APPENDIX C

Ecosystem Considerations for 2006

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

- Completed and posted a trial-website for the Ecosystem Considerations contributions and underlying data on the NOAA intranet. This will be made available on the internet after the final draft is completed this fall (December 2005).

- Updated the following sections in April 2005:
  - Introduction
  - Ecosystem assessment
  - Trends in groundfish biomass and recruits per spawning biomass
  - Seabirds
  - Combined standardized indices of recruitment and survival rate
  - Average local species richness and diversity of the groundfish community
  - Total catch-per-unit-effort of all fish and invertebrate taxa in bottom trawl surveys
  - Time trends in bycatch of prohibited species
  - Time trends in groundfish discards
  - Trophic level of the catch
  - Total annual surplus production and overall exploitation rate of groundfish
  - Groundfish fleet composition.

- Added the following sections in April 2005:
  - Executive summary with bulletized list of current issues
  - Western Alaska juvenile salmon ecology along the eastern Bering Sea shelf

- Updated the following sections in September 2005:
  - Ecosystem assessment
  - Executive summary
  - North Pacific climate overview
  - Ocean surface currents -PAPA trajectory index
  - Winter mixed layer depths at GAK 1 in the northern GOA
  - Eddies in the GOA
  - Bering Sea temperature and ice cover
  - Pollock survival indices
  - Bering Sea Zooplankton
  - Gulf of Alaska spring ichthyoplankton interannual trends study
  - Relationships between flatfish spatial districtions and the cold pool from 1982-2003
  - Gulf of Alaska small mesh trawl survey trends
  - Marine mammals
  - Status of groundfish, crab, salmon and scallop stocks
  - Total annual surplus production and overall exploitation rate of groundfish
  - Time trends in bycatch of prohibited species
  - Fishing overcapacity programs

- Added the following sections in September 2005:
  - Variations in water mass properties during fall 2000-2004 in the eastern Bering Sea-BASIS

- o Variations in phytoplankton and nutrients during fall 2000-2004 in the eastern Bering Sea- BASIS
- o Variations in juvenile sockeye and age -0 pollock distribution during fall 2000-2004 in the eastern Bering Sea- BASIS

- Deleted the following section in September 2005:
  - o Empirical evidence for North Pacific regime shifts from 1965-2003

- Updated the following section in November 2005:
  - o Added month and year of last update under the title of each contribution
  - o GOA survey bottom temperature analysis
  - o Summer bottom and surface temperatures – Eastern Bering Sea
  - o HAPC biota – Gulf of Alaska
  - o HAPC biota– Bering Sea
  - o Essential Fish Habitat
  - o Effects of Fishing Gear on Seafloor Habitat (table of research and list of publications)
  - o Nutrients and Productivity Processes in the southeastern Bering Sea
  - o Forage – Gulf of Alaska
  - o Forage – Eastern Bering Sea
  - o Prince William Sound Herring
  - o Update on EBS winter spawning flatfish recruitment and wind forcing
  - o ADF&G Gulf of Alaska Trawl Survey
  - o Bering Sea crabs
  - o Stock-recruitment relationships for Bristol Bay red king crabs
  - o Miscellaneous species – Gulf of Alaska
  - o Bering Sea jellyfish
  - o Miscellaneous species – Bering Sea
  - o Grenadiers in Alaska
  - o Seabirds (bycatch tables)
  - o Alaska Native Traditional Environmental Knowledge of Climate Regimes
  - o Time trends in bycatch of prohibited species
  - o Time trends in groundfish discards
  - o Areas closed to bottom trawling in the EBS/AI, and GOA
  - o Hook and line (longline) fishing effort in the GOA, BS, and AI
  - o Groundfish bottom trawl fishing effort in the GOA, BS, and AI
  - o Groundfish pelagic trawl fishing effort in the EBS
  - o Groundfish fleet composition

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

November 2004 Plan Team Meeting Comments:
1. The Teams discussed the overall goals of the Ecosystem Chapter and the different ways to view ecosystem considerations, i.e from the interaction of ecosystem considerations upon a single species stock assessment, as well as in a more aggregated form to look at the impact of the aggregated catch on the ecosystem as a whole. The latter is acknowledged to be the far more difficult task, but potentially greatly beneficial as an overall objective. The Teams encourage the Ecosystem Chapter authors to include a discussion of this type of backwards look at the previous year and how the TACs established for the previous year are evaluated as an aggregated impact on the ecosystem.

Response:
Total ecosystem impacts of aggregated catches are part of the ecosystem assessment objectives relating to ecosystem energy removal and redirection. Thus, total catch removals and discards and offal production need to be related to ecosystem (or community) changes. Trends in the slope and intercept of the size diversity spectrum relative to total catches are one way of looking at impacts. Also time trends in scavenger populations relative to discards and diversity indices relative to total removals would indicate possible impacts.

2. There was some discussion about splitting the Ecosystem Considerations section into two sections: Ecosystem Assessment and Ecosystem Status and Trend Information.

Response:
The editor did not split the Ecosystem Considerations into two sections this year because the Ecosystem Assessment is still in a draft format. Predictions from the multispecies model will be incorporated into this assessment in future drafts when bycatch data can be updated and when some methodological problems are solved.

December 2004 SSC Comments:
1. The Ecosystems Considerations ... document needs a concise overview section that emphasizes a few critical points that may need to be taken into consideration in the development and evaluation of the SAFE documents. Elements that should be included are: major changes in ocean climate that could affect recruitment (e.g., changes in advection patterns, water temperature, or mixing events that could affect ecosystem productivity), changes in prey populations, changes in predator populations, and major changes in impacts on other or protected species, and the aggregate effects of humans on the ecosystem. In addition, where possible, analyses of the biological and fisheries implications of these changes should be provided where known. Thus, this section of the document would provide a heads-up to changes that could affect managed fish population in the short or long term, or for critical conservation issues. Additionally, when appropriate, this section could point to gaps in our ability to interpret the changes noted and the potential need for research.

Response:
A summary of important and interesting trends was added as the Executive Summary in the front of the Ecosystem Considerations section.

2. The purposes of the Ecosystem Consideration Report will be best served if it does not become a repository of annual progress reports that provide information on the status of research programs, but little in the way of results and analysis of their significance. These might best be included as appendices that could inform the reader about ongoing work that addresses information needs identified in the chapter.

Response:
In this (November) draft, the summaries of studies pertaining to essential fish habitat and the effects of fishing gear on seafloor habitat were placed in an appendix. A summary of habitat research was kept in the main part of the Ecosystem Indicators section.

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 will be further developed to form a synthesis and will be framed in terms of the effects that humans have on the ecosystem versus the effects of the ecosystem on humans. This will be addressed next year (2006).

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

Climate
It has been shown that the North Pacific atmosphere-ocean system included anomalies during the winter of 2004-05 that were unlike those associated with the primary modes of past variability. This result suggests a combination of two factors: (1) that the nature of North Pacific variability is actually richer in variability than appreciated previously, and (2), that there is the potential for significant evolution in the patterns of variability due to both random, stochastic effects and systematic trends such as global warming. Notably, at the time of this writing, it cannot be determined whether the North Pacific is heading into a positive PDO-like condition or some other state. The Bering Sea (BS) shows three multidecadal regimes in surface air temperatures (SAT) fluctuations: 1921-1939 (warm), 1940-1976 (cold), and 1977-2005 (warm). It is worth noting that the two previous regimes had a similar pattern, when SAT anomalies were strongest at the end of the regime, right before the system switched to a new one. 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 (Rodionov et al., this report).

2004-2005 was a weak El Nino year, with minor or atypical impacts in the North Pacific. 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). May 2005 sea surface temperatures in the EBS continued to be warm, indicating that summer bottom temperatures were also warm, since May sea surface temperature is a good predictor of summer bottom temperatures in the EBS (Rodionov, this report).

Biological Trends
Coinciding with the warm conditions in the eastern BS, summer zooplankton biomass has been anomalously low in the past five years (2000-2004) in all four geographic domains (Napp and Shiga, this report). Jellyfish biomass, sampled in the EBS bottom trawl survey, has also been low in the past 5 years (2001-2005) relative to the peak biomass that occurred in 2000 (Lauth, this report). Summer bottom trawl surveys in the EBS, although not designed to sample forage fish, indicate the abundance of sandlance was low during this period (2000-2005) (Lauth, this report). The warming trend in the EBS may have implications for some flatfish because their habitat selection appears to be influenced temporally by varying environmental conditions. Rock sole and flathead sole appear to be distributed further north in warmer conditions (Spencer, this report).

In the GOA, large- and small-scale environmental conditions appear to affect the distribution and abundance of larval fish. Basin-scale environmental conditions in February through April, and local-scale conditions in late-March through early-April, are most influential in terms of prevalence of fish larvae in late spring (Doyle et al., this report). New analyses conducted on the GOA small mesh survey data, to account for spatial and temporal variability in the survey samples, confirm that the GOA biological community shifted after the 1977 climate regime shift. Observed changes include a trend towards increased catches of jellyfish, arrowtooth flounder, walleye pollock, flathead sole and decreased catches of Pandalid shrimp, capelin, Pacific sandfish red king crab, and sculpins. Although, catches of pandalid shrimp increased after 1998, there is no evidence at this time of a rapid community reorganization, such as that which followed the 1976-77 shift (Litzow, this report). Eulachon catches have also been high since about 2001 in both the nearshore GOA small mesh survey and the offshore NMFS GOA bottom trawl survey.

Until 2002, the majority of seabird species showed no discernable population trends in both the BS and GOA. Of those populations that did show a trend, the majority of populations in the SE BS (including the

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Pribilof Islands) and GOA were decreasing and, in the SW BS, were increasing. Overall, breeding chronology was early or typical in 2002 for most regions and species within feeding guilds, and in fact there were no cases of later than normal chronology (Fitgerald et al., this report).

The number of northern fur seal pups born on the Pribilof Islands continued to decline. However, increases in Steller sea lion non-pup counts were observed in 2004 in all areas except the central GOA (slight decline) and the eastern GOA (similar counts as 2002). These time series are updated biennially and updates to these time series in 2006 will indicate whether these trends in marine mammal populations continued. 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 increases in the rate of predation by killer whales (Sinclair and Testa, this report).

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. The spatial distribution of individual species appears to drive changes in species richness. Local species diversity is a function of the number of species and their relative abundance in each haul. Changes in local species richness and diversity are strongly confounded with natural variability in spatial distribution and relative abundance (Mueter, this report).

Annual surplus production (ASP) indices, the sum of new growth and recruitment minus deaths from natural mortality, suggest high variability in groundfish production in the EBS and a decrease in production between 1978 and 2004. Production in the GOA was much lower on average, less variable, and decreased slightly from 1978 to 2004. Because trends in ASP indices are largely driven by variability in walleye pollock in the EBS and variability in walleye pollock and arrowtooth flounder in the GOA, the index was also examined without these stocks included. The results suggest a strong, significant decrease in aggregate surplus production of all non-pollock species from 1978 – 2004 in the Bering Sea and a similar decrease in surplus production aggregated across stocks (excluding pollock and arrowtooth) in the GOA over this period. 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 1978-2004. In the Gulf of Alaska, long-term trends in ASP were less pronounced but declines were evident for 5 out of the remaining 9 species, while three species showed no obvious long-term trends and (besides arrowtooth flounder) only thornyhead production increased notably from the late 1970s to the 1990s. Long-term declines in ASP and low production in recent years in the EBS are a result of low recruitment, reduced growth, increased natural mortality or some combination thereof. These declining trends suggest that substantial reductions in total catches may be necessary in the near future. It is unclear whether existing levels of precaution implemented at the single-species level will be sufficient to deal with declines in overall system productivity when trying to meet multi-species or ecosystem objectives (Mueter, this report).

Fishing Impacts
Time trends in bycatch of prohibited species are examples of ecosystem-based management indices that may provide early indications of direct human effects on ecosystem components or provide evidence of the efficacy of previous management actions. Interestingly, the bycatch of "other salmon" and herring increased markedly in 2003 and 2004. Between 2002 and 2003, herring bycatch increased by over 600% and "other salmon" bycatch more than doubled. After the dramatic increase in 2003, the herring bycatch increased again by about 42% and "other salmon" bycatch almost doubled in 2004.

Most of the herring bycatch in all years occurs in the BSAI trawl fisheries, primarily during the months of July, August and September with smaller amounts in January through March and October. The recent rise in bycatch can be partly explained by increases of herring biomass; the biomass of Kuskokwim herring, for example, is estimated to have increased by about 34% in 2003 and again by about 32% in

2004. Observer data reveals differences in the distribution of both effort (all pelagic-trawl hauls) and bycatch (hauls with herring in the species composition) over the years 2002-04. In most months of 2003 and 2004, the amount of effort and bycatch increased noticeably in the northwestern-most portions of the fleet's range compared to 2002.

Part of the 2003 increase in "other salmon" bycatch could be explained by the 33% increase in the overall catch of "other salmon" in 2003 compared to 2002. The "other salmon" bycatch nearly doubled again in 2004, despite an almost 6% reduction in the overall catch.   In 1994, the North Pacific Fisheries Management Council and NMFS established the Chum Salmon Savings Area (CSSA) in parts of the Bering Sea and at times when salmon bycatch had been highest based on historical observer data. Unfortunately, in both 2003 and 2004 the highest chum salmon bycatch rates were outside of the CSSA and after its closure. Similar problems occurred in 2003 and 2004 with Chinook salmon bycatch outside of the Chinook Salmon Savings Area—the highest bycatch rates were encountered by the pollock trawl fleet outside of the Savings Area after regulations had forced its closure. The resulting Chinook salmon bycatch was about 28% higher in 2003 and 41% higher in 2004 than the long-term average over the period 1994-2002. To address these problems, the Council is considering other means to control salmon bycatch (Hiatt and Terry, this report).

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% (Fitzgerald et al., this report).

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 2000-2005 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.

Ecosystem Considerations sections from 2000 to the present are available on the Alaska Fisheries Science Center website at: http://access.afsc.noaa.gov/REFM/REEM/EcoWeb/EcosystemIndex.cfm
And 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 of the Bering Sea/Aleutian Islands and Gulf of Alaska Management Regions

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Summary

The primary intent of this section is to summarize 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. This is the second year that this assessment strategy is being used (first year was 2003) and not all of the modeling tools are ready for use in projections.

Climate regime shifts occurred in 1977, 1989, and possibly 1998 and effects of the first two shifts were observed in the Bering Sea and Gulf of Alaska. When the west coast waters 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 regime, the Bering Sea may become even warmer, with fish biomass transitioning northward allowing pollock a larger domain at the expense of cold and ice-adapted species, 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. Ecosystem responses to climate regime 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.

No significant adverse impacts of fishing on the ecosystem relating to predator/prey interactions, energy flow/removal, or diversity were noted. There are gaps in understanding the system-level impacts of fishing and spatial/temporal effects of fishing on community structure and prey availability. Fishing mortalities from a multispecies bycatch model can be used to drive multispecies and ecosystem predator/prey simulations to evaluate the predator/prey implications of these fishing strategies. Predictions from the multispecies model will be incorporated into this assessment in future drafts when bycatch data can be updated and when some methodological problems are solved. Validation of models, research and models focused on understanding spatial processes, and improvements in monitoring systems would improve our current understanding. 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.

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). Climate regime shifts occurred in 1977, 1989, and 1998 and effects of the first two shifts were observed in the Bering Sea and Gulf of Alaska. Changes were observed in 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 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's provides the historical perspective of status and trends of ecosystem components and ecosystem-level attributes using an indicator approach. Multispecies and ecosystem models provide the tools for prediction of possible future effects and form the basis for assessment of the possible future effects of fishing on BSAI and GOA ecosystems. Multispecies bycatch model predictions of catch, bycatch, and characteristics of various fishing strategies provide future predictions of realistic fishing mortalities expected for groundfish stocks and the bycatch of nontarget species in groundfish fisheries given the present bycatch and OY constraints of the groundfish fisheries of the BSAI and GOA. Fishing mortalities from the multispecies bycatch model can be used to drive multispecies and ecosystem predator/prey simulations to evaluate the predator/prey implications of these fishing strategies. These predator-prey models are not used for year-to-year management advice but provide a method for assessing the possible medium and long-term implications of fishing strategies on predator/prey relationships and energy flow in these systems. Predictions from the multispecies model will be incorporated into this assessment in future drafts.

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. Previous ecosystem analyses for the draft groundfish FMP environmental impact statements categorized effects into three main classes: predator/prey, energy flow and removal, and diversity. This report summarizes potential ecosystem impacts based on 2004 harvest recommendations. Unlike the Final Programmatic Supplemental Environmental Impact Statement (FPSEIS) (NMFS 2004b), which evaluated a whole suite of management alternatives, this analysis considers only fishing mortality changes encompassed by the TAC Environmental Assessment alternatives and OY cap constraints.

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

Data Sources and Models

Quantitative measures of some of the indicators mentioned above in a historical sense are derived from this report. Predictions of the future ecosystem status based on these indicators will be derived from three modeling approaches in future assessments. These model approaches include: 1) multispecies bycatch model, 2) age-structured multispecies predator/prey forecast, and 3) biomass dynamics predator/prey forecast. The first approach was used in the NMFS Programmatic Supplemental Alaska Groundfish EIS (NMFS 2003) to forecast dynamics of target groundfish species and bycatch amounts of other species. There are still some methodological problems doing forecasts with the latter two approaches that need to be resolved before their use in this assessment. Some of the issues that require further work include properly modeling prohibited species bycatch and the OY cap constraints along with target species catches. Recently, bycatch data has been unavailable due to changes in the catch accounting system, but hopefully these will be available soon. The other main issue that needs resolution is standardizing the way recruitment is handled in all three of these modeling approaches. These issues will be worked on in the coming year.

The first modeling approach is the multispecies bycatch model of J. Ianelli, described in NMFS (2003), Section 4.1.5. This bycatch model takes OY constraints, PSC bycatch limits, and the characteristic bycatch matrix of target groundfish fisheries along with single-species groundfish assessment parameters to project future catch and biomass trends of age-structured groundfish species and bycatch amounts of other species based on various fishing scenarios. Details of this modeling approach have been provided to the NPFMC and are contained in the final groundfish FPSEIS (NMFS 2004b). One purpose of using this model is to obtain realistic estimates of catch and instantaneous fishing mortality rates of target groundfish species for particular fishing rate strategies given the PSC bycatch limits and OY cap that constrain individual groundfish fisheries in this region from achieving allowable biological catch limits. This model can also provide indicators of fishing effects on non-target species through its bycatch estimates and some ecosystem level indicators derived from total catch.

In the 2003 Ecosystem Assessment (Jurado-Molina and Livingston 2003) the multispecies bycatch model was used to derive indicators for assessing the impacts of harvest levels on the ecosystem. The indicators chosen were ones that would characterize changes in predator/prey relationships, energy flow, and diversity. In predator/prey relationships, model outputs were used to obtain estimates of pelagic forage biomass of target species (walleye pollock and Atka mackerel in the BSAI and walleye pollock in the GOA). Total biomass of these species was used to derive this index. Bycatch estimates of squid, herring, and the managed forage species group from the model were used as another indicator of the magnitude of fishing impacts on these other forage species. Trophic level of the catch was an indicator of fishing down the food web, which is the sequential fishing down of species high in the food chain such that over time the fisheries are left only with mid-trophic level species as targets. Model estimates of catch biomass for each target and nontarget species group were combined with estimates of trophic level of each species group derived from food habits information to obtain estimates of the overall trophic level of the catch for each alternative. Fishing effects on top predator species were evaluated through model estimates of bycatch of sharks and birds. Model estimates of total retained catch and discards for target and nontarget species were used as an indicator of the effects of the alternatives on energy cycling characteristics of the ecosystem through energy removal (total retained catch) or energy redirection (discards). Finally, model estimates of bycatch of HAPC biota were used as an indicator of effects of fishing on functional (structural habitat) diversity.

It should be noted that the term "bycatch" in this section does not refer specifically to discards and is used to indicate incidental catch levels, whether those are discarded or not. Discarded amounts of target and incidental catch species are specifically noted and termed "discards."

The second modeling approach is the age-structured multispecies forecast (MSFOR), which uses predator/prey suitability estimates derived from MSVPA of dominant groundfish species in the eastern Bering Sea. This model will provide indicators of change mainly for target groundfish species such as walleye pollock, Pacific cod, Greenland turbot, arrowtooth flounder, rock sole, and yellowfin sole given the fishing scenarios and predator/prey relationships defined for these species in the eastern Bering Sea. Because this is an age-structured model, it may provide more clear understanding of the possible long term implications of fishing on target species that are also prey of other species.

The final modeling approach is the use of ECOPATH/ECOSIM, which approximates a whole ecosystem approach to evaluating fishing effects. Models for the EBS, GOA, and AI have been developed and are being investigated for providing indicators of change that relate more to ecosystem-level properties of energy flow and organization.

As with methods such as MSVPA/MSFOR, Ecopath dynamic methods (Ecosense) may be divided into retrospective and predictive analyses. In practice, the two methods must be used in concert, with retrospective analyses providing calibration for future scenario exploration.

The current eastern Bering Sea and Gulf of Alaska retrospective analyses have fitted model-predicted biomasses from 1991-2002 to time series data, in order to produce point estimates in vulnerability (prey selectivity/ interaction terms) and residual mortality for each species (see Jurado-Molina and Livingston 2003). In effect this replaces the equilibrium assumptions of the initial Ecopath model with a set of compensatory rate equations for each species that do not necessarily start in equilibrium. Since model outputs include predicted historical consumption rates for all species in the model, such retrospective analyses may be used to compare the natural range of variation of consumption of trophic levels or guilds to historical fisheries removal.

However, for predictive purposes a few major challenges remain. In Ecosim, species for which recruitment is tracked (age-split species, including all major groundfish) are modeled using delay-difference equations calibrated to measured growth rates. To produce a stock recruitment relationship, an additional set of parameters are included as detailed in Walters et al. 1997. Specifically, the number of age-0 (larvae) produced is a function of the number and average weight of adults and the amount of food consumed by adults in a given year. A pair of parameters governs a nonlinear "strategy trade-off" curve which determines whether, given the current number and weight of adults and availability of food, food is apportioned to somatic or reproductive growth. Including such differences between species in these basic aspects of life-history strategy (e.g. King and McFarlane 2003) may be a key to correctly capturing the food web's overall response to fisheries exploitation.

In the model, after the numbers of larvae are predicted by above method, their predation mortality is explicitly modeled as a function of their predators' foraging through recruitment age. Thus, factors such as increased cannibalism in pollock are directly modeled into the resulting number of recruits. Initial tests of these methods, however, revealed that these models still lack the capacity to predict recruitment for the historical time period. As recruitment for many species in Alaska seems to contain strong extrinsic (environmental) components it is not surprising that the addition of explicit reproductive strategy and mortality parameters does not greatly improve predictive capability for groundfish recruitment.

Therefore, for the near term it is likely that these models will be used in a manner similar to the multispecies bycatch model; that is, for forecast scenarios "future" recruitment will be drawn from distribution of past observed recruitment levels, and additionally scenarios of regime shifts of recruitment will be modeled. Preparations for such scenarios will require further analysis; with over 60 groundfish species to consider, sensitivity analyses indicate that some examination of appropriate covariance structures between multiple recruitment inputs is desirable.

The current version of Ecosense allows for the specification of fisheries by projected gear effort, catches, or exploitation rates. However, no dynamic (adaptive) adjustments to fishing rates are currently implemented. Initial attempts to apply the 20-year catch streams generated by the the multispecies bycatch model for the analysis of SEIS alternatives indicated that, for some alternatives, divergence between Ecosense and multispecies bycatch predictions were magnified by not including such dynamic optimization (adaptive management policies) directly within Ecosense. Continued scenario analysis will require the simulation of such adaptive policies.

Finally, in order to model 140+ species groups in three ecoregions, the coordination, review, and provision of data from multiple agencies and divisions within NOAA, for the purposes of making timely updates to these models, is expected to be a major component of this ongoing work. The implementation of consistent data management for use in these models is currently underway.

Fishing Scenarios
The following fishing scenarios are proposed to evaluate the present TAC-setting strategy of groundfish fisheries within the context of the PSC bycatch limits and OY cap that constrain these fisheries. These scenarios are similar to those alternatives considered in the TAC EA. Some differences are that we consider some scenarios with and without the OY cap to highlight the effect of that cap in constraining catch in the BSAI and to provide an evaluation of the implications of this constraint from a multispecies and ecosystem point of view. This evaluation was recommended by the NPFMC F40 review panel. Also, TAC EA alternative 4 will not be modeled here because that alternative is an attempt to mimic the constraints that the multispecies bycatch model explicitly considers. There may not be much contrast between alt 1 and alt2.2. Note that for the GOA, Alts 2.1 and 2.2 are identical (since the OY cap doesn't typically constrain TAC). Also, the difference between Alt 1 and 2.2 is only the author's adjustment.

Alt 1   : F= max Fabc, no OY cap
Alt 2.1 : status quo like, all caps in as before, not like PSEIS' PPA's but with Author's recommendations
Alt 2.2 : Same as Alt 2.1 but w/o 2 million ton cap
Alt 3   : As Alt 2.1 but half of maximum permissible Fabc's (for TAC setting)
Alt 5   : F=0

Results

The following is a summary of key ecosystem indicators in the baseline, obtained primarily from the Ecosystem Considerations Section (Tables 2-6). As mentioned in the Methods section, predictions from the multispecies and ecosystem predator/prey models are not yet available because methods for forecasting using the same bycatch and OY constraints and recruitment assumptions as the multispecies bycatch model are still being derived and updated bycatch data is not yet available. As these models and the forecasting methodology are verified, these results will be included in future assessments.

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 two minor regime shifts (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. The first of the minor shifts occurred in 1989, primarily in the winter PDO index. The second minor shift was in 1998, and was associated with a change in the sign of the second principal mode of North Pacific SST variability, the so-called 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. Since 1998, the polarity of the winter north-south pressure dipole reversed. The SST field in the eastern Bering Sea became anomalously warm, whereas colder-than-normal conditions were established along the U.S. West Coast.   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 and 2004, however, the summer and winter PDO indices became positive. During the winter of 2003, the SST anomaly pattern in the North Pacific resembled neither the PDO, nor the Victoria patterns. Winter temperatures were above the 1971-2000 average in the Bering Sea and near the average in the Gulf of Alaska and the U.S. West Coast.   El Ninos were present in both the winters of 2003-2004 and 2004-2005. The increase in SST along the coast of South America which is associated with El Ninos, was brief, and conditions returned to neutral in July (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory, August 16, 2005).

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. Sea surface temperature in May

2005 was above its long-term average value, which means that the summer bottom temperatures will likely be also above average.

