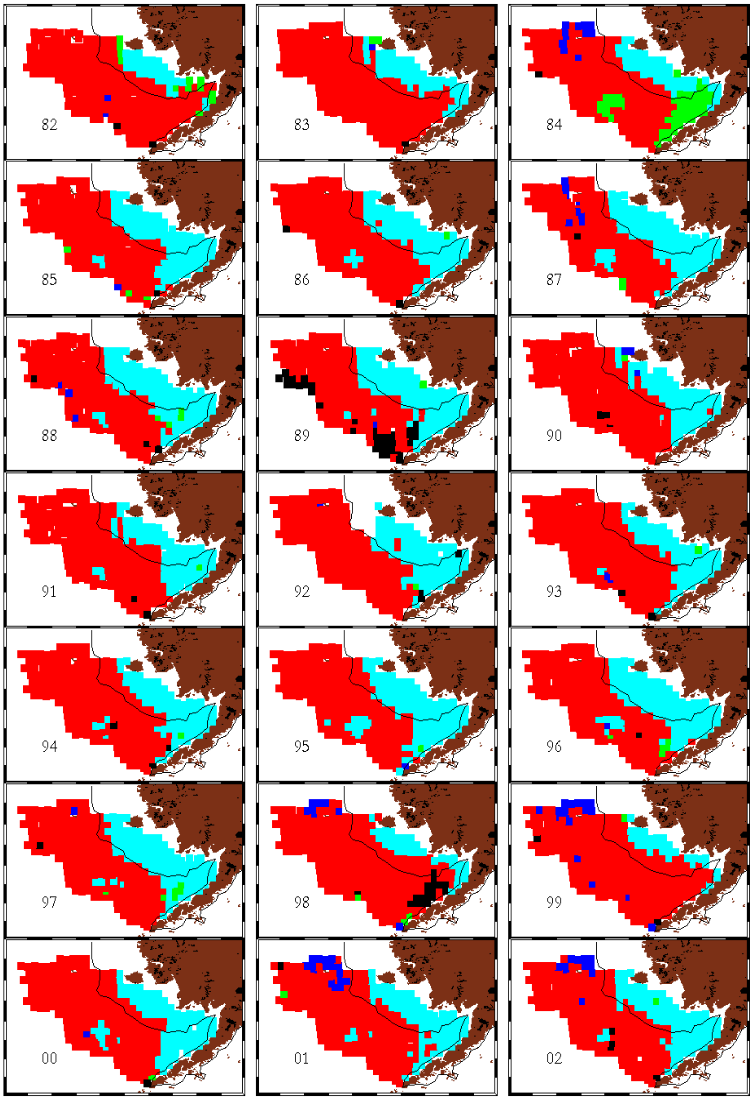

Figure 167. Survey stations clustered by the similarity of their core taxa assemblage. A maximum of 5 clusters are displayed. Stations are color-coded by cluster membership for visual interpretation. Colors are assigned to clusters to facilitate the spatial comparison of station groupings across surveys, not necessarily to imply the same colored stations across surveys have the same underlying community structure. Solid black line delineates the 50 m isobath. The two largest clusters are respectively 'inshore' (cyan) and 'offshore' (red) of the 50 m isobath. Each panel has the 2-digit survey year.