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, 1989, and 1998 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 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). After 1989 water temperatures were cooler and more variable in the coastal GOA, suggesting production may have been lower and more variable. After the 1998 regime shift, increased storm intensity from 1999 to 2001 resulted in a deeper mixed layer depth in the central GOA, and winter coastal temperatures were average or slightly below average. 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 It has been shown that the North Pacific atmosphere-ocean system included anomalies during the winter of 2004-05 that were unlike those associated with the primary modes of past variability. This result suggests a combination of two factors: (1) that the nature of North Pacific variability is actually richer in variability than appreciated previously, and (2), that there is the potential for significant evolution in the patterns of variability due to both random, stochastic effects and systematic trends such as global warming. Notably, at the time of this writing, it cannot be determined whether the North Pacific is heading into a positive PDO-like condition or some other state. The Bering Sea shows three multidecadal regimes in SAT fluctuations: 1921-1939 (warm), 1940-1976 (cold), and 1977-2005 (warm). It is worth noting that the two previous regimes had a similar pattern, when SAT anomalies were strongest at the end of the regime, right before the system switched to a new one. 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 (see the Pacific Climate overview section). It is unknown if changes observed after the 1998 shift will persist in the Gulf of Alaska and how long the current conditions in the Gulf of Alaska will last.

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
Estimated 2005 spawning biomass of GOA walleye pollock is 211,660 t, or 37% of the unfished biomass and below $B_{40\%}$ (229,000 t) (Dorn et al. 2004). The 1999 and 2000 year class strengths are above average and strongly influence estimates of spawning biomass (Dorn et al. 2004). The estimates of the 2004 stock is larger than previous years and is due to the increasing contribution of the 1999 and 2000 yearclasses to the adult biomass (Dorn et al. 2004).

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). From 2000 to 2004, total biomass increased to a much higher level (Lowe et al. 2004). The total age 3+ biomass estimate for 2005 is 485,700 mt, a decrease of approximately 14% from the 2003 estimate of biomass (Lowe et al. 2004). Female spawning biomass is projected to be above $B_{40\%}$, but is expected to drop below in 2007 to 2010 (Lowe et al. 2004). Atka mackerel are not considered overfished nor approaching an overfished condition (Lowe et al. 2004). The 1999 yearclass is the largest estimated yearclass in the time series, and the 2000 yearclass is also expected to be strong.

BS walleye pollock population status and trends
Bottom trawl and EIT survey biomass estimates for 2004 were 54% and 8% lower than estimates in the previous year (2003 for bottom trawl surveys and 2002 for the EIT survey) (Ianelli and Barbeaux 2004). Peak exploitable biomass occurred in 1985 and declined to 1991. Exploitable biomass (ages 3 and older) of EBS pollock since 1991 increased and has been variable at about 10-11 million tons (Ianelli et al. 2002). The strong 2000 year class remains at high levels; however, estimates indicate the stock will drop below $B_{40\%}$ by 2006 (Ianelli and Barbeaux 2004). The 2005 stock size is estimated to be at the lowest level since 1992 (Ianelli and Barbeaux 2004).

Herring
Bycatch in the BSAI groundfish fisheries (130.5 to 1723.3 mt) is typically higher than that in the GOA groundfish fisheries (2.2 to 283.8 mt) (T. Hiatt, Alaska Fisheries Science Center, personal communication). Herring bycatch in federally- managed FMP groundfish fisheries increased in 2003 and 2004 in the BSAI and in 2004 in the GOA (Hiatt and Terry, 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).

The 2003 and 2004 BSAI herring bycatch estimates represent 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 is 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. 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). The estimates for GOA squid bycatch were last updated in 2003. Bycatch of squid in the BSAI decreased from a high of 9000 t in 1978 to a few hundred tons in 1987-95 (Gaichas et al. 2004). Squid bycatch in the BS also decreased from 1997 to 2000 (1,474 to 384 t) and increased in 2001 (1,766 t) due to high catches in areas 517 and 519 (Gaichas et al. 2004) and in 2002 (1,344 t).

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). In 2001, catch of Sticheidae fish (4.66 t) was also higher than in previous years (0.03 -3.53 t) due to catches in areas 610, 620, and 630, but then decreased to 0.1 t in 2002 (Gaichas and Boldt 2003; Nelson 2003).

Estimated biomass of smelts, capelin and eulachon, in the GOA has ranged from a low of 7,535 t in 1984 to a high of 116,080 t in 2003 (Nelson 2003). GOA exploitation rates of eulachon and capelin were 0.2%, 1.0%, and 0.2% for both species in 1999, 2001, and 2003 respectively (Nelson 2003). Record high catches of Pacific sandfish were caught in the Eastern GOA in 2003.

Bycatch of forage species has been variable in the BSAI. 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. 2004). Summer fishing areas typically occur on the east side of Kodiak Island and in nearshore waters along the Alaska Peninsula. Most recommended TACs for 2005 are approximately 30% higher than those recommended for 2004 (Dorn et al. 2004). However, since 1992, the GOA pollock TAC has been spatially and temporally apportioned to reduce potential impacts on Steller sea lions (Dorn et al. 2004). 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.

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).

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) 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 and Barbeaux 2004). The spatial distribution of the winter fishery varied in 2002-2004. 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
In 2005 and 2006, 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).

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).

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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 1980's, 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).

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 will also be 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 will be 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 2001-2004, and none has yet occurred in 2005 (223 t Guidelines Harvest Level; 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 will be 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. Counts of adult and juvenile animals provide an index of the population status. NMFS estimates that the western Steller sea lion population increased approximately 6-7% from 2002 to 2004. This is similar to the rate of increase observed between 2000 and 2002. There were regional differences in the trends observed between 2002 and 2004. Trend site counts increased between 2002 and 2004 in the three Aleutian Islands sub-areas (Western, Central and Eastern) and in the western Gulf of Alaska, from the Shumagin Islands through Unimak Pass (Figure 91and Figure 92). However, in the eastern portion of the range of the western Steller sea lion population, trend site counts remained stable (near Prince William Sound in the eastern Gulf of Alaska) or decreased (around Kodiak Island in the central Gulf of Alaska). 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. Understanding and prediction of fishery competition with marine mammals for prey is the intense focus of research in Alaska. Improvements in understanding species movements, distribution, and prey requirements in a seasonal sense and bycatch characteristics of groundfish fisheries on finer spatial/temporal scales are needed to develop and improve predictive models of catch and bycatch composition in a spatial and seasonal sense.

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

Groundfish catch biomass in the BS is dominated by walleye pollock. Catches of pollock increased from 1999-2003 and were slightly lower in 2004. Catch biomass in the AI was dominated by walleye pollock from about 1980 to 1991; after which Atka mackerel, Pacific cod, and rockfish became the dominant catch. Pollock comprised the majority of catch in the GOA from about 1976 to 1985, after which it represented approximately 1/3 to 1/2 of the catches up until 2004. After 1985, Pacific cod, sablefish, halibut, and rockfish represented the other 1/2 to 2/3 of the catch.

The trophic level of catch in the BS and AI has remained stable at least since the early 1960's (Livingston 2003). The trophic level of catch in the GOA has also remained stable at least since the early 1980's (Livingston 2003).

5.) Removal of top predators

<u>Groundfish fishery bycatch of:</u>

   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. 2004; Boldt et al. 2003).

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 59% fulmars, 20% gulls, 12% unidentified birds, 4% albatross, 3% shearwaters, 2% all other birds. Of the total longline seabird bycatch, 93% was caught in the BSAI, and 7% in the GOA. Pots catch primarily Northern fulmars, trawl and longline fisheries catch a wider variety of seabirds. In 2002, total catch of seabirds was 3,835 in the BSAI and 259 in the GOA (Fitzgerald et al. 2003). In 2003, seabird bycatch estimates increased slightly, but were still low relative to 1998, despite a large increase in fishing effort. In particular, overall bycatch of Laysan albatross, black-footed albatross, and northern fulmars increased (Fitzgerald et al. 2004). 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 (Fitzgerald et al. 2004). Most bycatch of black-footed albatross occurs in the GOA longline fisheries (Fitzgerald et al. 2004). After a peak of nearly 700 black-footed albatross taken in 1996, the bycatch has undergone a steady downward trend (Fitzgerald et al. 2004). Numbers rose again in 2003, due to a slight increase in bycatch rates coupled with a larger increase in overall effort in the GOA (Fitzgerald et al. 2004). Total bycatch of fulmars in the longline fisheries peaked in 1999 and dropped substantially since, with a slight increase in 2003 (Fitzgerald et al. 2004).

   Pinnipeds

Incidental mortality of pinnipeds in groundfish fisheries was low from 1998-2003, and did not exceed PBRs, and are not expected to have a direct effect on the population status of pinnipeds (Sinclair 2004). Between 1998 and 2003, an average of 36 harbor seals was taken annually in fisheries in both SEAK and the GOA, and 31 were taken in the BS (Sinclair 2004). An annual average of 3.7 and 25.9 Steller sea lions were taken in the Eastern and Western Pacific (Sinclair 2004). Sixteen Northern fur seals on average were taken in the East North Pacific annually (Sinclair 2004).

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

BS Greenland Turbot

CPUE and AFSC bottom trawl surveys on the slope and shelf of the BS indicate that Greenland turbot abundance decreased from 1979-85, declined moderately from 1985-91, and continued to decline in 1993-2001 (Ianelli et al. 2002). There are some signs of improvement since 2000 but these estimates must be viewed with caution (Ianelli and Barbeaux 2004).

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 1960-70s and the present. The 2004 model results indicate that the estimated biomass increased from 327,622 t in 1961 to a high of 2,391,550 t in 2003 (Turnock et al. 2004).

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). ATF biomass increased more than 2.5 times from 1976 to 1996 (759,400 t; Wilderbuer and Sample 2004). The biomass has declined 7% since then to the 2004 estimate of 710,000 t (Wilderbuer and Sample 2004).

Sablefish

Sablefish abundance increased in the mid-1960's, declined in the 1970's due to heavy fishing, increased in the late 1970's and 1980's, and has since decreased. 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, but is projected to decrease in the short-term future (Sigler et al. 2004).

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

Total catch of groundfish provides an index of how many vessels are potentially exchanging ballast water resulting in the possible introduction of non-native species. Total catch of groundfish in the eastern BS was relatively stable from 1984 to the mid-1990's at approximately 1.7 million t. In 1999 there was a decrease in catch primarily due to decreased catches of pollock and flatfish. Catches of pollock have since increased to approximately 1.8 million t in 2002 and 2003.

Total groundfish catch in the AI is much lower than in the BS and has been more variable (from 43,465 to 190,750 t between 1977 and 2003). Total groundfish 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 1970's to the early 1990's. 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 110,166 t.

In the GOA, total groundfish catch has ranged from less than 50,000 t in the 1950's to highs of almost 360,131 t in the mid-1960's, which was associated with high rockfish catches, and 355,506 t in the mid-1980's, which was associated with high pollock catches. Since the 1985 total catch has varied between 147,479 t (1986) and 261,694 t (1992). Catches in 2003 were 179,881 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 and Terry, this report). From 1998 to 2004, the biomass of groundfish discarded was higher in the BSAI (average 122,140 t) than in the GOA (average 24,210 t); however, the percent of groundfish discarded was higher in the GOA (approximately 12%) than in the BSAI (approximately 7%) (Hiatt and Terry, this report). In 2004, the GOA discards were the lowest in the time series (1994-2004) at 17,890 t (9.7% discard rate; Hiatt and Terry, this report).

Discards of Non-Target Species (last updated in 2003)
Catch and discards of non-target species have been relatively stable in the BSAI and GOA since 1997 (Gaichas and Boldt 2003). Non-target catch in both areas is primarily comprised of non-specified and other species categories (Gaichas and Boldt 2003). In the BSAI, jellyfish, starfish, grenadiers, and other fish dominated the non-specified group and skates, sculpins and squid dominated the other species category (Gaichas and Boldt 2003). In the GOA, grenadiers were the dominant fish caught in the non-specified category in all years; other fish were also important in 1998 (Gaichas and Boldt 2003). The other species category in the GOA consisted primarily of skates, but also included sculpins, dogfish, and unidentified sharks (Gaichas and Boldt 2003).

Scavenger Species in the GOA and BSAI:

Birds
Overall, breeding chronology was early or typical in 2002 for most regions and species within feeding guilds, and in fact there were no cases of later than normal chronology (Dragoo et al. 2004). Seabird productivity in 2002 was variable throughout regions and among species. Planktivores, concentrated in the SW Bering, tended to have average or above average productivity. Most surface feeding piscivores (primarily black-legged kittiwakes) were above average, particularly in the SE Bering and GOA, while some in the Chukchi and N. Bering were below average. Productivity of diving piscivores was mixed, with 16 of 39 cases (41%) showing below average success, concentrated in the SE and SW Bering. In terms of abundance, through 2002, declining seabird populations were the minority (18 of 88 cases), and most prevalent in the SE Bering (which includes the Pribilof Islands) and GOA. The highest proportion of increasing trends occurred in the SW Bering (7 of 21 cases). However, in all regions, the majority of species showed no discernable trend (Dragoo et al. 2004).

Gulls
Glaucous-winged gulls at Buldir (southwest Bering Sea) decreased significantly between 1992 and 2002 (Dragoo et al. 2004). Gull numbers at Kasatochi (southwest Bering Sea) were also lowest 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 (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).

Red-legged kittiwakes declined significantly at St. Paul Island in the southeast BS, but significantly increased at Buldir in the southwest BS (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 (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 the GOA has varied from 1828 t (in 2001) to 6484 t (in 2002) (S. Gaichas, personal communication). Estimated skate biomass in the EBS increased after 1985, peaked in 1990 (at 534,556 t), and has varied between 325,000 427,713 t (in 2004) since (Gaichas et al. 2004). Skate biomass in the AI increased from 10,123 t (in 1980) to 34,412 t in 2002 and to 53,047 in 2004 (Gaichas et al. 2004).

Sablefish

See #5.)

Cod

In the GOA the estimated biomass of Pacific cod increased in the early 1980's (approximately 800,000t), was high until the early 1990's, and then decreased through the present (Thompson et al. 2002). In 2004, the biomass estimate of cod was 501,000 t, the lowest biomass estimated in the time series (1978 to 2004) (Thompson et al. 2004).

The biomass of Pacific cod in the BSAI has declined from a high of 2,281,000 t in 1987, through to the present, with upturns in 1994 (1,518,000 t), 2001 (1,091,000 t), and 2003 (1,168,000 t) (Thompson and Dorn 2004). The 2004 biomass estimate is 1,155,000 t (Thompson and Dorn 2004).

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. 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 four 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
Twenty-one stocks or stock complexes of groundfish that represent the majority of catch biomass in the BSAI and GOA are considered not overfished (Livingston 2003). The status of 21 major and 151 minor stocks of groundfish in the BSAI and GOA are of unknown status (Livingston 2003). Salmon and scallop stocks are not considered overfished. Four of six species of crab in the EBS are considered overfished: Pribilof Islands Blue King crab, St. Matthew Island Blue King crab, EBS Tanner crab, and EBS Snow crab (Stevens et al. 2002).

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 that lack population estimates (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. 2004). 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 737.0 t (in 1999) to 2304.9 t (in 1997), comprising up to 5.3% of all non-target species caught (Gaichas, personal communication). Bycatch of HAPC biota is substantially lower in the GOA (27.4-46.1 t), and represents up to 0.21% of total non-target catch (Gaichas, personal communication). 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 (Brown 2003). In 2001, catches of seapens and anemones increased in Western and Central GOA, and catches of sponges and stony corals increased in eastern GOA (Brown 2003). Catches of seapens in the BS were the highest in 2003, but decreased slightly in 2004. Catches of sponges in the BS continued to decline from 2000 to 2004 (Walters 2003). In the Eastern AI, catches of seapens were the highest in the time series in 2002 (Brown 2004). The 2004 survey results showed a slight decrease in sponge and sea pen abundance in all AI areas except the southern Bering Sea, which showed a modest gain (Brown 2004). The abundance of stony corals decreased in all AI areas; whereas, catches of soft corals and Gorgonians were variable among areas (Brown 2004).

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). Most state waters (0-3 nmi) are closed to bottom trawling (Coon, this report). Closures in 2002 were similar to the previous 8 years, however, included additional closures around Steller sea lion haulouts (Coon, this report). The closures in effect in 2004 were the same as those in 2003 for both the BSAI and GOA (Coon, this report). Closures in 2005 were similar to those in 2004, however, there were additional closures as part of protection for Essential Fish Habitat encompassing a large portion of the Aleutian Islands (Coon, this report). 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.

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.

Combined standardized indices of recruitment and survival of major demersal and pelagic stocks in the BS and GOA also reflected climate changes (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 about 1989, followed by below-average recruitments during the early 1990s (GOA) or most of the 1990s (EBS) (Mueter, this report). Indices of survival as well as recruitment were exceptionally low in 1982 in the EBS primarily due to low survival / recruitment of flatfishes.   This was followed in both regions by unusually high survival and recruitment indices in 1984, when recruitment of all stocks except flathead sole in the GOA and yellowfin sole in the EBS was above average.   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 strongly correlated between the two regions and may be driven by variations in large-scale climate patterns such as the PDO, which changed sign in 1976/77, and the Victoria pattern, which changed sign in 1989/90 (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; NMFS Technical team for essential fish habitat of groundfish in the Bering Sea and Aleutian Islands 1998).

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 34 time series were calculated by subtracting the mean and dividing by the standard error, 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

Class	Attribute	Index	Series	Description	Source
Climate	Physical Environ.	Ice index	1954-2004	A combination of 6 highly correlated ice variables	http://www.beringclimate.noaa.gov/index.html
Climate	Physical Environ.	SAT	1916-2004	Surface winter air temperature	http://www.beringclimate.noaa.gov/index.html
Climate	Physical Environ.	PDO	1901-2004	Pacific Decadal Oscillation	http://jisao.washington.edu/pdo/PDO.latest
Climate	Physical Environ.	MaySST	1970-2004	May sea surface temperature	http://www.beringclimate.noaa.gov/index.html
Climate	Physical Environ.	AOI	1951-2004	Arctic Oscillation Index	http://www.beringclimate.noaa.gov/index.html
Climate	Physical Environ.	Summer BT	1982-2003	Summer bottom temperature	http://www.beringclimate.noaa.gov/index.html
Pelagic forage	Predator-prey	Herring	1978-2004	Togiak herring age-4 recruits	West, this report
Pelagic forage	Predator-prey	A.Mackerel	1977-2002	Atka mackerel log-transformed recruit per spawning biomass	NPFMC 2004a
Pelagic forage	Predator-prey	Pollock	1964-2002	Walleye pollock log-transformed recruit per spawning biomass	NPFMC 2004a
Pelagic forage	Predator-prey	Forage fish	1997-2002	Forage fish bycatch	Gaichas, this report
Pelagic forage	Predator-prey	Squid	1997-2002	Squid bycatch	Gaichas, this report
Top predators	Predator-prey	BS Trophic level	1954-2003	Bering Sea trophic level of the catch	Livingston, this report
Top predators	Predator-prey	AI Trophic level	1962-2003	Aleutian Island trophic level of the catch	Livingston, this report
Top predators	Predator-prey	Sharks	1997-2002	Shark bycatch	Gaichas, this report
Top predators	Predator-prey	Pinnipeds	1989-2004	Non-pup Steller sea lion counts	Sinclair and Testa, this report
Top predators	Predator-prey	GT	1973-2003	Greenland turbot log-transformed recruit per spawning biomass	NPFMC 2004a
Top predators	Predator-prey	ATF	1976-2000	Arrowtooth flounder log-transformed recruit per spawning biomass	NPFMC 2004a
Intro non-natives	Predator-prey	log(CPUE)	1982-2003	Total catch per unit effort of fish and invertebrates in bottom trawl surveys	Mueter, this report
Energy redirection	Energy flow	Cod	1977-2003	Pacific cod log-transformed recruit per spawning biomass	NPFMC 2004a
Energy redirection	Energy flow	BLKI	1975-2002	Black-legged kittiwake productivity (fledglings per egg) at St. Paul Island	D.E. Dragoo, USFWS, pers. comm.
Energy redirection	Energy flow	RLKI	1975-2002	Red-legged kittiwake productivity (fledglings per egg) at St. Paul Island	D.E. Dragoo, USFWS, pers. comm.
Energy redirection	Energy flow	BS H+L	1990-2001	Bering Sea Hook and line (longline) effort (number of hooks)	Coon, this report
Energy redirection	Energy flow	AI H+L	1990-2001	Aleutian Islands Hook and line (longline) effort (number of hooks)	Coon, this report
Energy redirection	Energy flow	BS Bottom Trawl	1990-2003	Bering Sea bottom trawl duration (24 hour days)	Coon, this report
Energy redirection	Energy flow	AI Bottom Trawl	1990-2003	Aleutian Island bottom trawl duration (24 hour days)	Coon, this report
Energy redirection	Energy flow	BS Pelagic Trawl	1995-2003	Bering Sea pelagic trawl duration (24 hour days)	Coon, this report
Energy removal	Energy flow	BS catch	1954-2003	Total catch Bering Sea	NPFMC 2004a
Energy removal	Energy flow	AI catch	1962-2003	Total catch Aleutian Islands	NPFMC 2004a
Species diversity	Diversity	HAPC	1997-2002	HAPC non-target catch Bering Sea/Aleutian Islands	Gaichas, this report
Species diversity	Diversity	BS Diversity	1982-2003	Bering Sea groundfish diversity (Shannon-Wiener index)	Mueter, this report
Species diversity	Diversity	BS Richness	1982-2003	Bering Sea groundfish richness (avg. # species per survey haul)	Mueter, this report
Other	Other	COMU	1976-2002	Common murre productivity (fledglings per egg) at St. Paul Island	D.E. Dragoo, USFWS, pers. comm.
Other	Other	TBMU	1976-2002	Thick-billed murre productivity (fledglings per egg) at St. Paul Island	D.E. Dragoo, USFWS, pers. comm.
Other	Other	BB Salmon	1956-2003	Total catch of Bristol Bay salmon	Eggers and Fair, this report
Other	Other	Jellyfish	1982-2003	Jellyfish biomass in survey catches	Lauth, this report
Other	Other	AK plaice	1975-1999	Alaska plaice log-transformed recruit per spawning biomass	NPFMC 2004a
Other	Other	Crab biomass	1980-2002	Total crab biomass	Otto and Turnock, this report
Other	Other	YFS	1964-1998	Yellowfin sole log-transformed recruit per spawning biomass	NPFMC 2004a
Other	Other	POP	1960-1993	Pacific Ocean perch log-transformed recruit per spawning biomass	NPFMC 2004a
Other	Other	Northerns	1977-1993	Northern rockfish log-transformed recruit per spawning biomass	NPFMC 2004a
Other	Other	Rock sole	1975-1997	Rock sole log-transformed recruit per spawning biomass	NPFMC 2004a
Other	Other	FHS	1977-2000	Flathead sole log-transformed recruit per spawning biomass	NPFMC 2004a

Table 3. The table on the next page displays standardized anomalies 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.

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	---

Class	Indicator	Normalized time series
Top predators	BS Trophic level	1954-2003
Climate	Ice index	1954-2004
Top predators	AI Trophic level	1962-2003
Energy removal	AI catch	1962-2003
Other	BB Salmon	1956-2003
Climate	SAT	1916-2004
Climate	PDO	1901-2004
Climate	MaySST	1970-2004
Energy removal	BS catch	1954-2003
Climate	AOI	1951-2004
Pelagic forage	Herring	1978-2004
Pelagic forage	A.Mackerel	1977-2002
Intro non-natives	log(CPUE)	1982-2003
Species diversity	BS Diversity	1982-2003
Other	Jellyfish	1982-2003
Other	AK plaice	1975-1999
Energy redirection	Cod	1977-2003
Pelagic forage	Pollock	1964-2002
Species diversity	BS Richness	1982-2003
Other	Crab biomass	1980-2002
Energy redirection	BLKI	1975-2002
Other	TBMU	1976-2002
Energy redirection	RLKI	1975-2002
Other	YFS	1964-1998
Other	POP	1960-1993
Other	Northerns	1977-1993
Top predators	GT	1973-2003
Top predators	ATF	1976-2000
Other	Rock sole	1975-1997
Other	FHS	1977-2000
Climate	Summer BT	1982-2003
Other	COMU	1976-2002
Energy redirection	BS H+L	1990-2001
Energy redirection	AI H+L	1990-2001
Energy redirection	BS Bottom Trawl	1990-2003
Energy redirection	AI Bottom Trawl	1990-2003
Energy redirection	BS Pelagic Trawl	1995-2003
Pelagic forage	Forage fish	1997-2002
Top predators	Sharks	1997-2002
Top predators	Pinnipeds	1989-2004
Pelagic forage	Squid	1997-2002
Species diversity	HAPC	1997-2002

Year columns (left to right): 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04

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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 error, 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

Class	Index	Series	Description	Source
Climate	MLD	1973-2001	Mixed layer depth at GAK1 (north GOA)	Sarkar et al., this report
Climate	AOI	1951-2004	Arctic Oscillation Index	http://www.beringclimate.noaa.gov/index.html
Climate	PDO	1901-2004	Pacific Decadal Oscillation	http://jisao.washington.edu/pdo/PDO.latest
Pelagic forage	Pollock	1969-2001	Walleye pollock log-transformed recruit per spawning biomass	NPFMC 2004b
Pelagic forage	Herring	1980-2003	Southeast Alaska age-3 herring recruits	Dressel et al., this report
Pelagic forage	Pandalids	1972-2003	Pandalid shrimp catch per unit effort in ADFG small mesh survey	Anderson 2004
Pelagic forage	Eulachon	1972-2003	Eulachon catch per unit effort in ADFG small mesh survey	Anderson 2004
Pelagic forage	Sandfish	1972-2003	Sandfish catch per unit effort in ADFG small mesh survey	Anderson 2004
Pelagic forage	Pricklebacks	1972-2003	Prickleback catch per unit effort in ADFG small mesh survey	Anderson 2004
Pelagic forage	Forage fish	1997-2002	Forage fish non-target catch	Gaichas, this report
Pelagic forage	Squid	1997-2002	Squid non-target catch	Gaichas, this report
Top predators	Trophic level	1956-2003	Gulf of Alaska trophic level of the catch	Livingston, this report
Top predators	Sharks	1997-2002	Shark non-target catch	Gaichas, this report
Top predators	Pinnipeds	1989-2004	Non-pup Steller sea lion counts	Sinclair and Testa, this report
Top predators	Sablefish	1960-1999	Sablefish log-transformed recruit per spawning biomass	NPFMC 2004b
Top predators	ATF	1961-1997	Arrowtooth flounder log-transformed recruit per spawning biomass	NPFMC 2004b
Intro non-natives	log(CPUE)	1990-2003	Total catch per unit effort of fish and invertebrates in bottom trawl surveys	Mueter, this report
Energy redirection	Cod	1977-2001	Pacific cod log-transformed recruit per spawning biomass	NPFMC 2004b
Energy redirection	BLKI	1983-2002	Black-legged kittiwake productivity (fledglings per egg) in Prince William Sound	D.E. Dragoo, USFWS, personal communication
Energy redirection	H+L	1993-2002	Hook and line (longline) effort (number of hooks)	Coon, this report
Energy redirection	Bottom trawl	1990-2002	Gulf of Alaska bottom trawl duration (24 hour days)	Coon, this report
Energy redirection	Total catch	1970-2003	Total catch Gulf of Alaska	NPFMC 2004b
Species diversity	HAPC	1997-2002	HAPC non-target catch Gulf of Alaska	Gaichas, this report
Species diversity	Diversity	1990-2003	Gulf of Alaska groundfish diversity (Shannon-Wiener index)	Mueter, this report
Species diversity	Richness	1990-2003	Gulf of Alaska groundfish richness (average number of species per survey haul)	Mueter, this report
Other	COMU	1976-2002	Common murre productivity (fledglings per egg) at Chowiet	D.E. Dragoo, USFWS, personal communication
Other	TBMU	1976-2002	Thick-billed murre productivity (fledglings per egg) at Chowiet	D.E. Dragoo, USFWS, personal communication
Other	Salmon	1900-2003	Total GOA salmon catch	Eggers, this report
Other	FHS	1984-1997	Flathead sole log-transformed recruit per spawning biomass	NPFMC 2004b
Other	POP	1977-1998	Pacific Ocean perch log-transformed recruit per spawning biomass	NPFMC 2004b
Other	Northerns	1977-1995	Northern rockfish log-transformed recruit per spawning biomass	NPFMC 2004b
Other	Thornyheads	1967-1992	Thornyhead rockfish log-transformed recruit per spawning biomass	NPFMC 2004b

Table 5. The table on the next page displays 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.

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	---

Class	Indicator	Normalized time series
Energy redirection	Total catch	1970-2003
Other	POP	1977-1998
Top predators	Trophic level	1956-2003
Climate	PDO	1901-2004
Other	Salmon	1900-2003
Other	Thornyheads	1967-1992
Top predators	Sablefish	1960-1999
Climate	MLD	1973-2001
Climate	AOI	1951-2004
Pelagic forage	Pollock	1969-2001
Other	COMU	1976-2002
Pelagic forage	Sandfish	1972-2003
Pelagic forage	Herring	1980-2003
Pelagic forage	Pandalids	1972-2003
Pelagic forage	Eulachon	1972-2003
Pelagic forage	Pricklebacks	1972-2003
Other	FHS	1984-1997
Other	Northerns	1977-1995
Energy redirection	BLKI	1983-2002
Top predators	Pinnipeds	1989-2004
Energy redirection	Cod	1977-2001
Pelagic forage	Forage fish	1997-2002
Pelagic forage	Squid	1997-2002
Energy redirection	H+L	1993-2002
Energy redirection	Bottom trawl	1990-2002
Species diversity	Diversity	1990-2003
Intro non-natives	log(CPUE)	1990-2003
Species diversity	HAPC	1997-2002
Other	TBMU	1976-2002
Species diversity	Richness	1990-2003
Top predators	Sharks	1997-2002
Top predators	ATF	1961-1997

The year columns across the matrix (left to right): 04, 03, 02, 01, 00, 99, 98, 97, 96, 95, 94, 93, 92, 91, 90, 89, 88, 87, 86, 85, 84, 83, 82, 81, 80, 79, 78, 77, 76, 75, 74, 73, 72, 71, 70.

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Conclusions
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 2 and 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) (Table 2 and Table 3). 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 (Table 2 and Table 3).

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—2004 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 1980's. 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 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 4 and 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 sharks 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.

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	Cool coastal waters in GOA from 1998 to fall of 2002. August 2002 to July 2005 cool interior and warm coastal waters in GOA.	Indicates that PDO shifted to positive in August 2002 to September 2004, was negative Oct-Dec 2004, returned to positive values in 2005 (Jan-July).
SST Anomalies	Winter 2004/2005 anomalously warm in the BS; 2005 warm in eastern-central GOA with patchiness of SST anomalies elsewhere	Mean winter Aleutian Low was deeper than average and shifted northwest of normal position, pumping warm air into the BS
EBS summer bottom temperature	The 2004 average bottom temperature was well above the 1982-2003 average, and the average sea surface temperature was also higher than average.	Bottom temperatures may affect pollock distribution
EBS ice cover index	Ice cover was below average in 2001, 2003, 2004, and 2005. Record low in 2005. Increased year-to-year variability in last decade.	Warmer waters on shelf, may result in northward shift of shelf ecosystems
Ice retreat index	Ice retreated early 1996-2005 (except in 1999)	The EBS may be shifting to an earlier spring transition
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 showed a return to normal conditions in 2004 and below average in 2005.	Surface water circulation in the GOA has been near average in the last five years but has become slightly negative (southward) in 2005.
Seasonal rainfall at Kodiak	Almost all winter and spring months in 2003-2005 experienced average or greater rainfall	Survival potential of age-0 walleye pollock increased, because it promotes eddies in the ACC, which may benefit the Pollock ("average to strong" recruitment)
Wind mixing south of Shelikof Strait	January-June of 1998-2005 have been below average except March 2003 and March 2005	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	2005 had same closures as 2004 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 46t for GOA in 2002, ranged from 27 to 46 t from 1997 to 2002.	About constant in GOA 1997-2001, with an increase 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 2004 increased slightly but was similar to 2003 and lower than 1991-97	Less trawling on bottom relative to 1991-97
Groundfish bottom trawling effort in AI	About the same in 2004 compared to 2003 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 2004 relative to 2003 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 2191 t for BSAI in 2002; ranged from 923 to 2548 t since 1997.	Similar to 2001 catches.
HAPC biota biomass indices in EBS bottom trawl survey	These groups have been better identified in the survey in the 1990's to present	Survey may provide biomass index for seapens, anemones, and sponges. More research needed to understand trends
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

INDICATOR	OBSERVATION	INTERPRETATION
Target Groundfish		
Groundfish fleet	Total number of vessels actually fishing in 2004 similar to 2003. During 2001 to 2004, trawl vessel counts decreased.	Relatively stable number of vessels participating since 2001, with the exception of trawl vessels.
Groundfish discards	Slightly decreased level in 2004 compared to 2003 and 2002 in GOA; slight increase in 2004 relative to 2003 in BSAI	Fairly stable rates of discarding since 1998
Total groundfish catch EBS	Total catch in 2003 as in 1990's, pollock dominant; increased pollock catch in 2003	Catch biomass about the same from 1984-2003
Total groundfish catch AI	Total catch in 2003 shows decline since about 1996, Atka mackerel dominant	Total catch returning to lower levels
Total biomass EBS/AI	Total about the same in 2004 as in 2003, slight decreasing trend in pollock, pollock dominant	Relatively high total biomass since about 1981
EBS recruit per spawner	Some above average recruitment in the early 1990's, most below average	Groundfish survival is low in mid- to late-1990's
BSAI groundfish stock status	In 2003, 0 overfished, 12 not subjected to overfishing	All major stocks are not overfished
Total groundfish catch GOA	Total catch lower in 2003 is similar to 2002	Total catch similar from 1985 through present
Total biomass GOA	Biomass declined 1982-01, slight increase in 2002 to 2004 to about same level as 1996, arrowtooth dominant and increasing; slight decrease in pollock biomass in 2004.	Relatively low pollock biomass compared to peak in 1982
GOA recruit per spawner	Recruit per spawner below average in the 1990's for most age-structured stocks	Groundfish recruitment is low in the 1990's
GOA groundfish stock status	In 2003, 0 overfished, 9 not subjected to overfishing	Many major stocks are not overfished
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	
Zooplankton		
BS zooplankton	No apparent trend 1954-1998; low biomass 1999-2004 in all domains	

INDICATOR	OBSERVATION	INTERPRETATION
Forage		
Forage bycatch EBS	24 t in 2002, 32-83 t in 1997-2001, mostly smelts	Lower smelt bycatch rates in 2002
Larval fish in GOA	Decadal trend in abundance of many species; elevated abundance in late 1980's to mid-1990's relative to early and mid-1980's	Basin-scale environmental conditions (Feb-Mar) and local-scale conditions (late March-early April) influence larvae abundance
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	Ranged from 27-125 t in 1997-2000, over 500 t in 2001, and 158 t in 2002; mostly smelts	Lower smelt catch rates in 2002 compared to 2001, but still above average.
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 for sandfish and eulachon. More research needed to interpret trends
Forage biomass indices from ADFG inshore small mesh survey in GOA	Osmerid biomass index increased in 2003 and was still high in 2005; highest relative abundance since 1980	Increase due primarily to increase in eulachon CPUE
Miscellaneous and other managed species		
GOA Jellyfish from ADFG small mesh survey	CPUE high since 1985; CPUE in 2003 remained high.	
EBS Jellyfish	2005 catches were slightly higher than 2004 but still low relative to 1992-2000.	Possible continuation of low levels of jellyfish biomass similar to the 1980's
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	Increased jellyfish catches in all AI areas in 2004	More research needed to interpret trends
Crab stock status - BSAI	4 stocks overfished (BS Tanner, EBS snow crab, and Pribilof Is. and St. Mathew Is. blue king)	Mixed crab stock status
EBS snow crab recruitment	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 1960's and early 1970's); weak year classes in 1980's and 1990's. Largest yearclass in last 20 years was the 1989 brood year.	Recruitment may partly relate to regime shifts (1977 and 1989)
Scallop stock status	1 stock- not overfished	

INDICATOR	OBSERVATION	INTERPRETATION
PWS Herring stock status	Pre-fishery run biomass estimate peaked in 1989; stock collapsed afterwards and remains low	Fishery remains closed for fall 2005 and spring 2006.
SEAK Herring stock status	2003 was one of the highest biomass estimates in the 24-year time series	Slight increasing or stable biomass trends at 7 of 9 locations
Togiak Herring stock status	2004 abundance and age 4 recruits increased slightly from 2003	Abundance is still below 1978-02 average; but population is considered stable because high abundance in 1980's may be a result of the ASA model
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	2004 catches of arrowtooth flounder were high; pollock catches in Barnabas Gully decreased slightly but still high; catches of tanner crabs decreased 50%	Increasing dominance of arrowtooth flounder
ADF&G small mesh inshore survey-GOA	Pandalid shrimp CPUE in 2005 similar to recent years	
NMFS bottom trawl survey-GOA	Survey may provide biomass index for some species	More research needed to interpret trends
Prohibited species bycatch	A large increase in bycatch rates of other salmon and herring in 2003 and 2004. Other 2004 bycatch rates show a decrease in bairdi, other tanner, and red king crabs; increases in chinook salmon, and little change in halibut bycatch rates relative to 2003	Prohibited species bycatch rates are mixed.
Non-specified species bycatch	Non-specified species bycatch was the lowest in 2001 (11,122 t), compared to other years (13,368 to 24,634 t). Bycatch in 2002 was 13,368 t.	Dominant species in non-specified bycatch were jellyfish, grenadier and starfish
Marine Mammals		
Alaskan sea lion western stock non-pup counts	2004 non-pup counts increased by 6-7% from 2002. Regional differences in trends.	Continued increase or stable counts in most areas; however, continued decline in central GOA
Alaskan eastern stock sea lion counts	Overall increase from 1991-2002 was 15.4%	Stable or slightly increasing at average of about 2%/yr
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)

INDICATOR	OBSERVATION	INTERPRETATION
Seabirds		
Seabird breeding chronology	Overall seabird breeding chronology was earlier than average or unchanged in 2002	Earlier hatching times are associated with higher breeding success
Seabird productivity	Overall, productivity of plankton feeding seabirds was average or above average in 2002; whereas, productivity of piscivorous seabirds was average or above average in 2002 (but varied across colonies and regions).	Variable chick production
Population trends	Mixed: majority showed no trend, 18 decreased, 17 increased through to 2002.	Variable depending on species and site
Seabird bycatch	2003 BSAI longline bycatch is slightly higher than 2002, N. fulmars dominate the catch (GOA longline bycatch is small and relatively constant) Trawl bycatch rates are variable and perhaps increasing	Unclear relationship between bycatch and colony population trends
Aggregate Indicators		
Trophic level catch EBS and AI	Constant, relatively high trophic level of catch since 1960's	Not fishing down the food web
Trophic level catch GOA	Constant, relatively high trophic level of catch since 1970's	Not fishing down the food web
Groundfish biodiversity EBS	Significant change in flatfish and roundfish species richness and evenness in late 1980's; stable to the present	An event in the 1970's sparked ecosystem changes that were perpetuated into the late 1980's and early 1990's; an event in the late 1980's countered the 1970's 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.
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	Positive values 1976/77 - 1989, negative values in early 1970's and most of 1990's in GOA and BSAI	Above-average groundfish recruitments from 1976/77 - 1989, below average recruitments in early 1970's and most of 1990's.
Combined standardized indices of groundfish survival	Varying patterns	Relatively low survival of demersal stocks in 1990's
Groundfish productivity BS	Variable but decreased from 1978-2004	

INDICATOR	OBSERVATION	INTERPRETATION
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

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 components by bringing together many diverse research efforts into one document. As we learn more about the role that climate, humans, or both may have on ecosystems, we will be able to derive ecosystem indicators that reflect this new understanding.

Physical Environment
Ecosystem Indicators and Trends Used by FOCI
Edited by S. Allen Macklin, NOAA/PMEL
Last updated: September 2005

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 – 2005
S. Rodionov, J. Overland, and N. Bond (NOAA PMEL)
Last updated: September 2005

Summary. *The winter of 2005 was characterized by atmospheric circulation anomalies that little resembled leading teleconnection modes. There was a weak El Niño event, but it had either a minor or atypical impact on the North Pacific. The PDO index was positive, suggesting that the climate regime established since the late 1970s still continues, but the distribution of sea surface temperature (SST) in the North Pacific did not closely correspond with the PDO loading pattern. The characteristic features of this distribution were a warm water pool in the east-central North Pacific and patchiness of SST anomalies elsewhere. The SST-based Victoria pattern, after being in its positive phase during 1999-2004, showed a sign of reversal in 2005. It was not consistent, however, with its atmospheric counterpart, a north-south dipole in sea level pressure (SLP). Instead, the anomalous SLP in 2005 featured an east-west dipole consisting of a negative anomaly centered along 170˚W from 40˚N into the Bering Sea, and a positive anomaly in the eastern Pacific from 40˚N into the Gulf of Alaska. This combination brought about southerly wind anomalies and an enhancement of cyclonic activity for the Bering Sea shelf, and a suppression of storminess in the eastern North Pacific.*

Climate in 2005
It is in the human nature to search for patterns, but it is difficult to characterize the winter of 2005 in terms of previously identified patterns of variability. In other words, it seems easier to describe this winter climate by what it was not. It was not a winter of a distinct El Niño-Southern Oscillation (ENSO) event. The distribution of sea-surface (SST) temperature anomalies in the North Pacific was neither the Pacific Decadal Oscillation (PDO), nor the Victoria patterns, and the Arctic Oscillation (AO) index was in the neutral phase, overall.

The Southern Oscillation Index (SOI) was negative in all months from June 2004 to June 2005, except January 2005 (Figure 1), and SST anomalies in the Niño 3.4 region in the central equatorial Pacific exceeded 0.5°C (Figure 2). It was enough to qualify as an El Niño event by some definitions, but it was in a weak category and accompanied by a number of uncharacteristic features. First, it did not extend all the way to West Coast of South America (Niño 1+2 region) where SST anomalies were predominantly negative (Figure 2). Second, there was a lack of persistent enhanced convection over the anomalously warm waters of the central equatorial Pacific, which has limited El Niño-related impacts on the global circulation patterns. For example, a weaker than average jet stream across the central and eastern Pacific in the winter of 2005 is inconsistent with El Niño.

The Aleutian low was stronger than normal and the PDO index, as expressed by the PC1 in Figure 3 (bottom panel), was positive, but the distribution of SST anomalies in the North Pacific (Figure 4) had little resemblance with the PDO loading pattern (Figure 3 upper panel). The characteristic features of this distribution in winter 2005 were a warm water pool in the east-central North Pacific and patchiness of SST anomalies elsewhere. Later, in spring and summer of 2005, the warm waters spread to the east, closer to the North American west coast, and negative SST anomalies in the western and central North Pacific became more pronounced. As a result, the whole pattern became much more like the positive phase of the PDO, and the PDO index values jumped above one standard deviation for the months from March through June.

The resemblance of the SST anomaly distribution in the winter of 2005 to the negative phase of the Victoria pattern (EOF2 in Figure 3) is somewhat greater than with the PDO, largely due to the heavy weight of the positive SST anomaly in the east-central North Pacific. The PC2 (EOF2) value in 2005 was negative for the first time since the shift in this pattern to the positive phase in 1999. The distribution of sea-level pressure (SLP) in the winter of 2005 (Figure 5), however, did not exhibit the north-south dipole pattern characteristic of the Victoria pattern. As in the previous seven years, SLP anomalies over the Bering Sea continue to be negative, indicating enhanced cyclonic activity there.
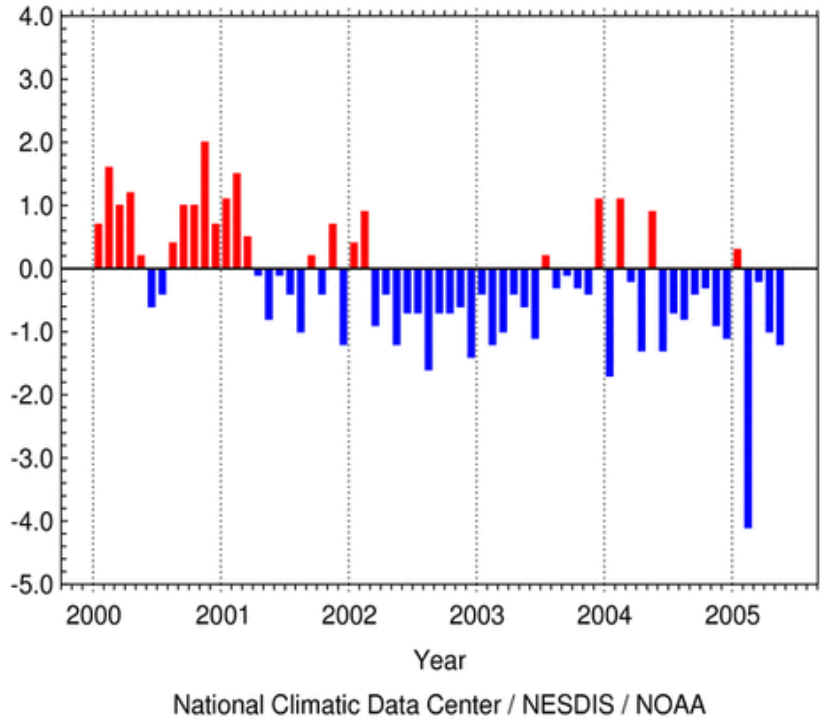
Figure 1. Mean monthly values of the Southern Oscillation Index, January 2000 through May 2005.
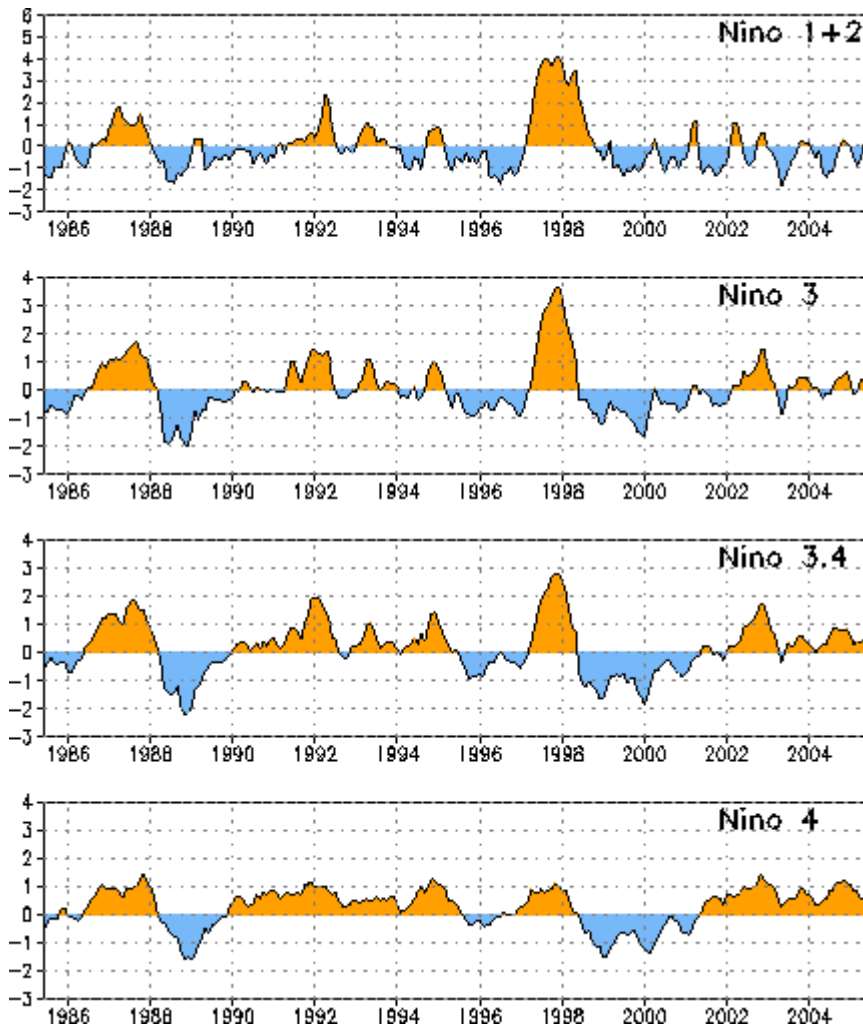
Figure 2. SST anomalies (deg. C) along the west coast of South America (Nino 1+2 region) and central
parts of the equatorial belt (Nino 3, 3.4, and 4 regions), 1985-2005.

One of the most salient features of the atmospheric circulation over the North Pacific in the
winter of 2005 was a strong and persistent high pressure cell off British Columbia. It split the
North Pacific storm track redirecting storms either to the Bering Sea or southern California.
During this winter, the Pacific Northwest (which includes Washington, Oregon, and Idaho)
received only 6.23 inches of precipitation making it the fifth driest winter on record since 1896.
In contrast, storms were bringing heavy rain to southern California triggering mudslides and
washing away roads and runways. Los Angeles, for example, received a total of 19.58 inches of
rain from December 2004 to February 2005, which makes this winter the forth wettest since
1945.
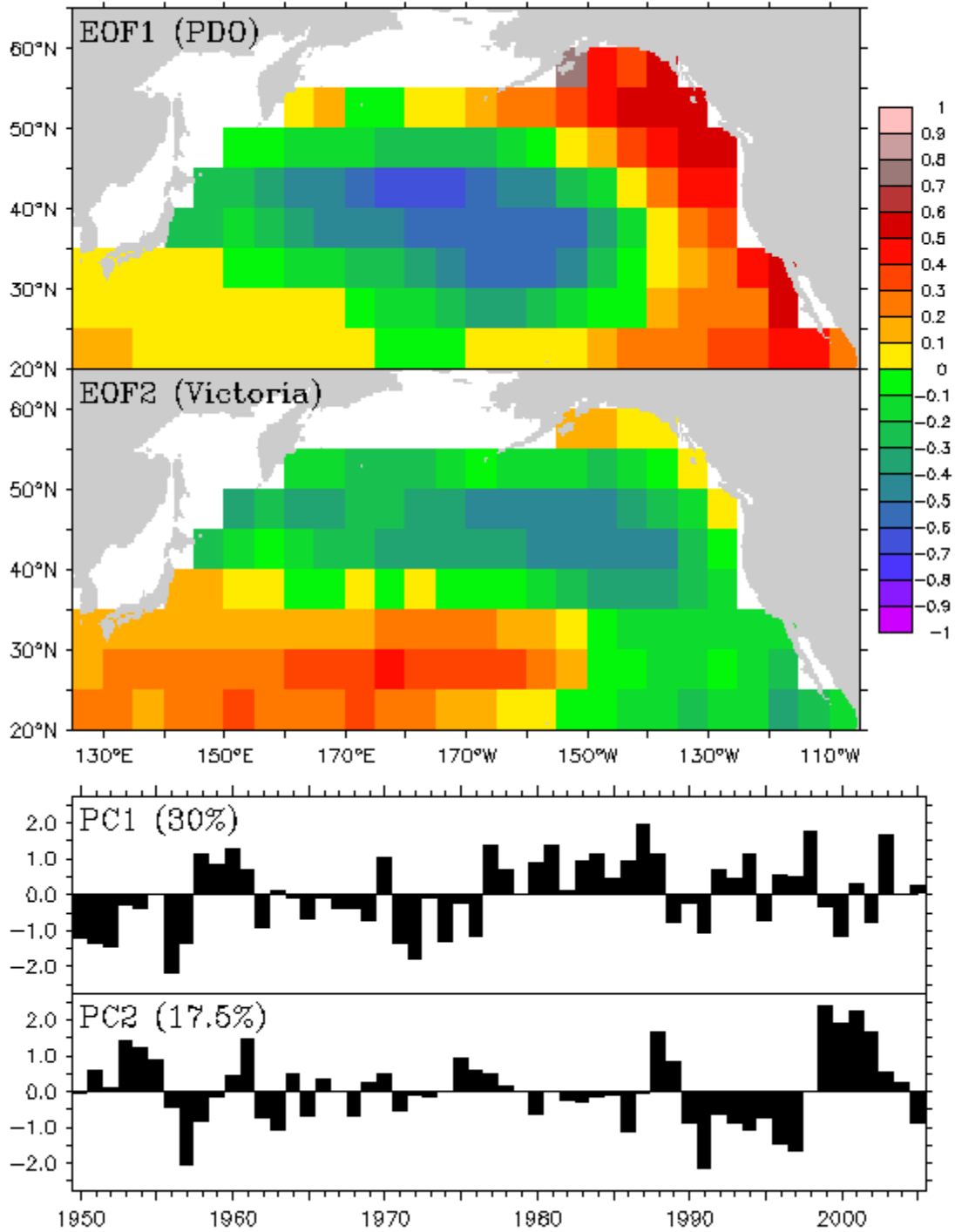
Figure 3. The first (PDO) and second (Victoria) empirical orthogonal functions of mean winter (Nov-Mar) SST anomalies in the North Pacific along with the time series of their principal components.
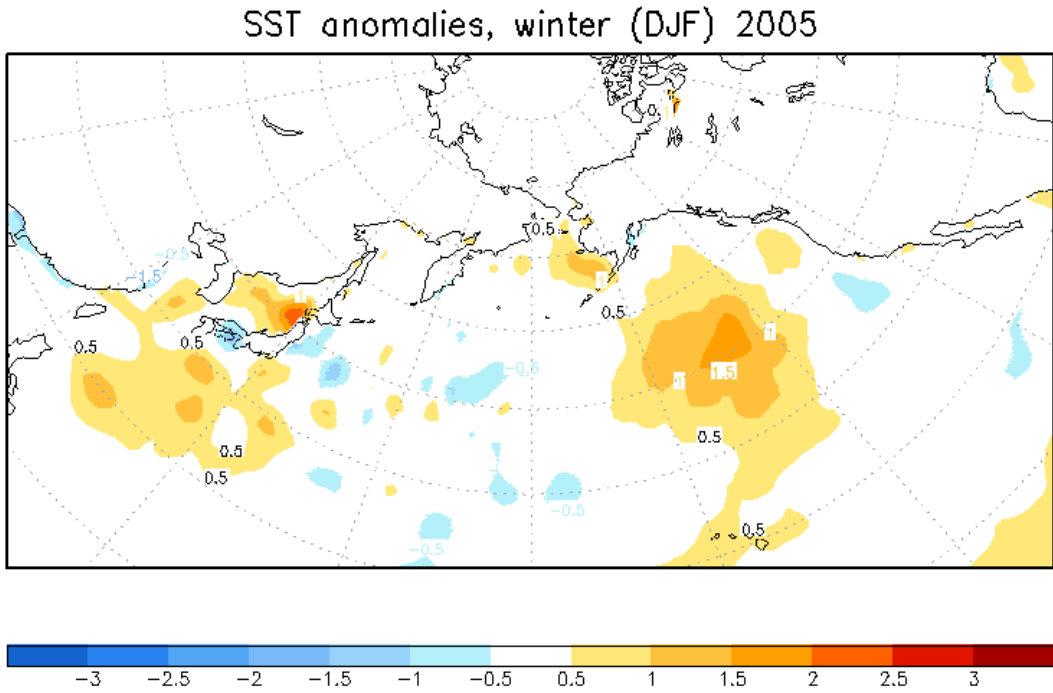
Figure 4. Mean seasonal SST anomalies in the winter (DJF) of 2005. Anomalies are relative to the 1971-2000 base period. Source data: NOAA OI.v2 SST monthly fields.
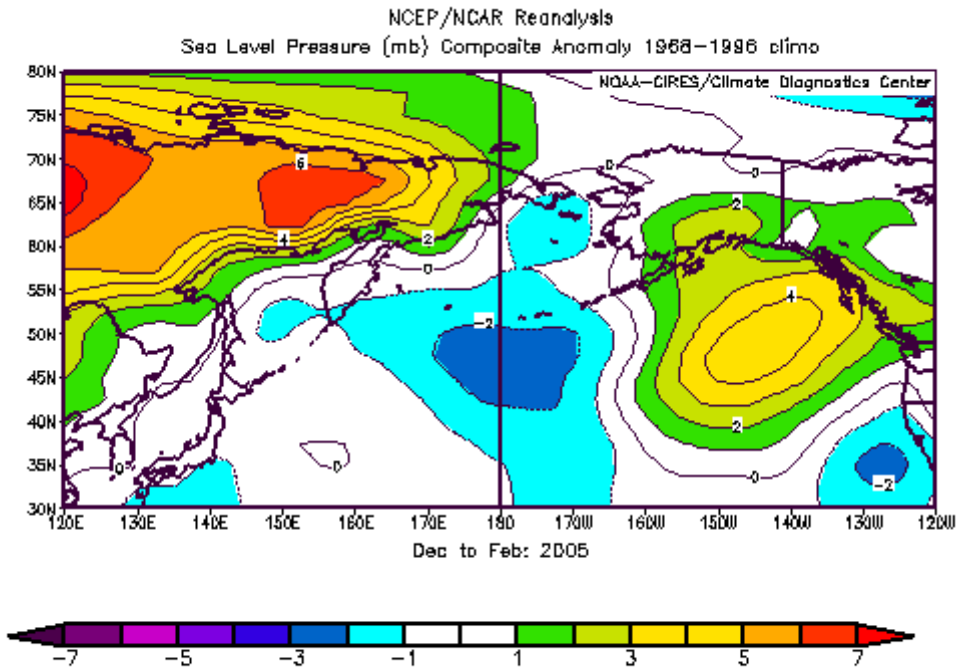
Figure 5. Mean seasonal SLP anomalies in the winter (DJF) of 2005. Anomalies are relative to the 1968-1996 base period.

The atmospheric circulation anomalies during the first half of 2005 appear to be linked to major disruptions in the marine ecosystem off the west coast of the U.S. The combination of higher than normal SLP to the northwest of Vancouver Island, and lower than normal SLP to the west of California during early 2005 (Figure 5) implies easterly wind anomalies, and in turn, anomalous poleward Ekman transports in the upper ocean off the coast of Oregon and Washington. This set of conditions was followed in spring and summer by lower than normal SLP off the U.S. west coast, leading to a delayed onset and a decreased intensity to coastal upwelling. The anomalous atmospheric forcing in winter and spring/early summer appears to have had substantial biological impacts in the northern portion of the California Current system, namely, a reduction in primary productivity, low zooplankton concentrations, and unusually high mortality rates for juvenile salmon and sea birds.

Recent Trends

The value of the winter PDO index in 2005 was close to the mean value of the index for the period since 1977 (Figure 6a). Although there were episodic excursions of the index into the negative territory, such as in 1989-1991 and 1999-2000, none of them materialized into a major regime shift similar in scale to those in the mid-1940s and late 1970s.

The summer (Figure 6b) and annual (Figure 6c) PDO index experienced a longer period of negative values since 1999, and there is the potential for a new regime shift. On the other hand, strongly positive values of the index in March-June 2005 suggest that the test for a regime shift based on the sequential algorithm (Rodionov 2005) will likely fail to support the regime shift in the late 1990s any longer.

Variations in the North Pacific Index (NPINCAR in Figure 6d, which measures the strength of the Aleutian low, is similar to those in the winter PDO index, particularly in the later part of the record. The correlation coefficient between the two is -0.72 for the period 1950-2005. The NPINCAR also shows no major regime shifts since 1977.

The lack of major regime shifts since the late 1970s does not mean that the climate remained the same throughout all this period. To investigate shorter-term, but sustained fluctuations in the system, the sequential method was applied to a number of climate indices, using a smaller cutoff length of 7 years. Figure 7a shows that the Aleutian low was the strongest for about a decade immediately following the regime shift in the late 1970s. Interestingly, the variability of the NPINCAR during that decade also increased. Occasional positive values of the index, however, did not seem to have had much effect on the North Pacific SST pattern, as expressed by the PDO index, which remained positive almost all this time (Figure 7b). In the late 1980s, the Aleutian low weakened substantially (the shift of 1988 is significant at p = 0.02), and the PDO index returned to its near-normal value. Later the Aleutian low strengthened again (the shift of 1996 is significant at p = 0.04), but not as much as in 1977-1987. The PDO index continued to fluctuate around its zero value until 2003, when it jumped to its highest value since 1941 signaling a possibility of a new regime shift.
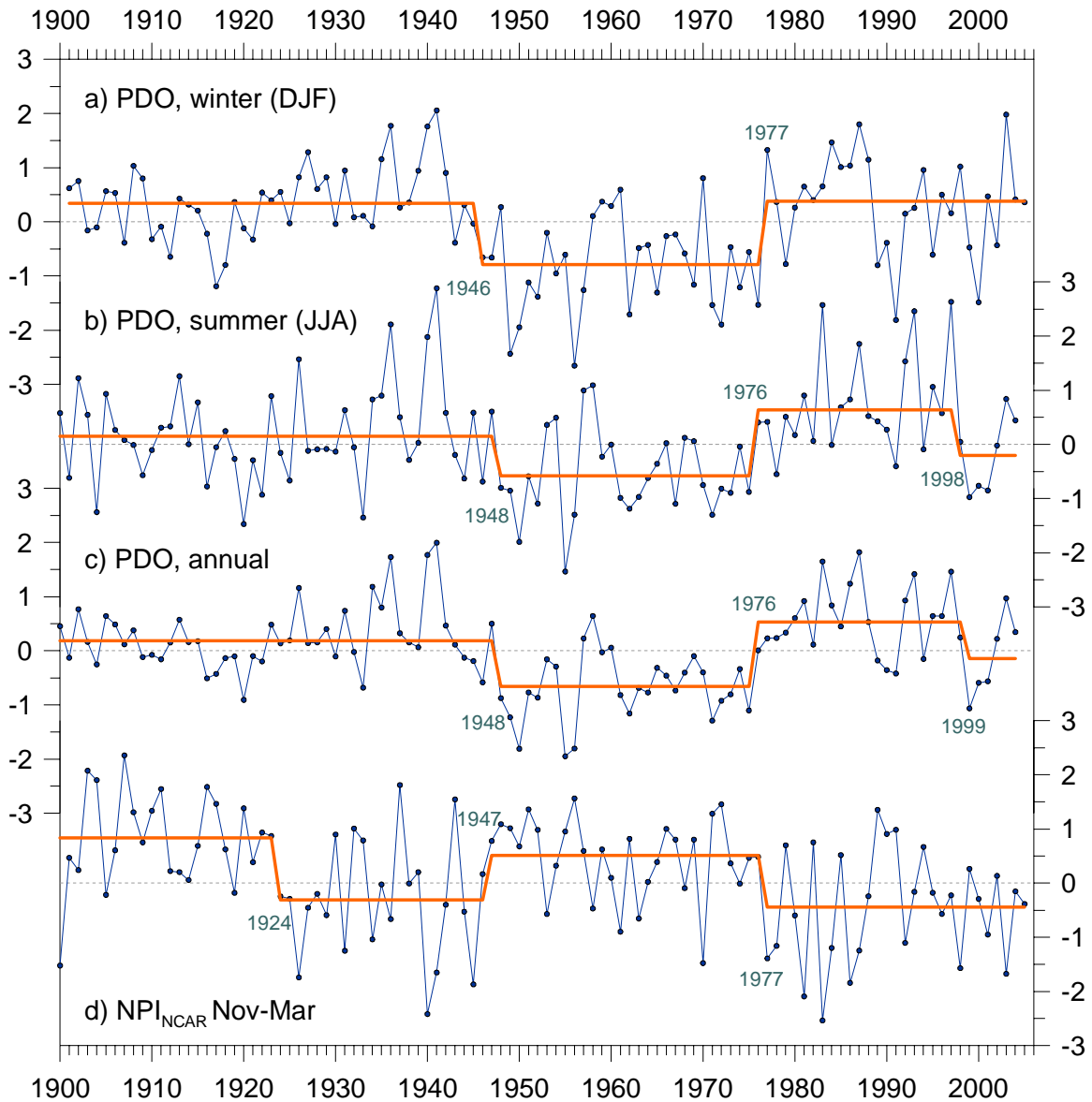
Figure 6. a) Mean winter (DJF) PDO index, 1901-2005, b) mean summer (JJA) PDO index, 1900-2004, c) Annual (Jan-Dec) PDO index, 1900-2004, and d) North Pacific index (Nov-Mar) from the National Center for Atmospheric Research, 1900-2005. The stepwise functions (orange lines) characterize regime shifts in the level of fluctuations of the indices. Shift points were calculated using the STARS method (Rodionov 2004), with the cutoff length of 15 years, the maximum significance level of 0.05, and the Huber weight function value of 1. The actual significance levels of the shifts are less than 0.0005.

The shift of the late 1980s was recorded in a number of fish stocks (McFarlane et al. 2000; Hare and Mantua 2000). As for the climate indices, the shift was particularly strong in the AO index that jumped to its record level in 1989 (Figure 7c). This state of highly positive AO index continued for 5 years. Since 1994 the index has fluctuated around its zero value.

Bond et al. (2003) argue that Pacific climate variability in recent years was associated primarily with the Victoria pattern, rather than with the PDO. This is clearly seen in Figure 3 (bottom

panel) where the PC1 (PDO) time series fluctuated around its zero value since the late 1980s, whereas the PC2 (Victoria) values were consistently negative in 1988-1997 and consistently positive in 1999-2004. To determine the atmospheric counterparts of the PDO and Victoria pattern, the PC1 and PC2 time series were correlated against geopotential height values at the 500-hPa level. Figure 8a shows that, over the North Pacific, the PDO is characterized by a dipole with the positive center at 15˚N, 180 and the negative center at 45˚N, 165˚W. This dipole practically coincides with the oceanic centers of the Pacific/North American (PNA) pattern. The atmospheric counterpart of the Victoria pattern is also a dipole with the centers at 30˚N, 165˚W and 60˚N, 165˚W (Figure 8b). The Victoria dipole is, practically, in quadrature with the PDO dipole.

The atmospheric PDO and Victoria indices are presented in Figure 7d and Figure 7e, respectively. The indices are calculated as the normalized differences in 500-hPa height anomalies in the positive and negative centers of the respected dipoles. The atmospheric PDO index correlates with its oceanic counterpart at r = 0.83; it also exhibits shifts in 1977 and 1989, but not in 2003. The correlation coefficient between the atmospheric and oceanic Victoria indices is r = 0.78. The regime of negative index values in 1990-1997, which is clearly seen in PC2 time series (Figure 3), is not statistically significant in the atmospheric Victoria index. The only statistically significant regime-like feature in the latter index is a sequence of positive values in 1998-2002. Neither the PDO nor the Victoria indices can fully explain an abrupt shift to warmer conditions in the Bering Sea since 2000 (see the Bering Sea section).

In order to capture the part of atmospheric circulation in Figure 5 relevant to the Bering Sea, we calculated an index that represents a difference in SLP between two areas, 45-60˚N, 130-150˚W and 40-65˚N, 160-180˚W, normalized by its standard deviation. The positive (negative) values of this East-Central North Pacific (ECNP) index indicate positive (negative) east-west SLP gradient and predominantly southerly (northerly) winds over east-central North Pacific and the Bering Sea. The ECNP index does not correlate with the PDO or the Victoria indices. It is interesting, however, that all 20 positive values of the index since 1970 coincide with positive values of either the PDO or Victoria indices. It is important to underscore that the ECNP index does not represent a major mode of climate variability, such as the PDO or Victoria patterns. Instead, it appears to capture the essential elements of both these patterns pertinent to warming in the Bering Sea. The time series of the ECNP index for January-February is shown in Figure 7. The index is almost the same if averaged over the entire winter season, December through March. However, the shift in 2000 is most significant for the January-February index. As shown in the Bering Sea section, this year marks the beginning of a warm period in the sea.
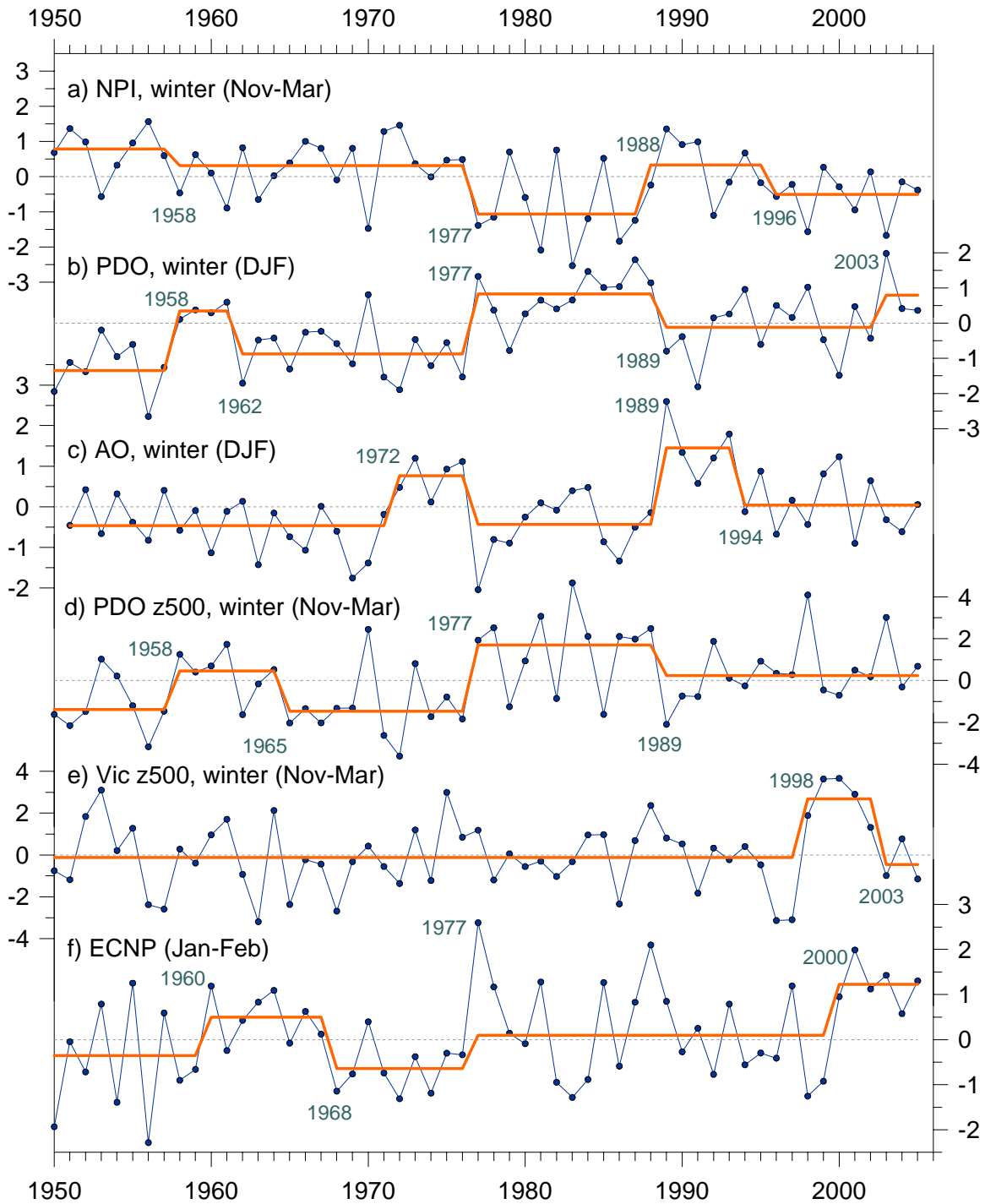
Figure 7. a) Mean winter (Nov-Mar) NPINCAR, 1950-2005, b) Mean winter (DJF) PDO index, 1950-2005, c) Mean winter (DJF) Arctic Oscillation index, 1951-2005, d) Mean winter (Nov-Mar) atmospheric PDO index at the 500-hPa level, 1950-2005, e) Mean winter (Nov-Mar) atmospheric Victoria index at the 500-hPa level, 1950-2005, and f) January-February East-Central North Pacific index, 1950-2005. The stepwise functions (orange lines) characterize regime shifts in the level of fluctuations of the indices. Shift points were calculated using the STARS method (Rodionov 2004), with the cutoff length of 7 years, the maximum significance level of 0.2, and the Huber weight parameter of 1.

a) R [PC1 (PDO) vs. z500]

Nov to Mar: 1949 to 2003; 500mb Geopotential Height
Seasonal Correlation w/ Nov to Mar PC1PDO.txt

NCEP/NCAR Reanalysis

b) R [PC2 (Victoria) vs. z500]

Nov to Mar: 1949 to 2003; 500mb Geopotential Height
Seasonal Correlation w/ Nov to Mar PC2Victoria.txt

NCEP/NCAR Reanalysis
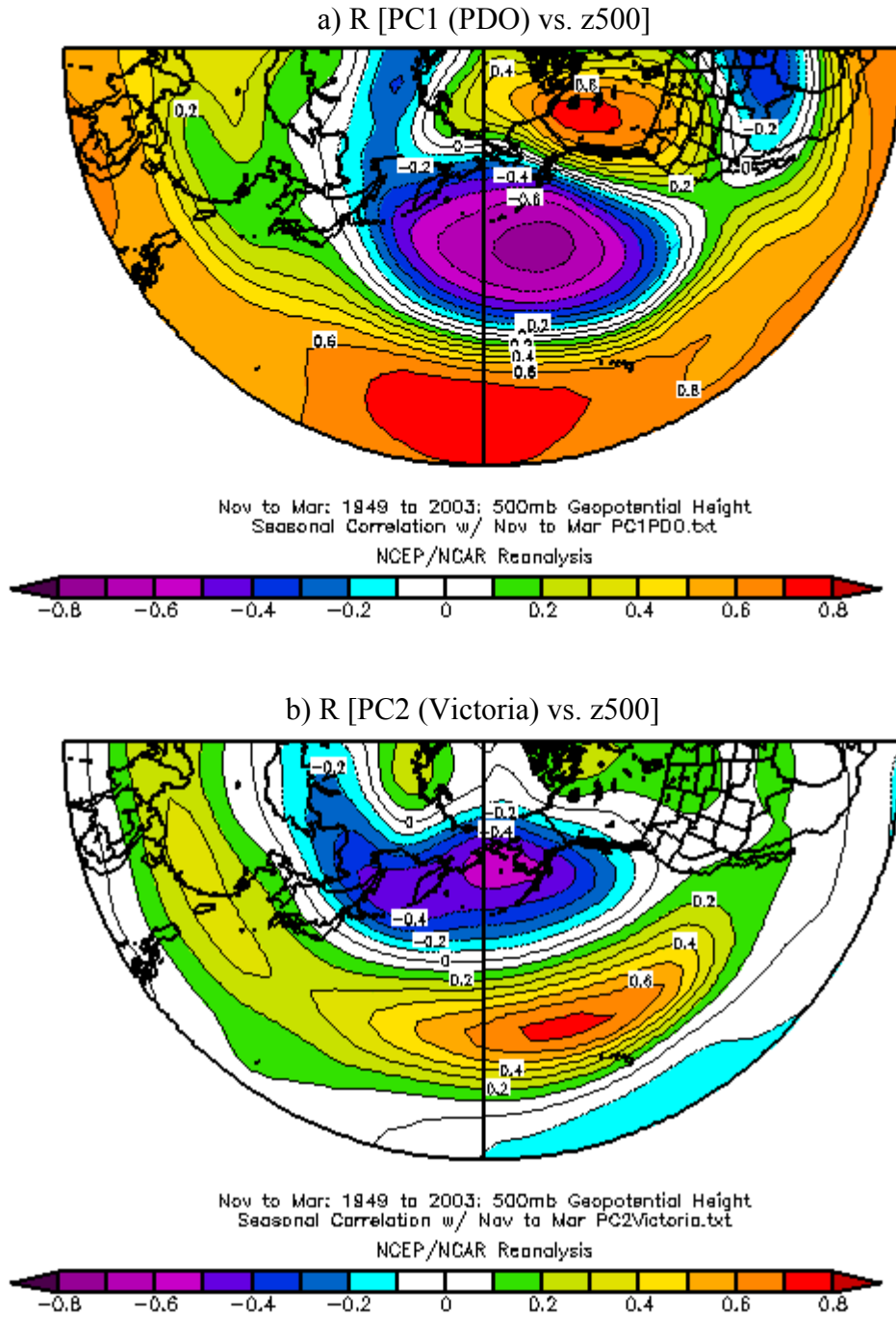
Figure 8. Correlation coefficients between mean winter (Nov-Mar) 500-hPa heights at grid points with (a) PC1 (PDO) and (b) PC2 (Victoria) time series from Figure 3.

It has been shown that the North Pacific atmosphere-ocean system included anomalies during the winter of 2004-05 that were unlike those associated with the primary modes of past variability. This result suggests a combination of two factors: (1) that the nature of North Pacific variability is actually richer in variability than appreciated previously, and (2), that there is the potential for significant evolution in the patterns of variability due to both random, stochastic effects and

systematic trends such as global warming. Notably, at the time of this writing, it cannot be determined whether the North Pacific is heading into a positive PDO-like condition or some other state.

GULF OF ALASKA

Pollock Survival Indices –FOCI

Contributed by S. A. Macklin, NOAA/PMEL
Last updated: September 2005

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 interannual 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. 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

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). The amount of measured monthly rainfall drives 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 nearly immediate run-off, also favors 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 9. 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. Thus, the 2005 pollock survival potential based on precipitation, alone, is a bit less than in 2004, although still in the category of "average to strong" recruitment. Interestingly, the precipitation-based survival index does not appear to track any of the long-term climate indices (e.g., Arctic Oscillation (AO) index, Pacific Decadal Oscillation (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.

Precipitation-based pollock survival index
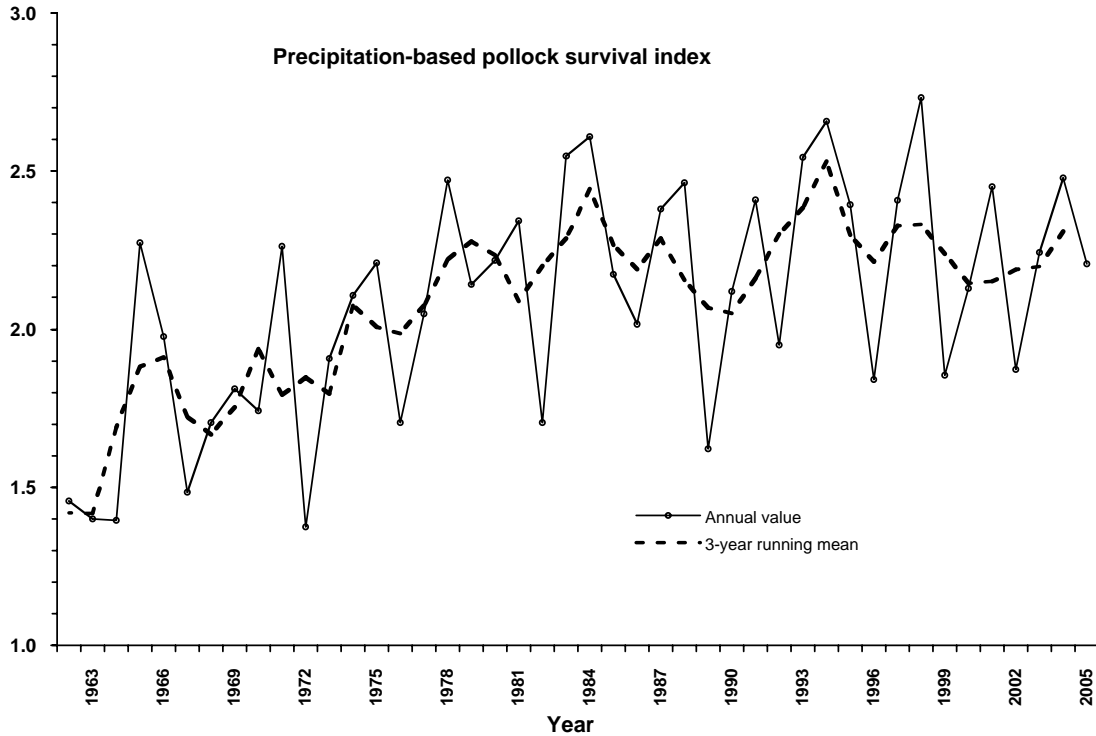
Figure 9. Index of pollock survival potential based on measured precipitation at Kodiak from 1962 through 2005. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Wind mixing at the southwestern end of Shelikof Strait

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 10. 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 and March 2005, monthly averaged wind mixing in Shelikof Strait has been below the 30-

year (1962-1991) mean for the last eight January through June periods (1998-2005). This may be further evidence that the North Pacific climate regime has shifted in the past decade.
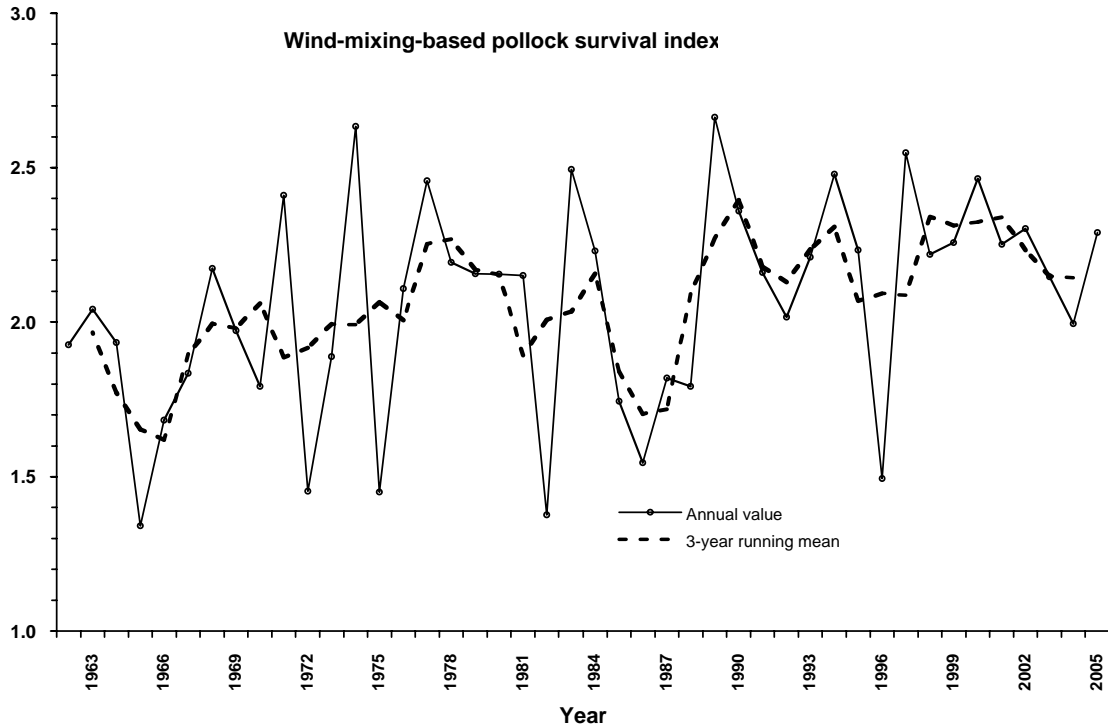
Figure 10. Index of pollock survival potential based on modeled wind mixing energy at [57°N, 156°W] near the southwestern end of Shelikof Strait from 1962 through 2005. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Ocean transport in the western Gulf of Alaska –FOCI
Contributed by P. J. Stabeno, NOAA/PMEL
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

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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 11), 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.
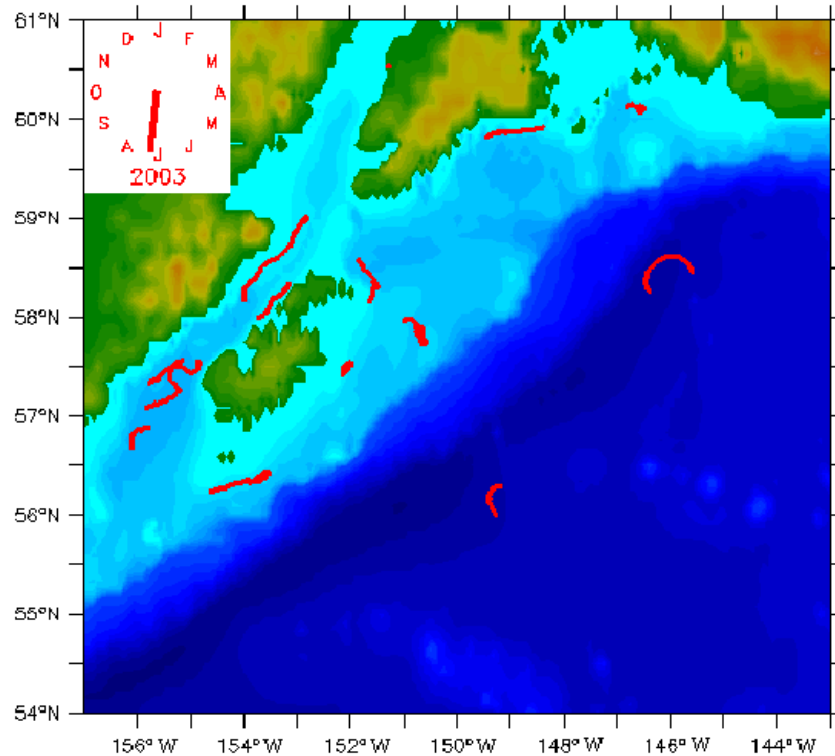
Figure 11. Tracks of satellite-tracked drifters for the period October 14-18, 2001, show sluggish flow on the shelf, except for within Shelikof Strait.

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
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 12). 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 12). By averaging EKE over region c (see box in Figure 12), we obtain an index of energy associated with eddies in this region (Figure 13).
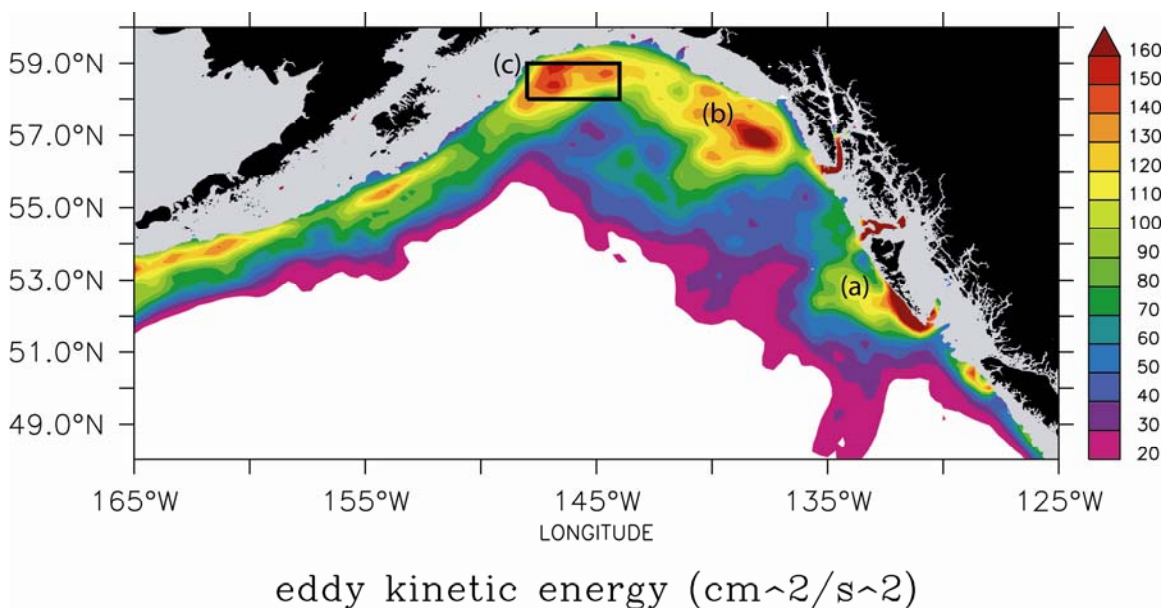
Figure 12. Sea surface height anomaly from TOPEX/Poseidon, ERS-1/2 and Jason merged altimetry. Positive anomalies imply anticyclonic circulation. Black box outlines region over which EKE was averaged for Figure 13.

The seasonal cycle (calculated from the entire time series) of EKE averaged over the box shown in Figure 12 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/.
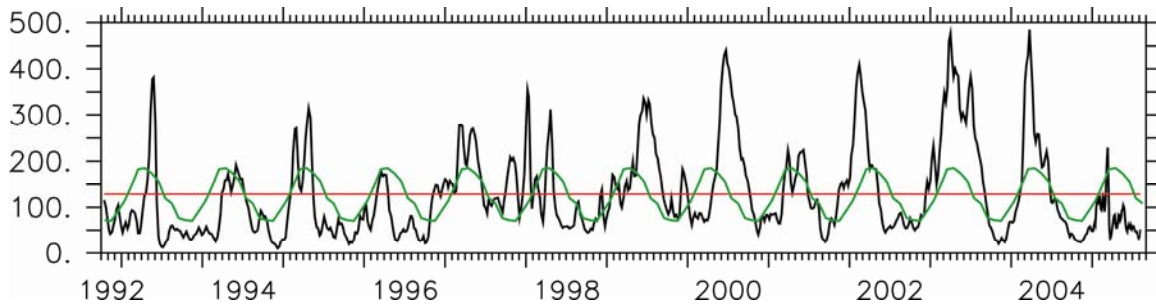
Figure 13. Eddy kinetic energy (EKE) averaged over the region shown in Figure 12 calculated from altimetry. Black: weekly EKE. Red: mean over entire time series. Green: annual cycle.

Ocean Surface Currents – Papa Trajectory Index 2005
Contributed by W. James Ingraham, Jr., Alaska Fisheries Science Center (Retired)
Last updated: September 2005

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 100 times starting at Ocean Station Papa (50º N, 145º W) on each December first for 90 days for each year from 1901 to 2004 (ending February 28 in the following 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 14) 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 winters with anomalous northward surface water circulation in the eastern Gulf of Alaska; values below the mean indicate winters with anomalous southward surface water circulation.

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This year the long expected change in modes from north to south has narrowly occurred in the 5-year running mean.   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 2005 calculations and shows a southward shift yet still near normal conditions. 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. After 2 years of mean values in 2001 and 2002, a value below the mean has occurred with this year's data. 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.
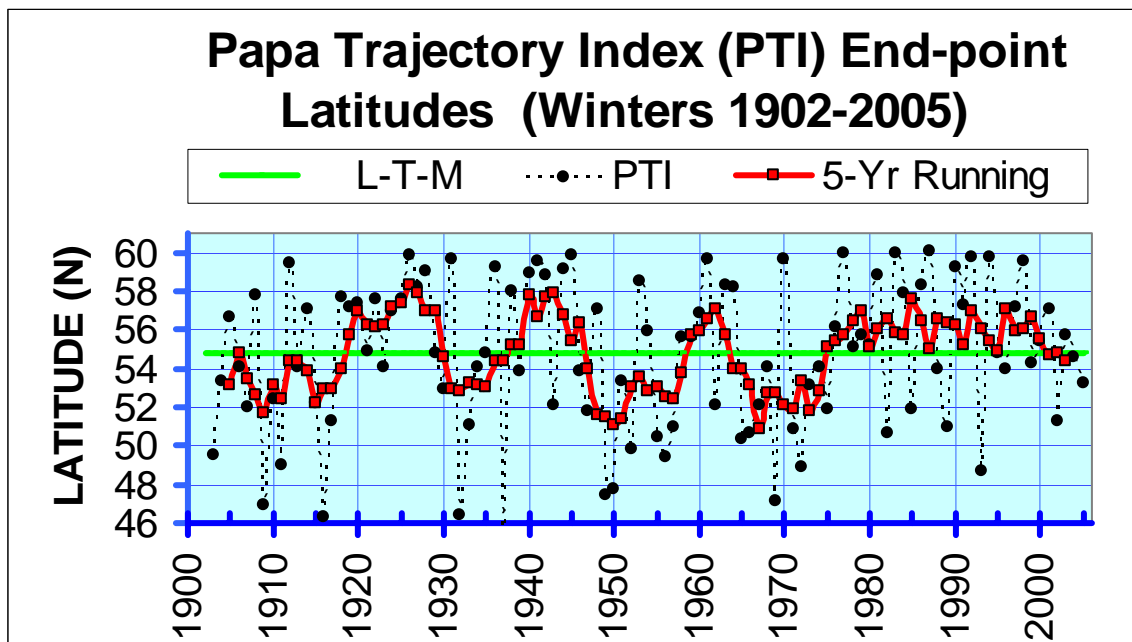
Figure 14. Annual, long-term mean, and 5-year running mean values of the PAPA Trajectory Index (PTI) time-series from winter 1902-2005. Large black dots are annual values of latitude of the end points of 90-day trajectories started at Ocean Weather Station PAPA (50º N, 145º W) each December 1, 1901-2004. 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 (michael.martin@noaa.gov)
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 15 shows the results plotted by depth with year on the x axis, while Figure 16 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 15). Bottom temperatures appeared to be near normal in 2005 with the notable exception of the large positive anomaly at depths less than 50 m.
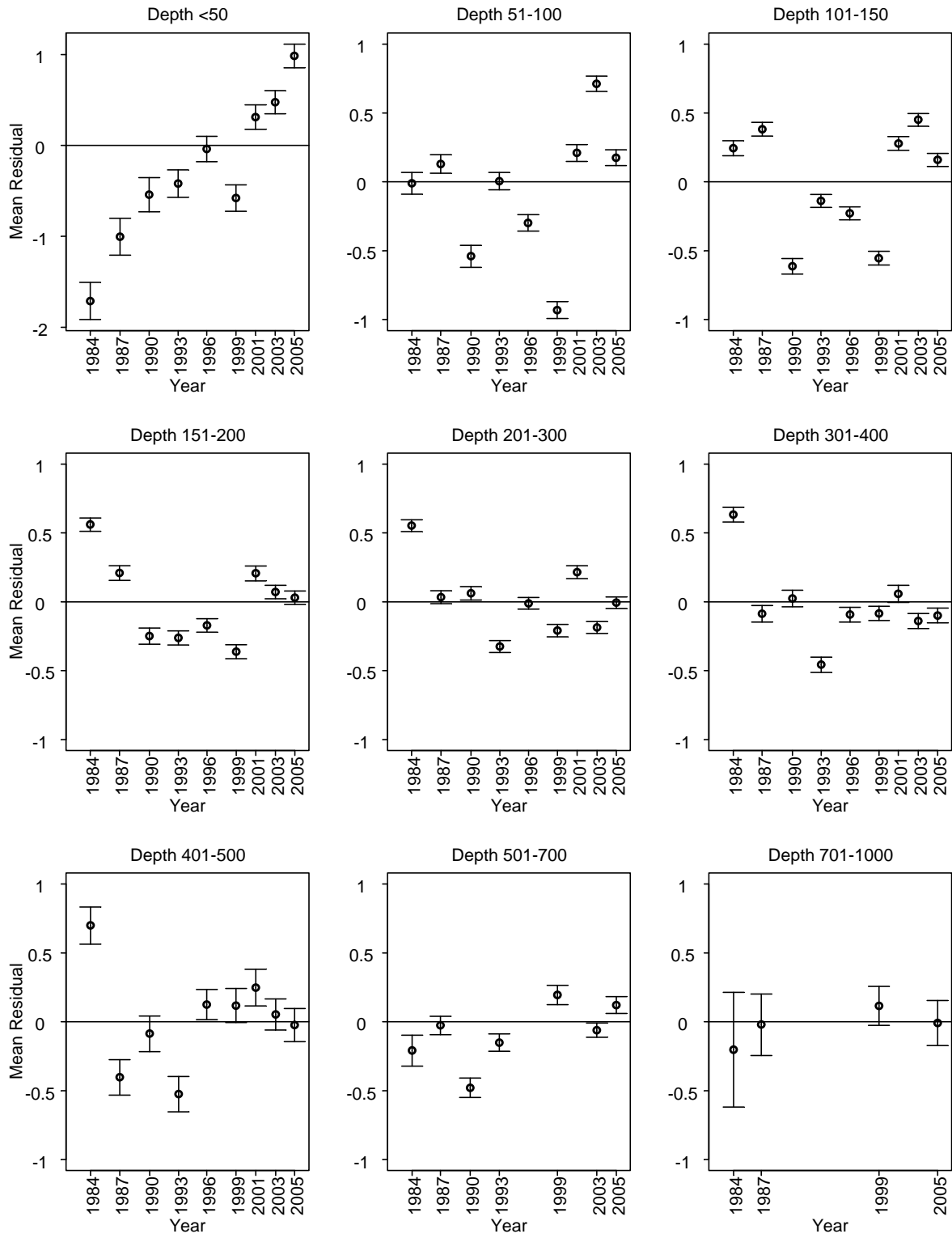
Figure 15.   Mean temperature anomalies plotted by year within each depth stratum. Error bars are standard errors. Note expanded scale in < 50 m plot.
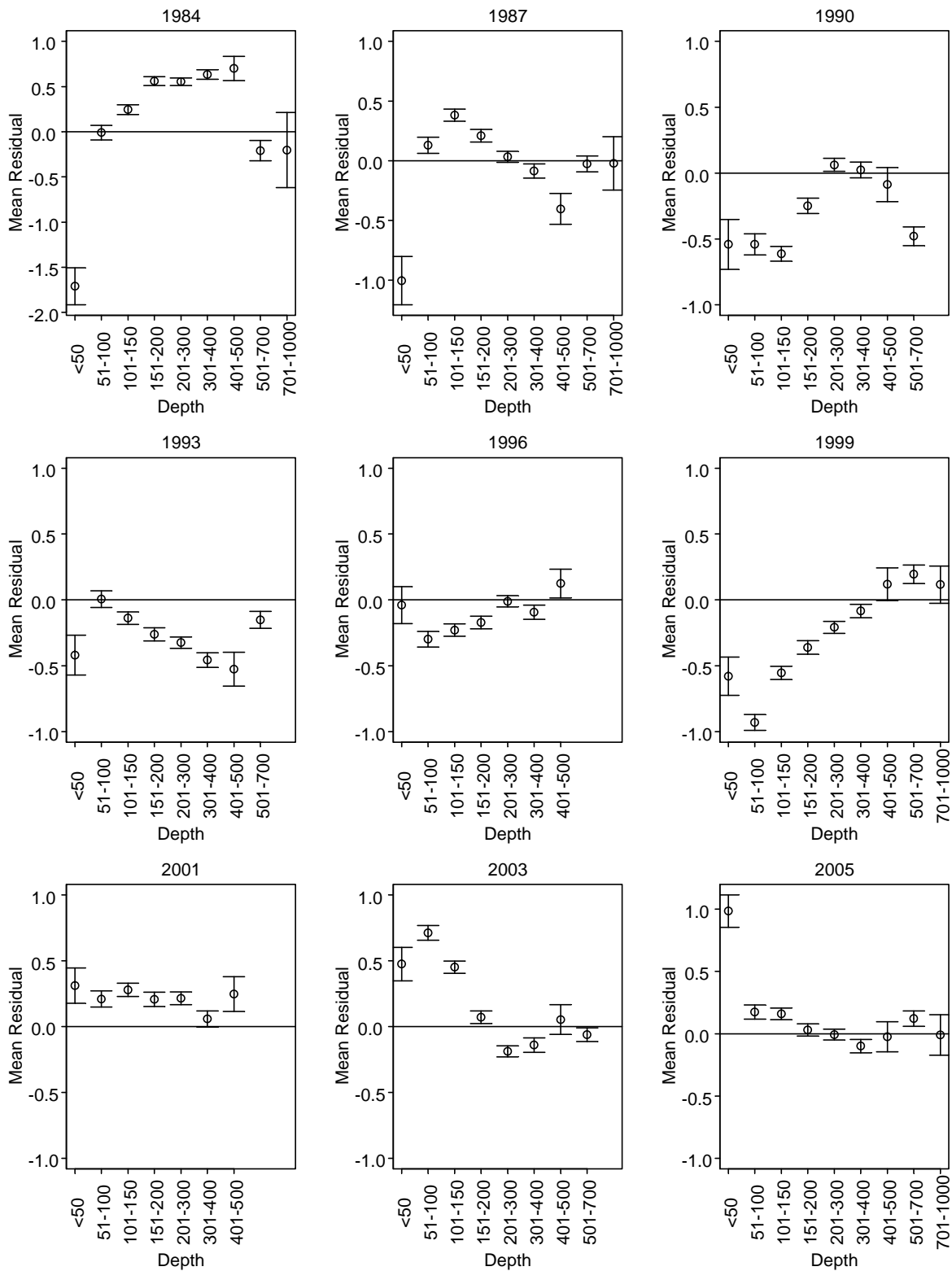
Figure 16. Mean temperature anomalies plotted by depth stratum within each year. Error bars are standard errors. Note expanded scale in 1984 plot.

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

Contributed by N. Sarkar, T. C. Royer, C. E. Grosch, Center for Coastal Physical Oceanography, Department of Ocean, Earth and Atmospheric Sciences, Old Dominion University, Norfolk, VA 23529. Corresponding author: N. Sarkar, sarkar@ccpo.odu.edu
Last updated: September 2005

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.

$$y = -0.0025x - 158.09$$
$$R^2 = 6E\text{-}07$$

Figure 17. Winter mixed layer depth (m) at GAK 1 from 1974-2005.

The deepest winter MLDs at GAK 1 from 1974 to 2005 (Figure 17) 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 31 year record, however the winters of 2003-2004 and 2004-2005 had deeper than average mixed layers.

The deepest winter MLDs from 1974 to 2005 show a deepening linear trend. Nevertheless, this trend is not statistically significant. Thus the only conclusion is that during 1974-2005, 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.

EASTERN BERING SEA - 2005

Temperature and Ice Cover - FOCI

S. Rodionov, P. Stabeno, J. Overland, N. Bond, and S. Salo, PMEL/NOAA
Last updated: September 2005

Summary. The anomalously warm winter of 2005 follows similarly warm winters of 2003 and 2004. Although surface air temperature in the winter of 2002 was colder than 1961-2000 average, the depth-integrated temperatures at Mooring 2 indicate that the shift to warmer conditions in the Bering Sea began in the spring of 2000. 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. Sea surface temperature in May 2005 was above its long-term average value, which means that the summer bottom temperatures will likely be also above average.

The winter of 2005 in the Bering Sea was anomalously warm, with the mean winter (DJFM) surface air temperature (SAT) at St. Paul being 2.34°C (or 1.4 standard deviations) above the 1961-2000 average. This increases our confidence that a shift toward a warmer climate in the Bering Sea occurred in 2001 (Figure 18a). The significance level for this shift is 0.09, which is based on the two-tailed Student t-test for the difference in the mean SAT values for the periods 1990-2000 and 2001-2005. This difference would have been even more statistically significant if there were no "outliers", specifically, a cold winter in 2002, and a warm winter in 1996. In response to this warming, the Bering Sea is experiencing a northward biogeographical shift (Overland and Stabeno 2004). If this shift continues over the next decade, it will have major impacts on commercial and subsistence harvests as Arctic species are displaced by sub-Arctic species.

Milder winters in the Bering Sea can partly be explained by the tendency for anomalously low SLP (Figure 18b), which indicates an enhanced cyclonic activity and increased advection of warm Pacific air. The level of cyclonic activity over the Bering Sea is linked to the strength of the Aleutian low, but it can also be associated with the north-south dipole of the Victoria pattern. The shift in Bering Sea pressure index (BSPI) in 1977 reflects the basin-wide climate shift and strengthening of the Aleutian low. The 1989 and 1998 shifts in the BSPI appear to be mostly a response to phase shifts in the Victoria pattern. In addition to cyclonic activity, an important factor responsible for thermal conditions in the Bering Sea is the mean meridional flow in the lower troposphere. As discussed in the Pacific section of the report, the East-Central North Pacific (ECNP) index (which takes into account both these factors) showed a statistically significant increase since 2000, suggesting greater Pacific influence on the Bering Sea.

This recent warming in the Bering Sea is not confined to the winter season. Figure 19a shows monthly SAT anomalies at St. Paul for the period from January 1995 through May 2005. Note the sharp transition from very low temperatures in the early winter of 2000 to anomalously warm conditions in late winter and spring of that year. Similar transitions, to a lesser degree, were observed in winter-spring of 1998 and 2002. Stabeno and Overland (2001) argue that the Bering Sea appears to have shifted toward a pattern of earlier spring transition. Since March 2002, SAT anomalies remained positive for 37 consecutive months until April 2005, which was slightly colder than normal. This is the longest run of positive SAT anomalies during the period of record extending back to 1916.
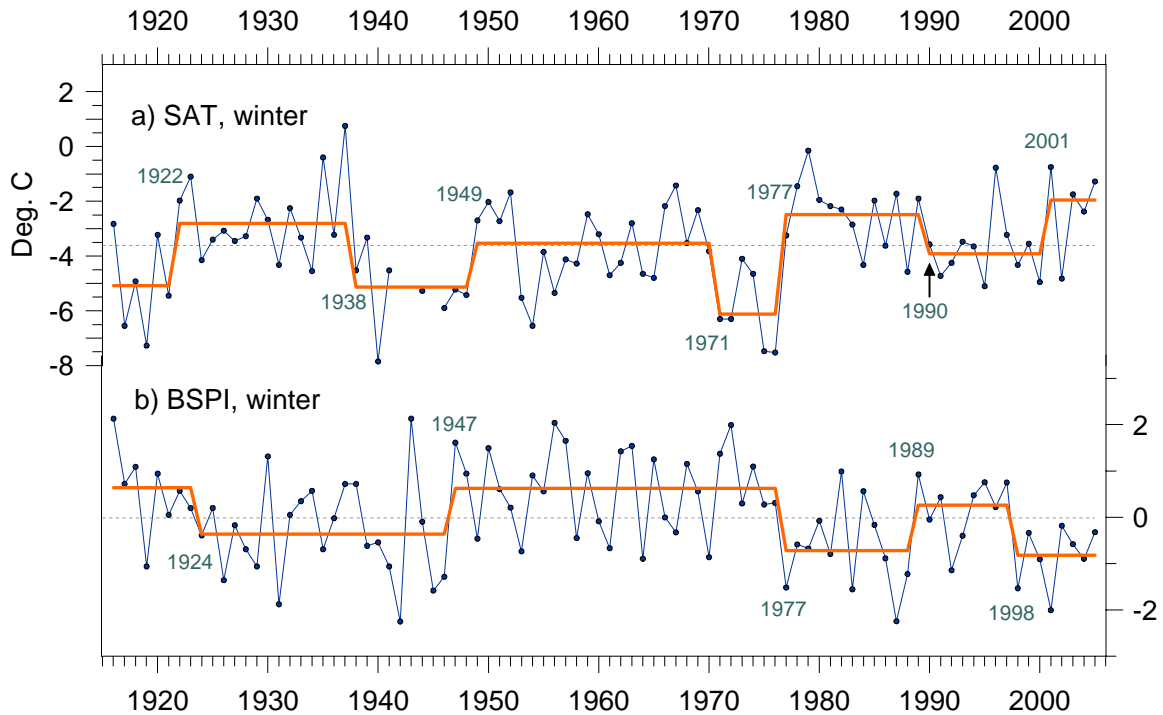
Figure 18. Mean winter (DJFM) a) surface air temperatures in St. Paul, Pribilof Islands and b) Bering Sea pressure index. The dashed line for the top graph indicates the mean SAT value of -3.62°C for the base period, 1961-2000. Positive (negative) values of BSPI suggest anticyclonic (cyclonic) conditions in the Bering Sea. 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. The latter reduces the effect of "outliers", if they exceed one standard deviation from the mean value of the corresponding regime.

To put this recent warmth in perspective, we calculated mean monthly SAT anomalies for the entire record since 1916 and smoothed them with 13-mo averages (Figure 19b). It is clear from this time series that the magnitude of the recent warmth is comparable with the major warm episodes in the 1930s and immediately after the regime shift in the late 1970s.

Figure 19b also shows three multidecadal regimes in SAT fluctuations: 1921-1939 (warm), 1940-1976 (cold), and 1977-2005 (warm). It is worth noting that the two previous regimes had a similar pattern, when SAT anomalies were strongest at the end of the regime, right before the system switched to a new one. 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 (see the Pacific Climate overview section).

Monthly SAT anomalies at St. Paul
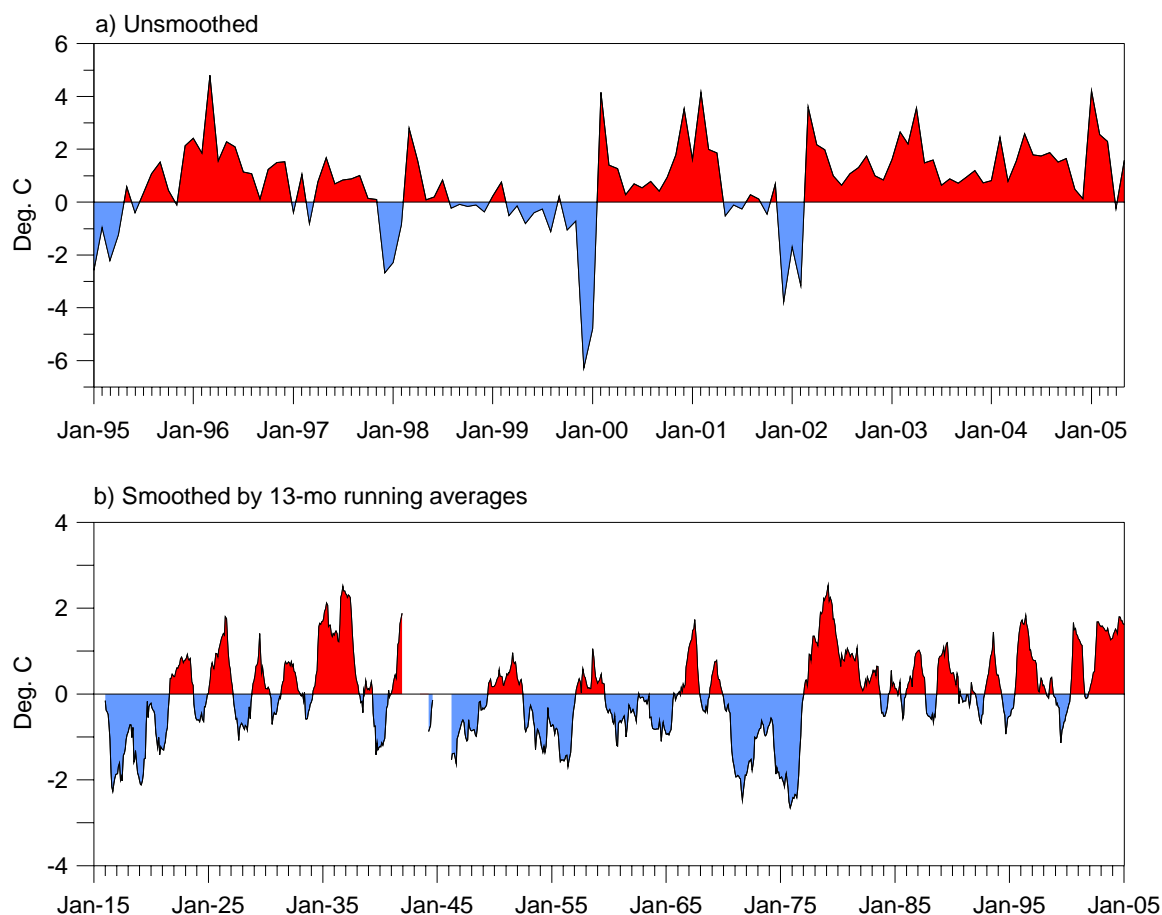
Figure 19. Mean monthly surface air temperatures anomalies in St. Paul, Pribilof Islands, a) unsmoothed, January 1995 through May 2005, and b) smoothed by 13-mo running averages and referred to the central month of the window, January 1916 through January 2005. The base period for calculating anomalies is 1961-2000.

An increase in year-to-year variability since the mid-1980s can also be seen in the Ice Cover Index (ICI, Figure 20a). In 2001, the ice cover index (ICI) plunged to a record low value, and then a new record was set in 2005.

As Figure 20b illustrates, there is a clear overall downward trend in the ice retreat index (IRI). The IRI represents the number of days with ice cover after March 15 in the 2˚ x 2˚ box (56-58°N, 163-165°W) that includes Mooring 2 (57˚N, 164˚W). Since the early 1970s, the index is declining at an average rate of almost 1 day per year, a trend significant at the 95% level. In the season of 2005, ice was practically absent in the box. A brief cold spell in April did bring about ice barely above the 10% threshold (Figure 21). This threshold is used to calculate the beginning and end of ice season (Figure 22). Based on this definition, the 2005 ice season lasted only 5 days. Similarly short ice seasons (less than 2 weeks) were observed in 2001 and 2003. In 2000 and 2002, in contrast, ice arrived to the vicinity of Mooring 2 very early, about one month prior to the average date for the beginning of ice season on January 14. Note, however, that starting with the 1996 ice season, if ice arrives early, it retreats early too (with the exception of 1999). This supports the shift in the Bering Sea toward earlier spring transition (Stabeno and Overland 2001).
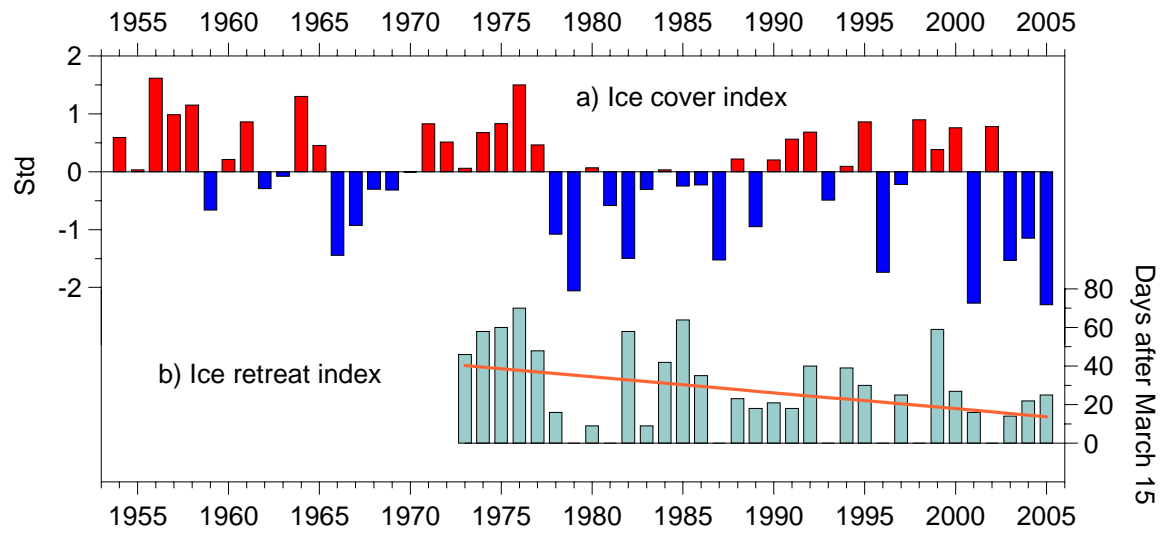
Figure 20. a) Ice cover index, 1954-2005, and b) ice retreat index and its linear trend (orange line), 1973-2005.
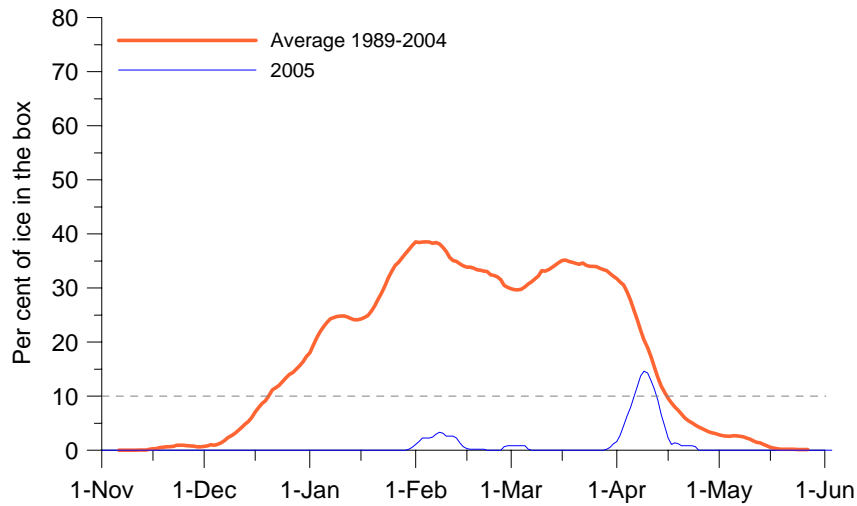
Figure 21. Percentage of ice cover in the 2˚ x 2˚ box (56-58°N, 163-165°W) during the winter of 2005.
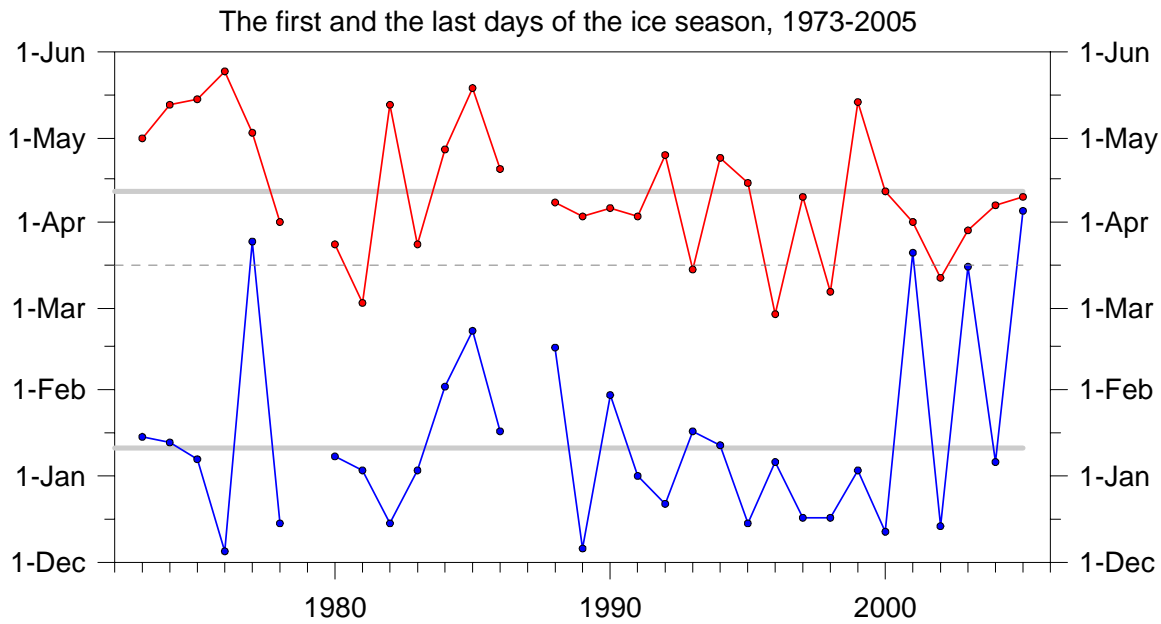
Figure 22. The first and last days of the ice season, 1973-2005. The gray solid horizontal lines are the mean dates for these two variables. The dashed line (March 15) is used as a threshold to calculate the ice retreat index. No ice was present in the box in 1979 and 1987.

The decrease in sea ice directly impacts water column temperature and salinity, and the timing of the spring bloom. These changes can be seen clearly in the data collected at two sites, Mooring 2 and Mooring 4 (Figure 23). The very cold temperatures (indicated by black) are accompanied by the *in situ* melting of ice. Generally, stratification develops during April. The water column exhibits a well-defined two-layer structure throughout the summer consisting of a 15-25 m wind mixed layer and 35-40 m tidally mixed bottom layer. When the bottom temperature is less than 2˚C, by definition it represents a "cold pool". In earlier years (1995, 1996, 1997, and 1999) bottom temperatures were below the 2˚C threshold, but in more recent years the temperatures are much warmer, indicating the failure of the formation of the southern cold pool.
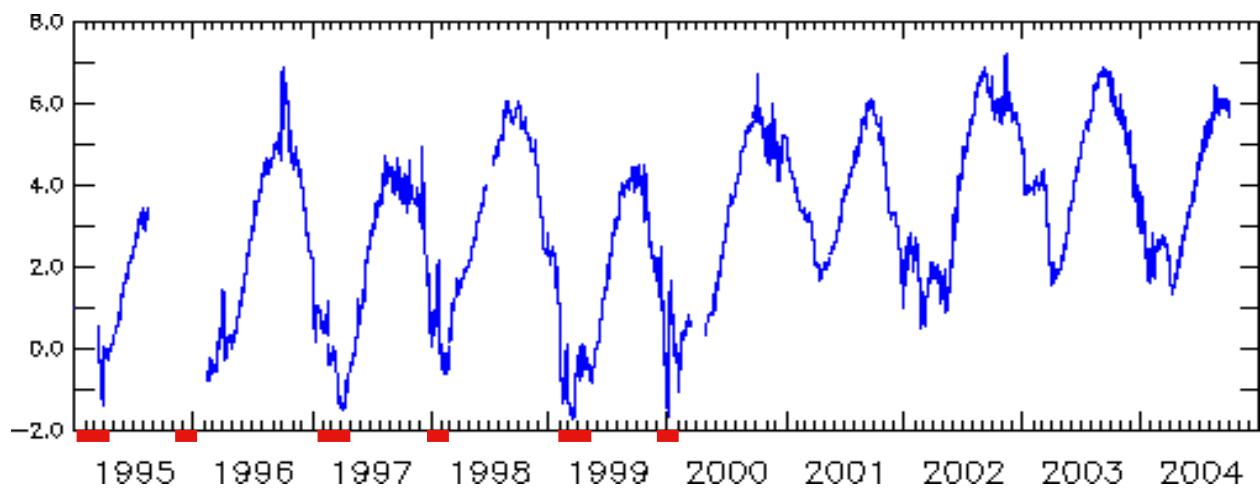
Figure 23. Depth integrated temperature at Mooring 2. The red lines at the bottom of the plot indicate when ice was present over the mooring.

The depth-averaged temperature at Mooring 2 (Figure 24) includes strong annual cycle, of course, but also a striking transition that occurred in 2000. During each winter from 1995 through 2000, ice was advected over the site cooling the water column. Beginning in 2001, ice (concentration greater than 10%) has not been over the mooring. This has been accompanied by a prominent warming of 3°C in the winter and about 2°C in the summer.

Sea surface temperature in May, when the southeastern Bering Sea is free of ice, appears to be a good predictor for summer bottom temperature. The correlation coefficient between May SSTs averaged over the southeastern Bering Sea (MaySST index) and mean bottom temperature for the same region is r = 0.82 (P < 0.001) for the period 1982-2003. Although May SST somewhat decreased in the past two years from its all-time maximum in 2003, it remains well above its long-term average value (Figure 25). Therefore, all indications are for a continuation of the warmth of the recent years through the summer of 2005.
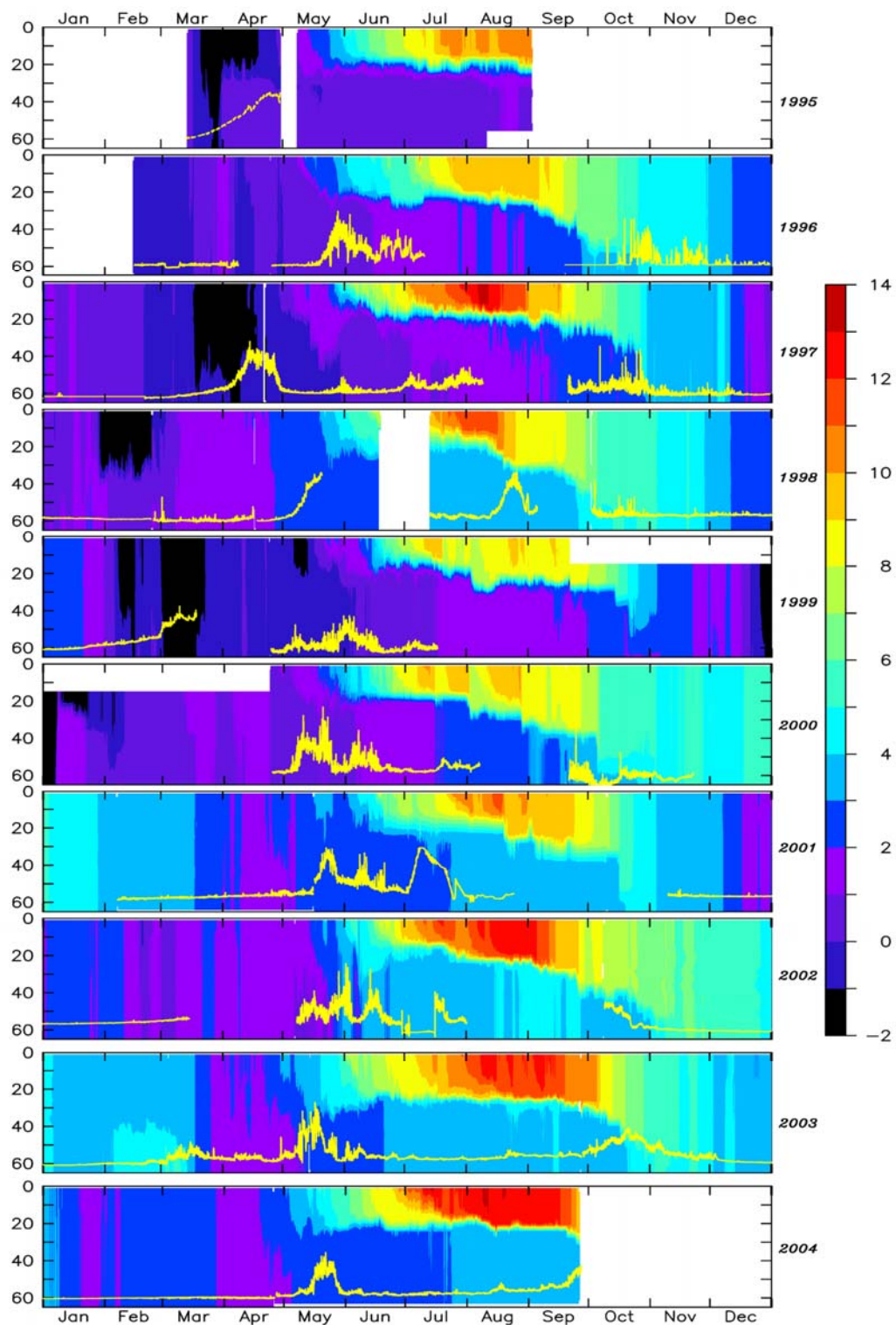
Figure 24. Contours of temperature measured at Mooring 2, 1995-2004. The coldest temperature (black) occurred when ice was over the mooring. The yellow line is fluorescence measured at ~11m. Note that early blooms are associated with the presence of ice.

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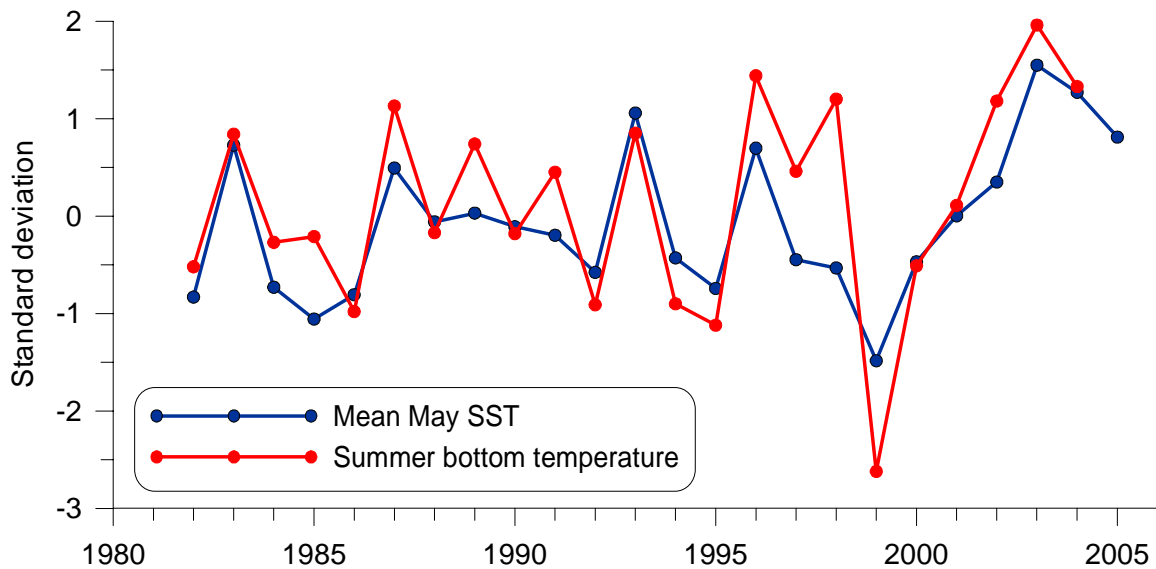
Figure 25. The MaySST index and mean summer bottom temperature in the southeastern Bering Sea, 1982-2005.

Simulated Drift Trajectories in the Southeast Bering Sea –FOCI
Contributed by Dylan Righi, FOCI, NOAA/PMEL
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 26). 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 27 (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.
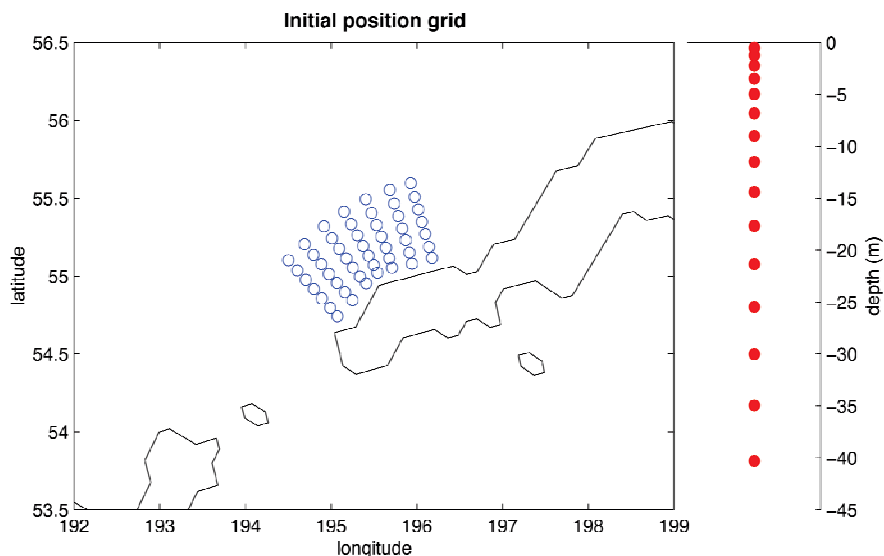
Figure 26.   Simulated drifter initial horizontal (left) and vertical (right) positions.

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 28 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 28). 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.
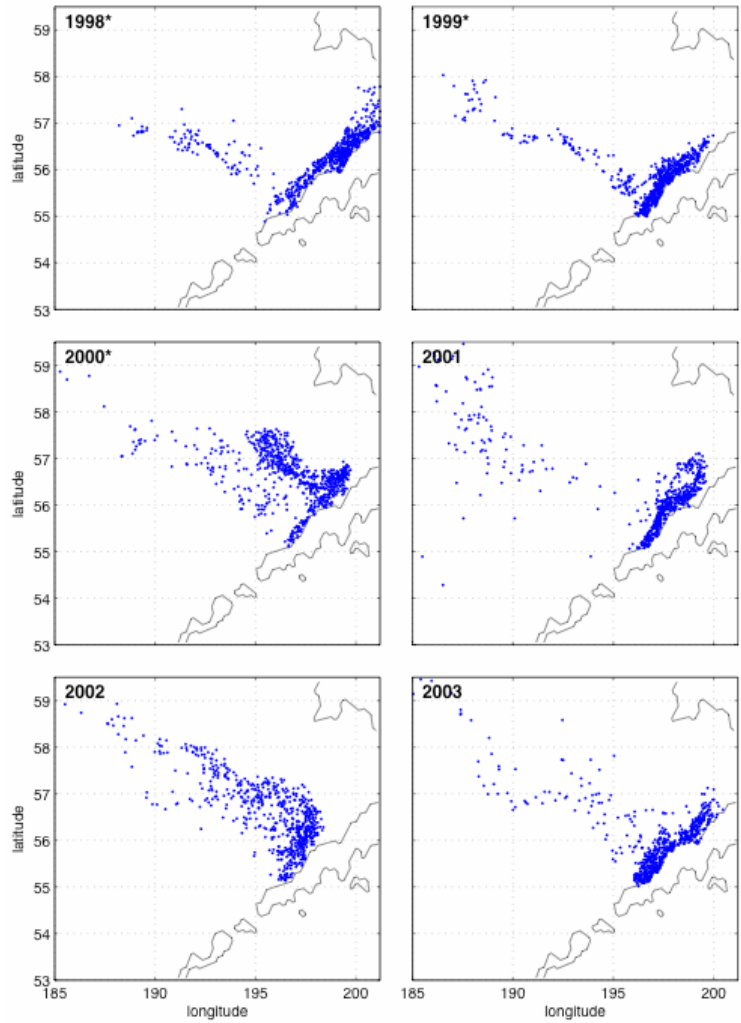
Figure 27. Endpoints for 90-day drifter trajectories for 1998-2003.
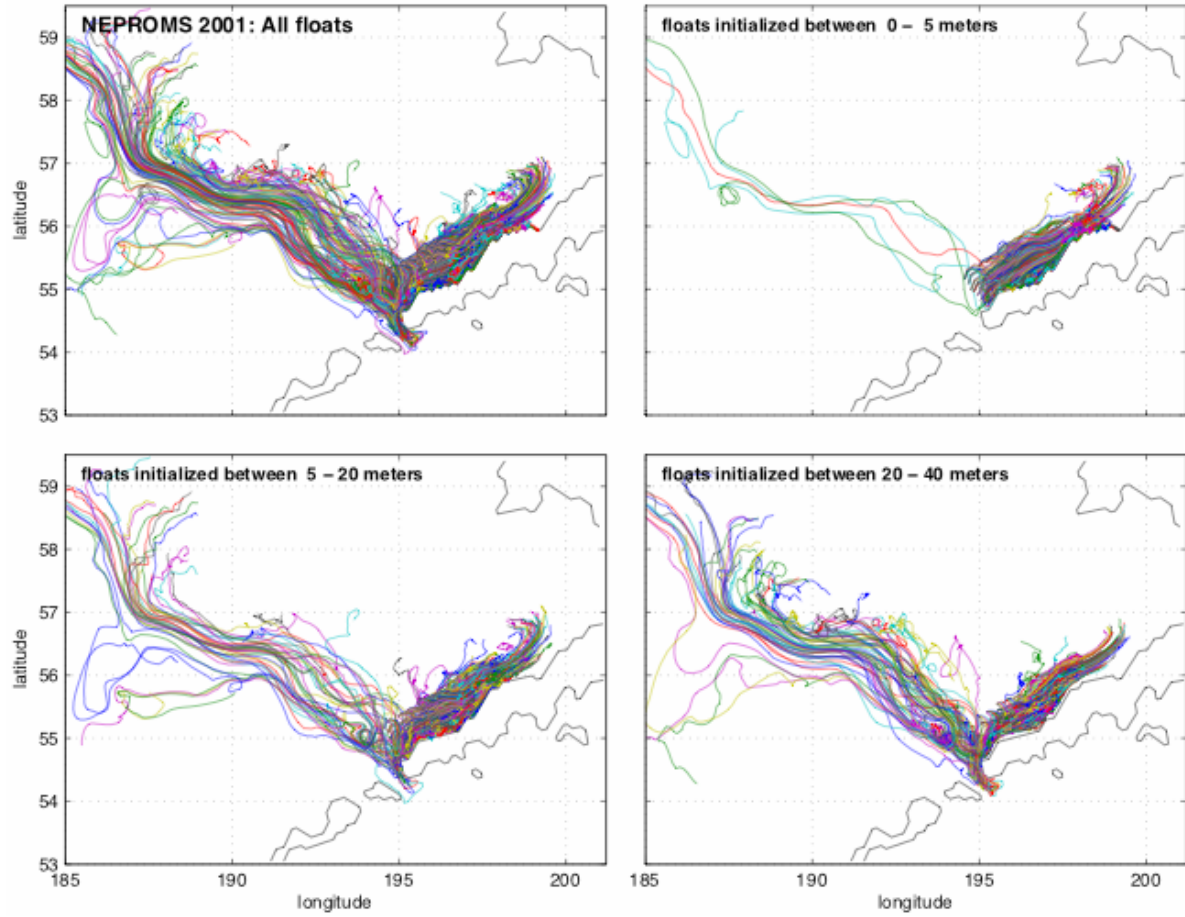
Figure 28. Full trajectories for the 2001 90-day simulated drifters. Upper left panel shows all drifters, while the upper left and bottom panels show drifters divided as a function of initial release depth.

Summer bottom and surface temperatures – Eastern Bering Sea
Contributed by Robert Lauth, Alaska Fisheries Science Center
Last updated: November 2005

The annual AFSC bottom trawl survey for 2005 was started on May 30 and finished on July 25. The average bottom temperature was 3.47˚C, well above the 1982-2004 mean of 2.58˚C (Figure 29). Bottom temperature anomalies from the long-term station means were positive over the most of the shelf region except for the northern sections of the inner and middle shelf regions (Figure 30). Maximum anomalies occurred in the inner and middle domain with 17 stations over +2 degrees Celsius. The 'Cold Pool', usually defined as an area with temperatures less than 2 degrees Celsius, surrounded St. Matthew Island and extended south to about 58.6˚N, about one half a degree further north than last year.

The average 2005 surface temperature, 7.42˚C, was lower than in 2003 or 2004 (long term mean 6.75˚C). About two-thirds of the 2005 survey stations had increases in temperatures with 49 stations having increases 2˚C above long-term station means (Figure 30). The largest surface temperature differences were in the middle domain and southeast portion of the inner domain.
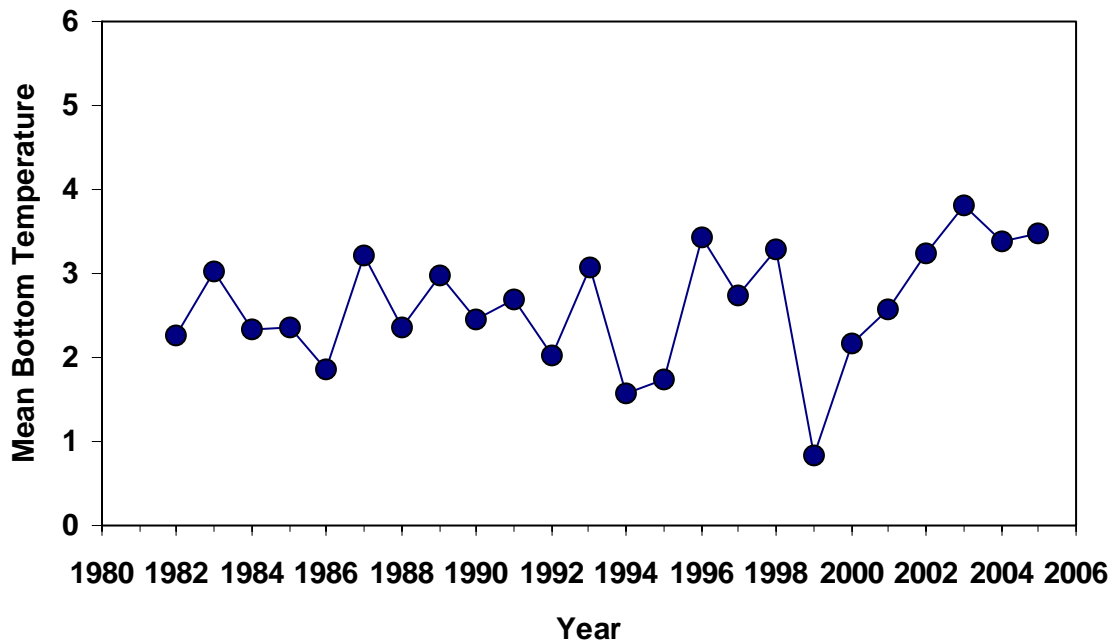
Figure 29. Mean summer bottom temperature (˚C) in the standard bottom trawl survey area of the eastern Bering Sea Shelf, 1975-2005. Temperatures for each tow are weighted by the proportion of their assigned stratum area.
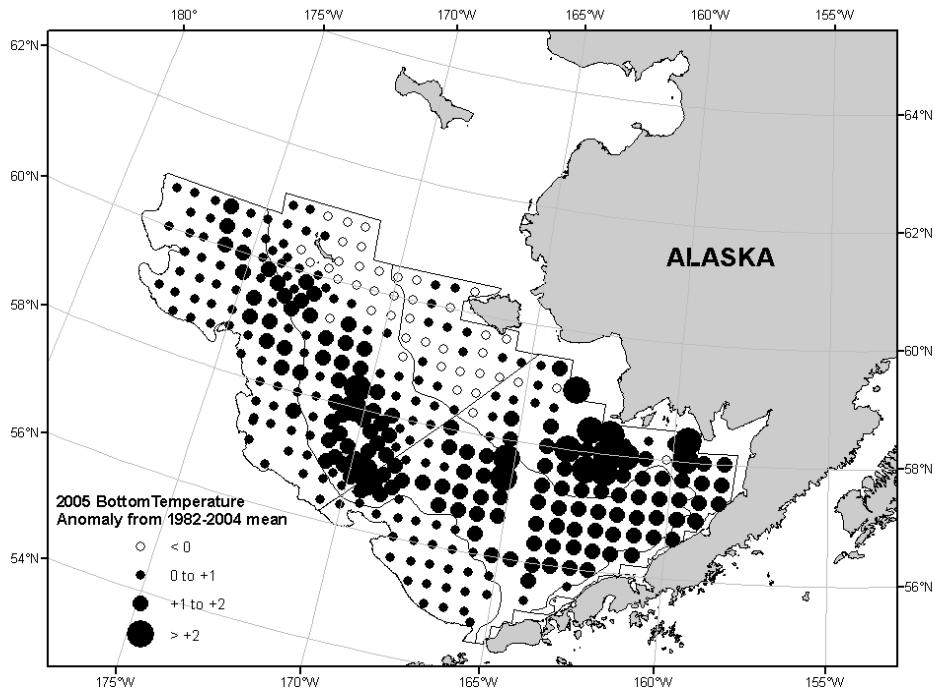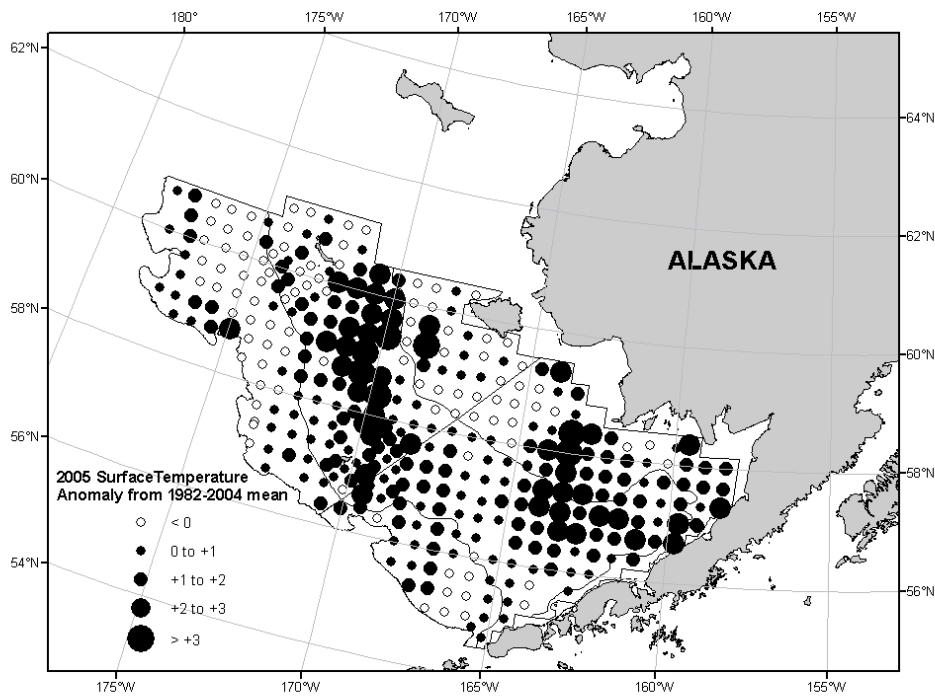
Figure 30. Summer surface (top panel) and bottom (bottom panel) temperature anomalies in 2005 from the 1982-2004 mean at standard bottom trawl survey stations in the eastern Bering Sea.

Variations in water mass properties during fall 2000-2004 in the eastern Bering Sea-BASIS
Lisa Eisner, Ed Farley, Jim Murphy, Auke Bay Laboratory, NMFS
Last updated: September 2005

Oceanographic and fisheries data have been collected in the Eastern Bering Sea (EBS) during fall 2000-2004 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 15-30 km resolution, although spatial coverage varied by region and by year. Bristol Bay stations were sampled from mid August to early September during all five years. While, stations in the central and northern Eastern Bering Sea were generally sampled from mid September to mid October. Oceanographic data were obtained from vertical conductivity-temperature-depth (CTD) profiles and laboratory analyses of discrete water samples at select depths (2003 and 2004 only). 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 2000-2004 in the Eastern Bering Sea are shown in Figure 31. Bristol Bay surface temperatures were warmer in 2002, 2003 and 2004 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. Surface salinities in the Middle Domain of Bristol Bay were lower in 2003 and 2004 than in earlier years. Analyses of vertical sections in Bristol Bay (data not shown) indicate that the pycnocline depths were shallower in 2002 and 2004 than in 2000 and 2001. The location of the cold pool, deep cold water formed during ice melt, can have a large impact on fisheries distributions. The cold pool was observed south of St. Lawrence I. (between 168 and 174°W and 60 to 63°N) in 2002 and 2004 during early October and mid September, respectively (see Figure 39 in the *Nutrients and Productivity* section of this report).
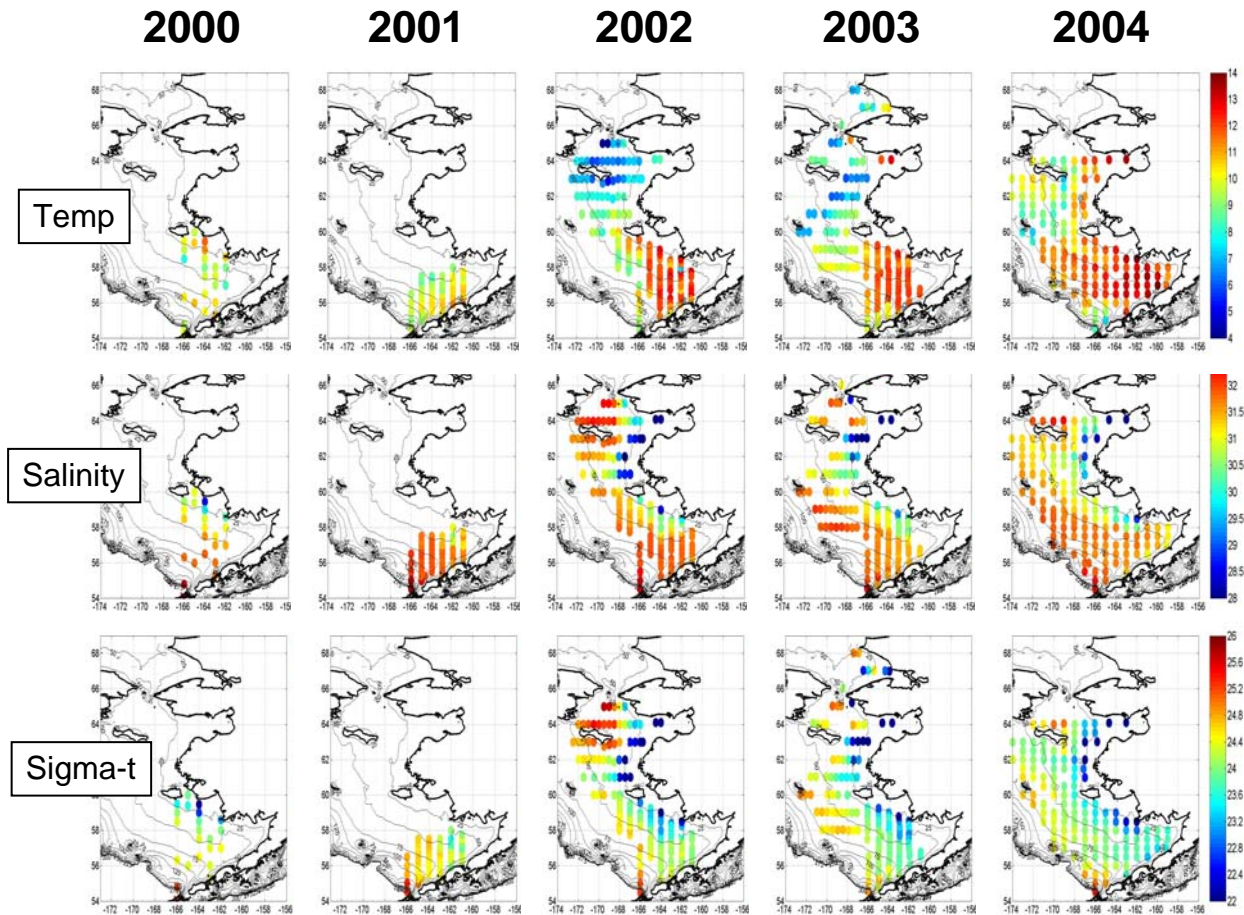
Figure 31. Surface (5 m) temperature (°C), salinity and density (sigma-t, kg m^{-3}) from CTD casts collected mid-August to mid-October, 2000-2004. Bristol Bay stations were sampled from late August to early September for all years.

ALEUTIAN ISLANDS

Water temperature data collections – Aleutian Islands Trawl Surveys
Contributed by Harold Zenger, Alaska Fisheries Science Center
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 32). 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 32). 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.
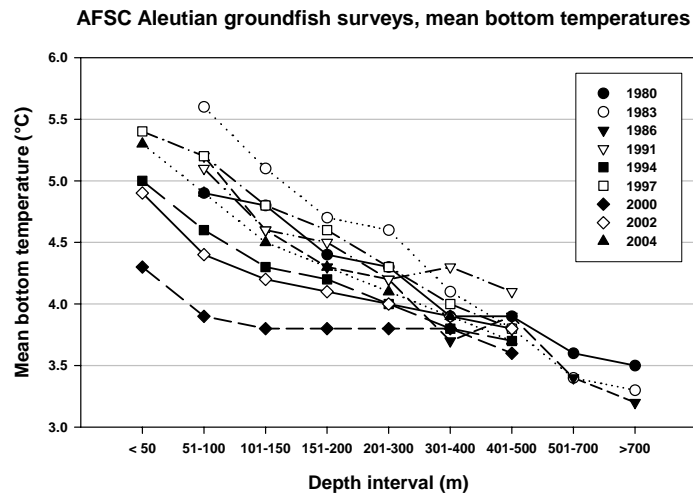
ENSO events are monitored using the Multivariate ENSO Index (MEI) which is based on six observed variables over the tropical Pacific: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. Given 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 33). 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 33). 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).

AFSC Aleutian groundfish surveys, mean bottom temperatures

Figure 32. Mean bottom temperatures from the Alaska Fisheries Science Center (AFSC) groundfish surveys (1980-2004).

Mean bottom temperature vs. mean MEI
(March to end of survey period)
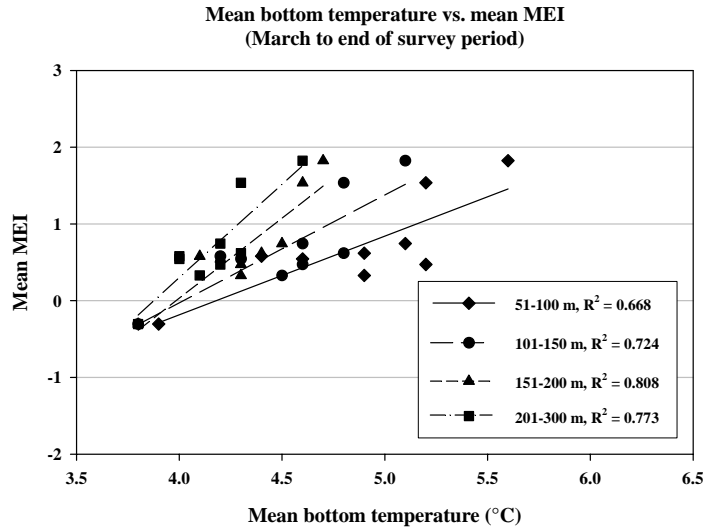
Figure 33. Multivariate ENSO Index (MEI) as a function of mean summer bottom temperatures in the Aleutian archipelago.

Water Temperatures Across the Survey Area

Figure 34 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 35 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.
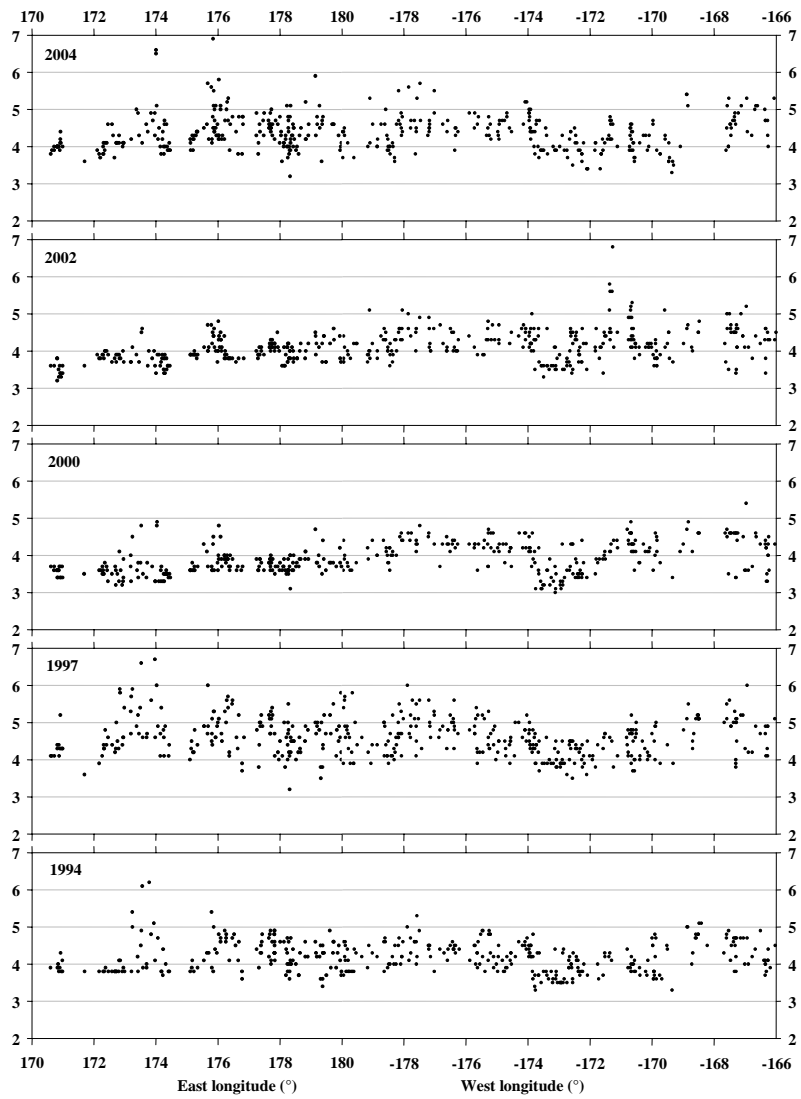
Figure 34. Bottom temperatures collected during the five most recent AFSC Aleutian Islands bottom trawl surveys, by longitude
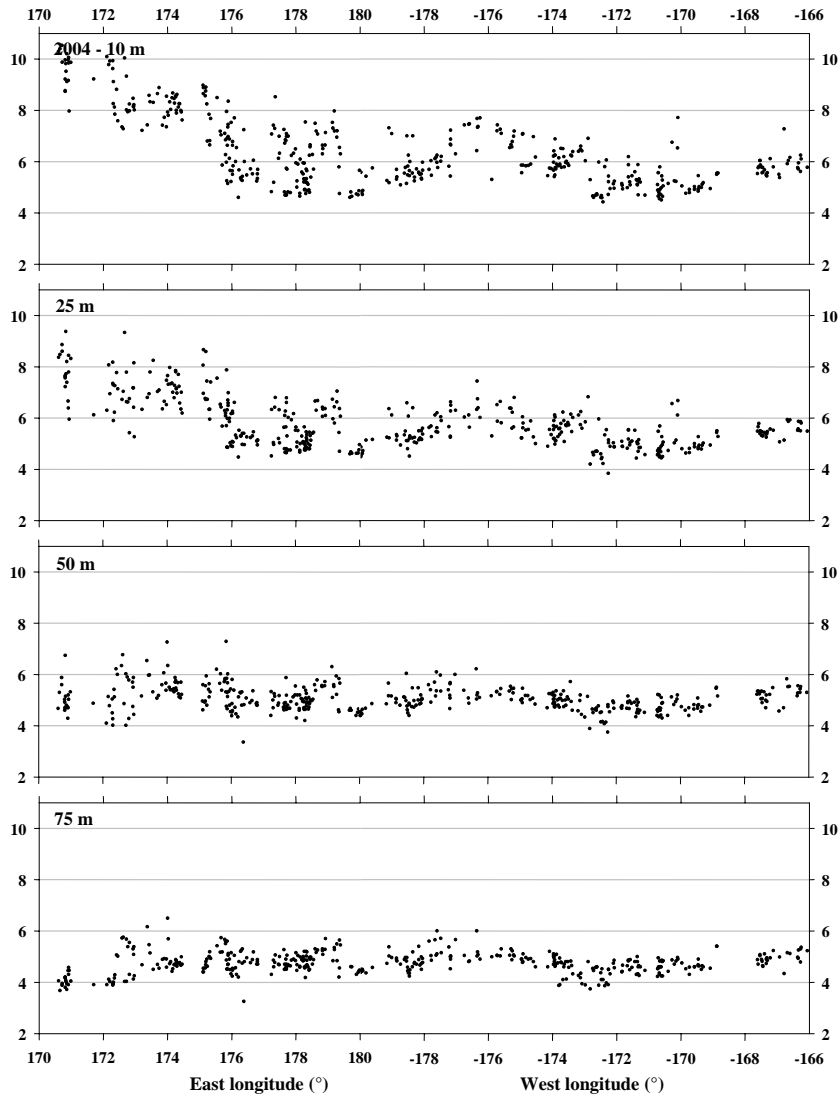
Figure 35. Temperatures at 12 depths by longitude, collected during the 2004 AFSC Aleutian Islands bottom trawl survey.

Figure 36 continued. Temperatures at 12 depths by longitude, collected during the 2004 AFSC Aleutian Islands bottom trawl survey.

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HAPC Biota – Gulf of Alaska
Contributed by Michael Martin, AFSC, RACE Division (michael.martin@noaa.gov)
Last updated: November 2005

The biennial survey in the Gulf of Alaska does not sample any of the HAPC fauna well. The survey gear does not perform well in many of the areas where these organisms are 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 organisms. Variability is also an important issue as point estimates are often strongly influenced by a very small number of catches. Therefore, the survey results provide very limited information about abundance or abundance trends for these organisms. Perhaps the most notable aspect of the results is the general lack of detectable abundance trends due to the variability of the estimates (even ignoring the catchability issues mentioned above). A couple of general patterns are clearly discernible, however. Sponge (Porifera) abundance generally decreases from west to east across the GOA. Sea anemones (Actiniaria) also seem to be more abundant in the central and western GOA than in the eastern GOA (Figure 36).
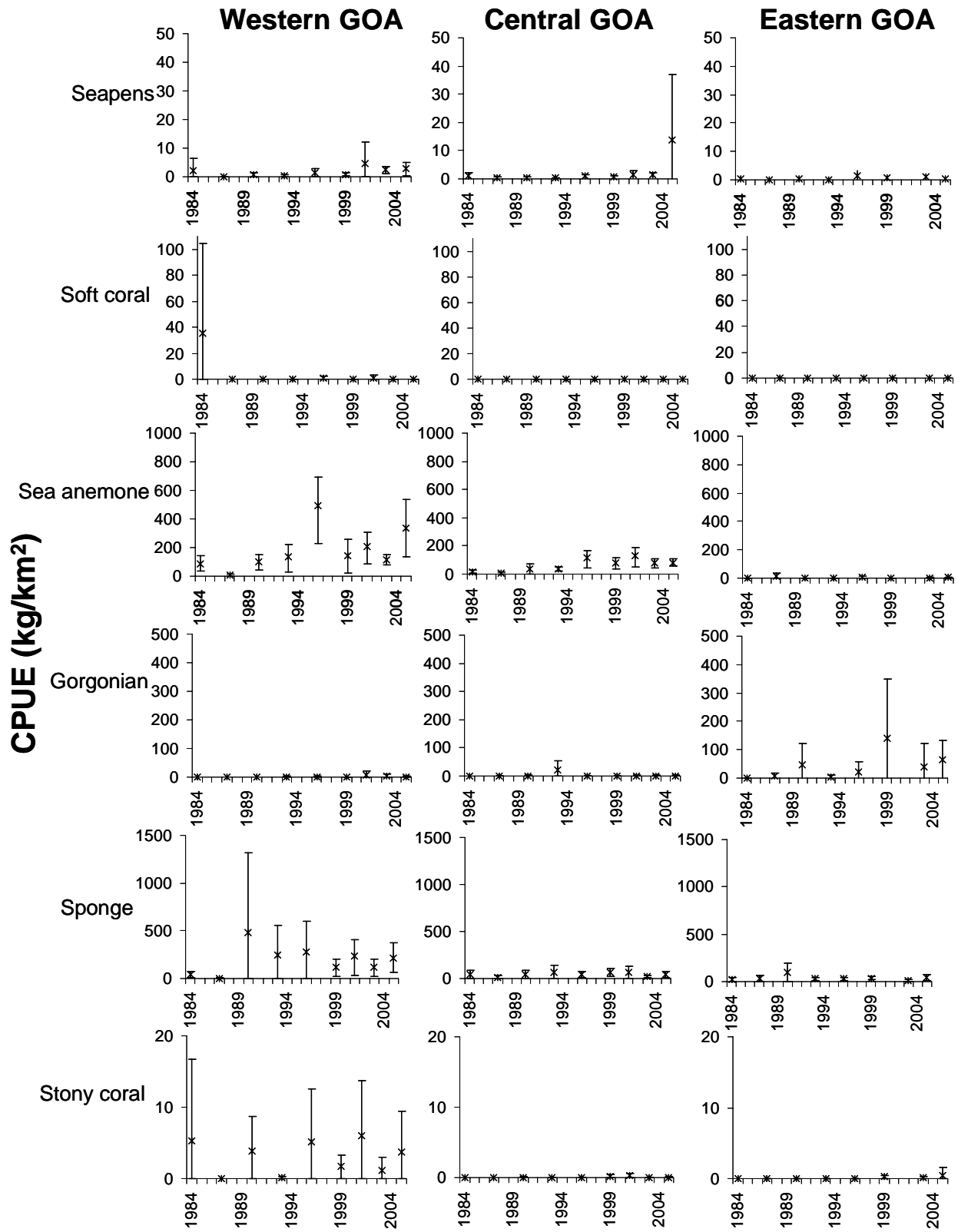
Figure 36. CPUE of HAPC organisms from the Gulf of Alaska biennial survey from 1984 through 2005. Error bars represent 95% confidence intervals.

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HAPC Biota – Bering Sea
Contributed by Robert Lauth, Alaska Fisheries Science Center
Last updated: November 2005

Groups considered to be Habitat Area of Particular Concern (HAPC) biota include: seapens/whips, corals, anemones, and sponges. Corals are rarely encountered on the Bering Sea shelf so were not included here. It is difficult to detect trends of HAPC groups on the Bering Sea shelf from the Resource Assessment and Conservation Engineering (RACE) bottom trawl survey results from 1982 to 2005 because of the relatively large variability in CPUE (Figure 37). Further research on the life history characteristics of these organisms is needed to interpret these trends.
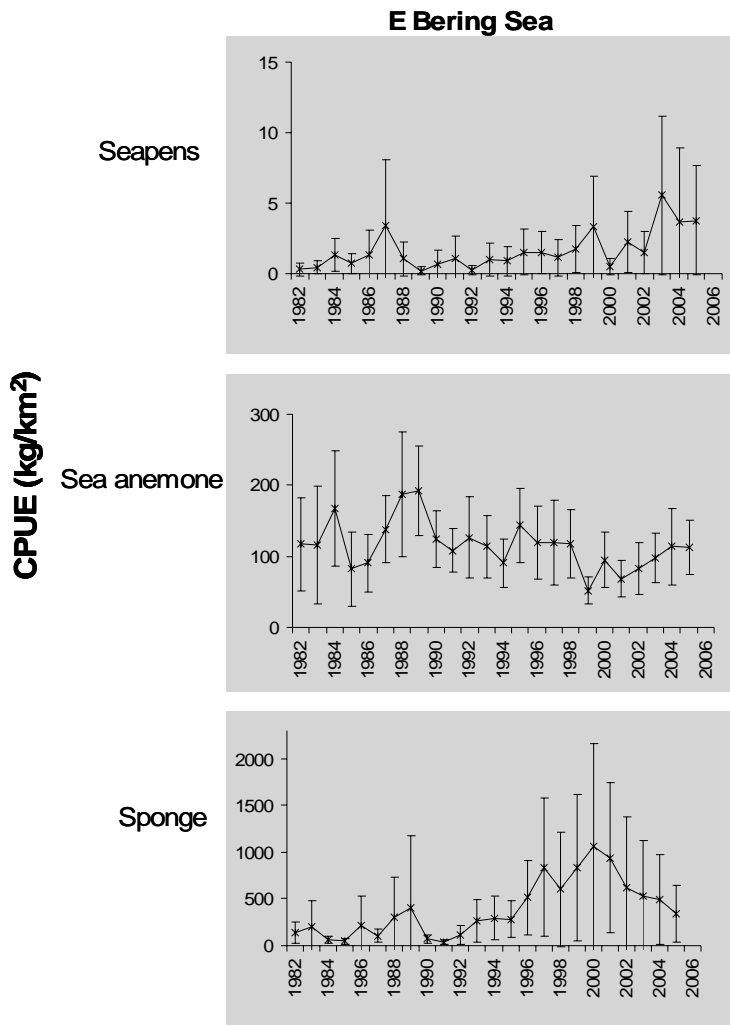
Figure 37. Catch per unit effort (CPUE) trends of HAPC biota from the Resource Assessment and Conservation Engineering (RACE) bottom trawl survey of the Bering Sea shelf, 1982-2005. Data points are shown with 95% confidence intervals.

HAPC Biota – Aleutian Islands
Contributed by Eric Brown, Alaska Fisheries Science Center
Last updated: November 2004

This is the first look at biomass index trends of HAPC biota (seapens/whips, coral, sponges, and anemones) from the RACE bottom trawl survey in the Aleutian Islands. This survey is not designed to assess these organisms and further detailed examination of these results is needed to assess whether there are meaningful trends.

Sea anemones are common in trawl catches but the apparent large increase seen in the southern Bering Sea in 2000 was due to two large catches of 27 kg and 48 kg with other catches rarely exceeding 3 kg (Figure 38). The generally low CPUE of sea anemones in the Aleutian Islands compared to the GOA may be due the "rareness" of suitable habitat. The apparent increase in abundance of soft corals in the central Aleutians in 1991, gorgonian corals in the western Aleutians in 1991 and stony corals in the central Aleutians in 1997 was also highly influenced by a few unusually large catches. The relative abundance of sea pens appears to be increasing in most areas however catch rates tend to be quite low (Figure 38). Seapens may require habitat with higher flow and very fine sand. Flat, sandy bottom substrates are rarer in the Aleutian Islands compared to the GOA or BS, resulting in a patchy distribution and, therefore, high variability in seapen CPUE.   In contrast, the frequency of occurrence and relative abundance of sponges has been consistently high in each of the three Aleutian regions but like many of these groups it is unknown whether the survey is an appropriate tool for measuring or tracking abundance.

The 2004 survey results showed a slight decrease in sponge and sea pen abundance in all areas except the southern Bering Sea, which showed a modest gain. The abundance of stony corals decreased in all areas; whereas, catches of soft corals and Gorgonians were variable among areas.
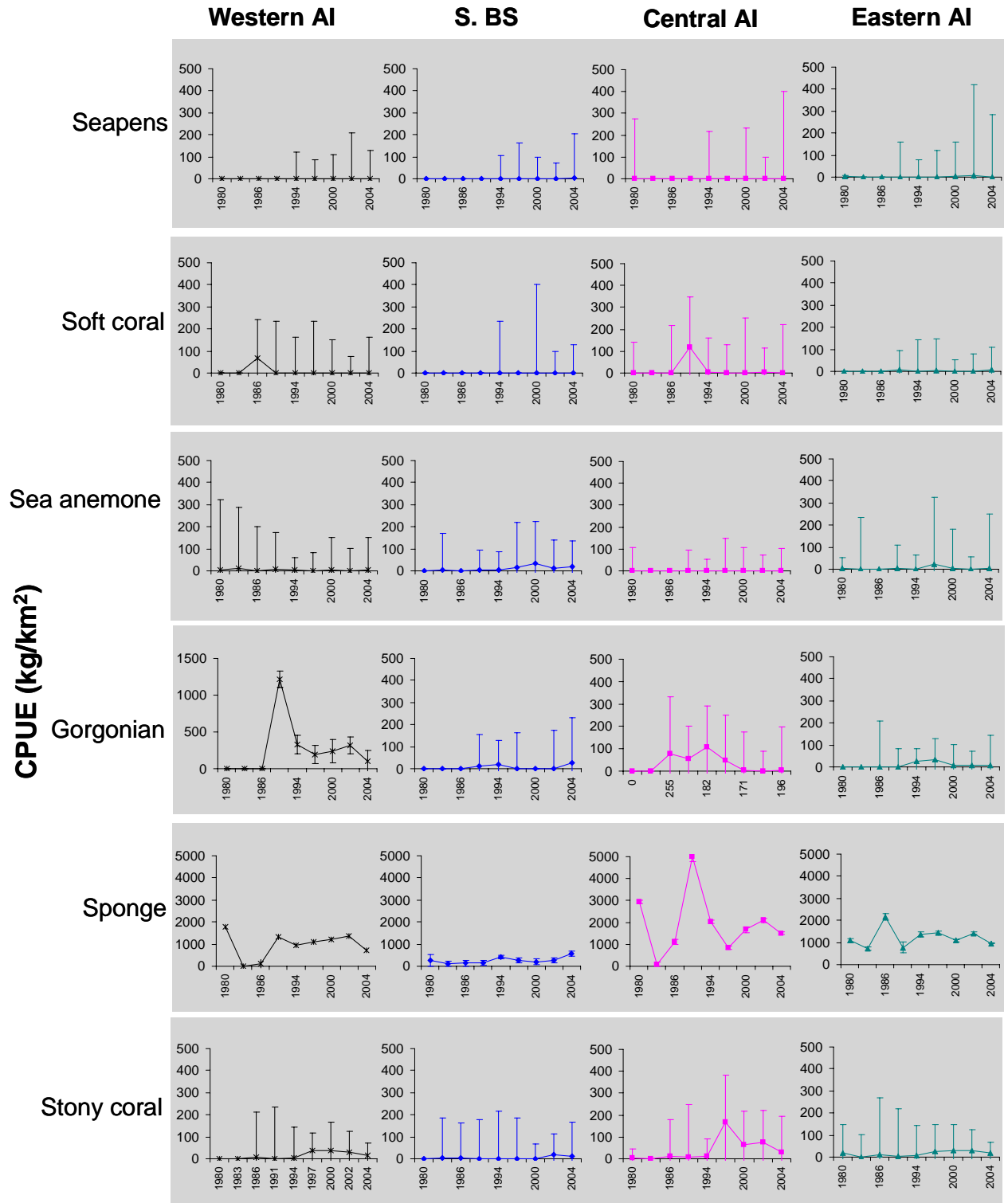
Figure 38. Catch of HAPC organisms per unit area in the western Aleutian Islands (AI), south Bering Sea (BS), central AI, and eastern AI, in bottom trawl surveys conducted between 1980 and 2004. 95% confidence intervals are shown.

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Effects of Fishing Gear on Seafloor Habitat
Edited by Jonathan Heifetz (Alaska Fisheries Science Center, Auke Bay Laboratory)
Last updated: November 2005

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 1 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 recruitment 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)

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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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Nutrient and Chlorophyll Processes on the Gulf of Alaska Shelf
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Last updated: November 2004

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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Last updated: November 2005

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 2000-2004 in the eastern Bering Sea-BASIS
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Last updated: September 2005

Oceanographic and fisheries data have been collected in the Eastern Bering Sea (EBS) during fall 2000-2004 for the U.S. component of a multiyear international research program, Bering-Aleutian Salmon International Survey (BASIS; Figure 39). Stations were located between 54°N and 68°N, at 15-30 km resolution, although spatial coverage varied by region and by year. Bristol Bay stations were sampled from mid August to early September during all five years. While, stations in the central and northern Eastern Bering Sea were generally sampled from mid September to mid October. Forage fish were captured with a surface net trawl and oceanographic data were obtained from vertical conductivity-temperature-depth (CTD) profiles and laboratory analyses of discrete water samples at select depths (2003 and 2004 only). 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 40). 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 39). 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 39). These ammonium values may provide a broad indicator of prior production over the growing season.

2000   **2001**   **2002**   **2003**   **2004**

Temp (°C)

Ammonium (µM)

(30-40 m)
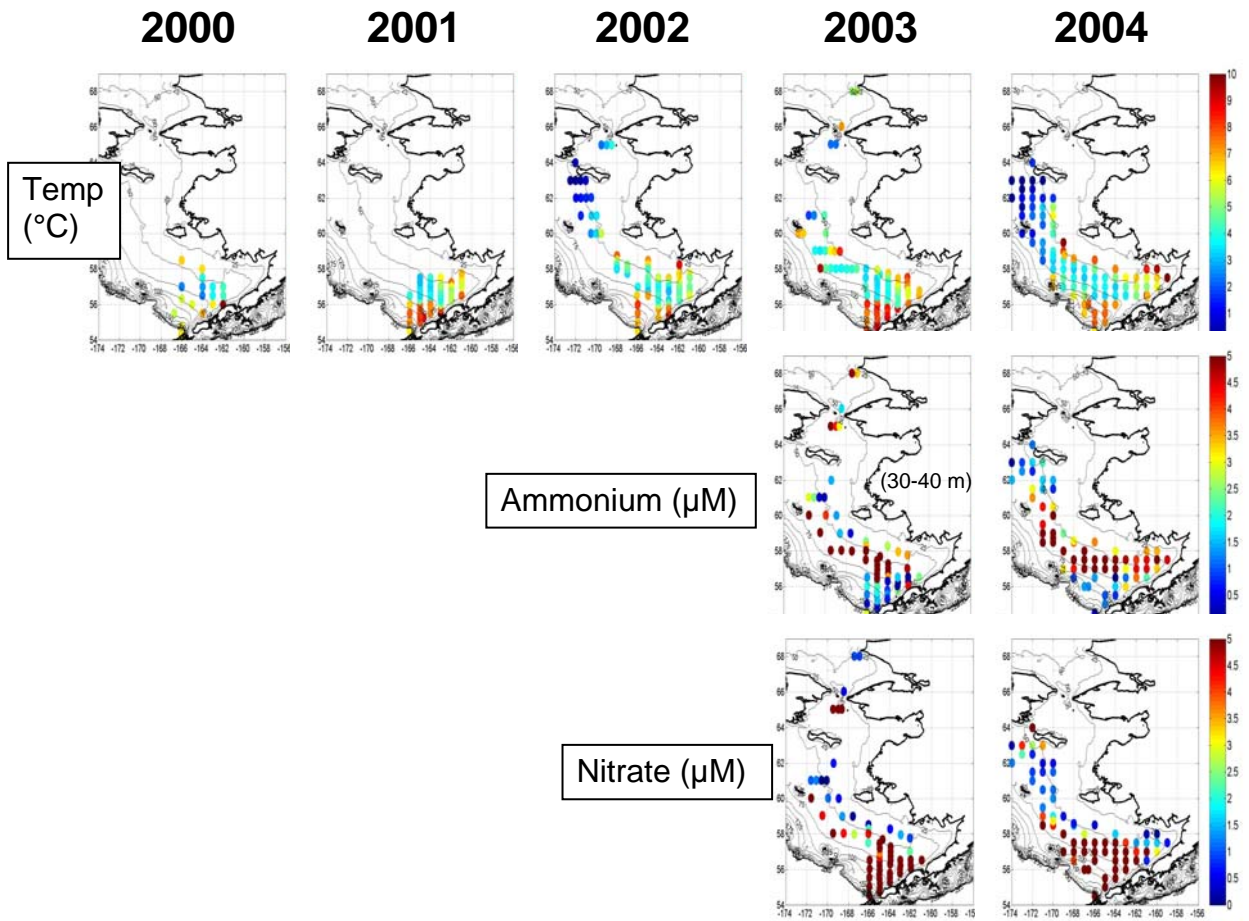
Nitrate (µM)

Figure 39. Deep (40 m, unless indicated) temperature, ammonium and nitrate concentrations during fall in the EBS.

2003　　　　**2004**

5 m
Total Chl a
(µg L-1)

5 m
Chl a >10 µm
(µg L^{-1})

5 m
Nitrate
(µM)
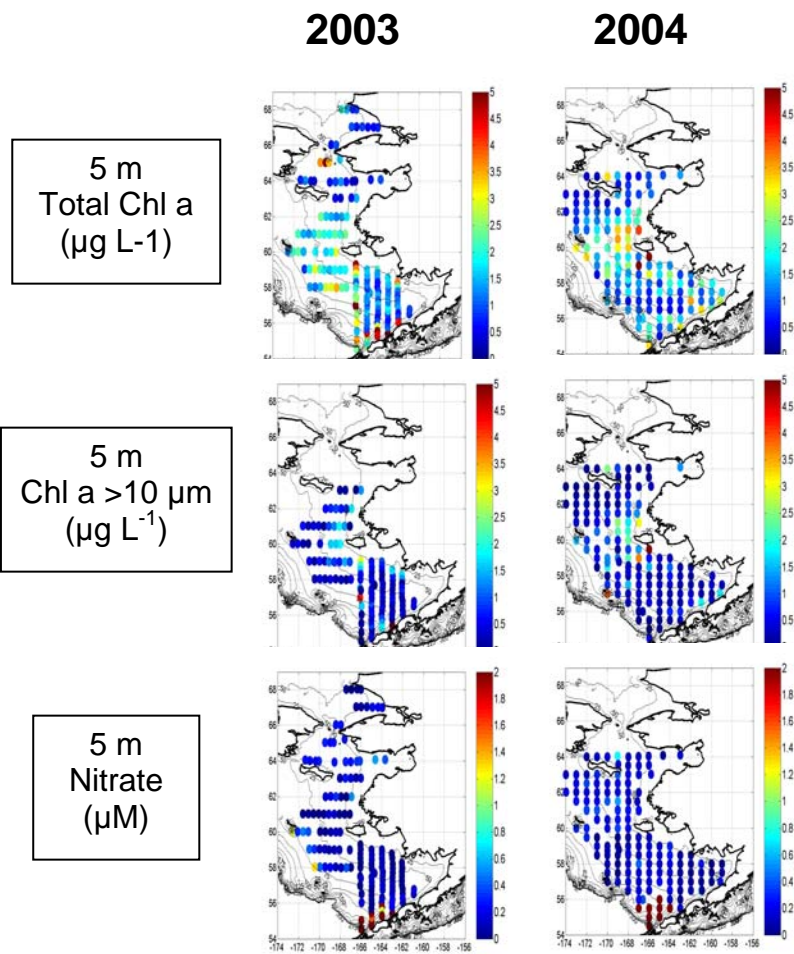
Figure 40. Surface (5 m) total chlorophyll a, chlorophyll a size fraction > 10 µm, and nitrate concentrations in the EBS during fall 2003 and 2004.

Zooplankton

Bering Sea Zooplankton
Contributed by Jeffrey Napp, Alaska Fisheries Science Center, and Naonobu Shiga, Hokkaido University, Japan
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 41). 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.
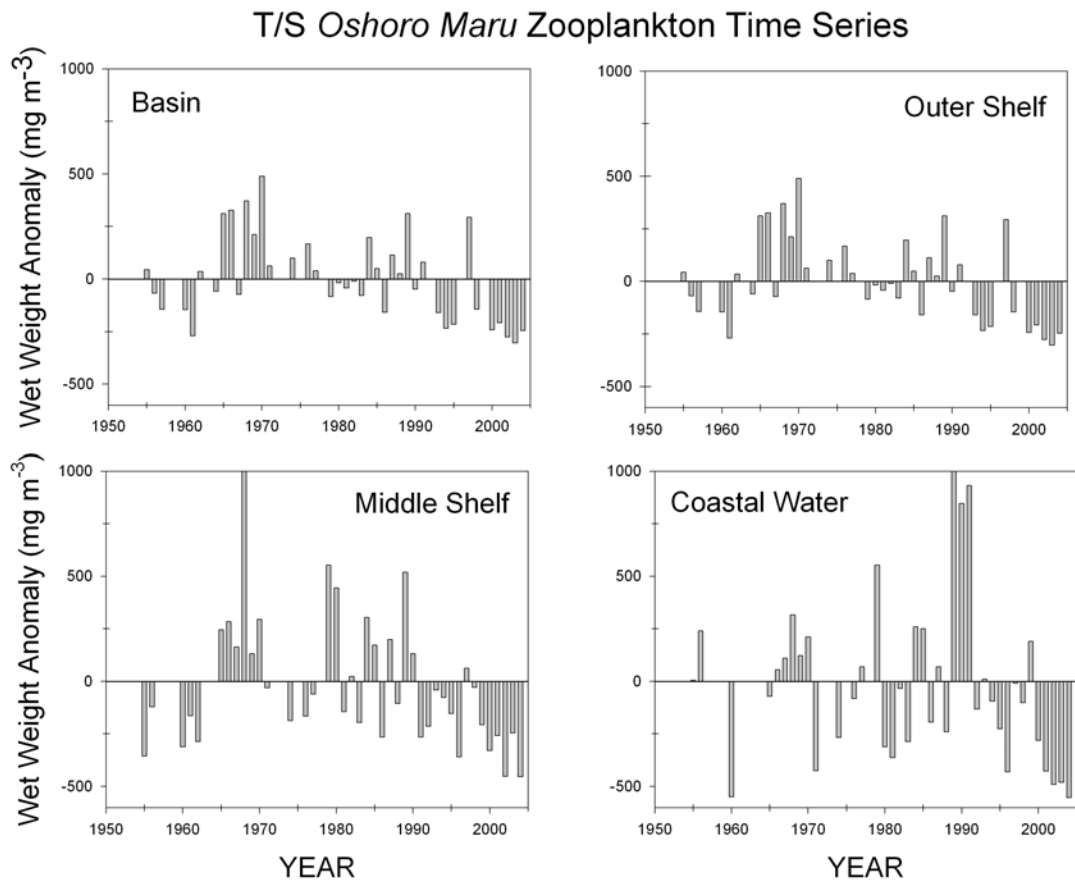
Figure 41.   Zooplankton biomass anomalies at stations in regions of the deep basin of the Bering Sea and in the outer, middle and coastal domains of the southeastern Bering Sea shelf sampled during the T/S Oshoro Maru Summer Cruises. Data from 1977 to 1994 from Sugimoto and Tadokoro (1998). Data from 1995 to 2004 from Dr. N. Shiga.

Forage Fish

Exploring Links between Ichthyoplankton Dynamics and the Pelagic Environment in the Northwest Gulf of Alaska.
Contributed by Miriam Doyle and Mick Spillane, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, and Susan Picquelle and Kathryn Mier, Alaska Fisheries Science Center.
Last updated: September 2005

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 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. Interannual variation in the observed abundance of ichthyoplankton species in this area may reflect interannual variation in the timing and quantity of local egg and larval production, egg mortality, larval survival and growth, and the transport of eggs and larvae into and out of the study area. It is hypothesized that these early life history dynamics are species-specifically linked to unique combinations of environmental variables.

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).

For the time-series, unique patterns of periodicity and amplitude of variation in abundance are apparent among species (Table 10). Some commonality is observed, especially for the deepwater spawners (northern lampfish, arrowtooth flounder and Pacific halibut) that display a decadal trend of enhanced abundance during the 1990s. Species-specific seasonality is apparent in the associations between late spring larval abundance and environmental variables (Table 10). There is, however, a general trend indicating that basin-scale environmental conditions in February through April, and local-scale conditions in late-March through early-April, are most influential in terms of prevalence of larvae in late spring. Observed species-specific patterns of association between late spring larval abundance and environmental variables seem to reflect geographic distribution and early life history patterns among species. For example, the deepwater spawners

arrowtooth flounder and Pacific halibut show a common, strong connection with the Shelikof water transport variables (FLOWKL8 and RI) that probably reflects their dependence on advection onto the shelf, and retention processes in this area, for successful larval survival. Another example is the opposite response of northern and southern rock sole to the temperature variables, reflecting their different geographical distributions. Further work continues at the individual species early life history level to investigate potential mechanisms underlying the observed links between species and environmental variables. This type of ichthyoplankton time-series study shows good potential for identifying levels of resilience or vulnerability of individual species early life history patterns to fluctuating oceanographic conditions.

Table 8. Numerically dominant species of fish larvae included in the study, ranked according to percentage occurrence in the study area 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 rocksole	35.05	5.29
Stenobrachius leucopsarus	Northern lampfish	33.03	5.88
Sebastes spp.	Rockfishes	30.99	29.03
Lepidopsetta bilineata	Southern rocksole	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 analysis (abbreviation on left), and source of data.

Basin Scale Variables

	Monthly	Source
CUI	Coastal Upwelling Index at 60 N 155.5 W	NOAA / PFEL
FRESH	GOA River Discharge	Tom Royer
SST1	Sea Surface Temperature (SST) 57.5N,155.5W	NOAA / NCEP Reanalysis
SST2	Sea Surface Temperature (SST) 57.5N,149.5W	NOAA / NCEP Reanalysis
PDO	Pacific Decadal Oscillation (Leading PC of SST)	Mantua et al. 1997
NPI	North Pacific Index (sea level pressure)	Trenberth and Hurrell 1994
MEI	Multivariate ENSO Index	NOAA / CDC
	Preceding Winter	
PDOw	1st Leading Principal Component for Winter (Nov-Mar) SST	Bond et al. 2003
VICw	2nd Leading Principal Component for Winter (Nov-Mar) SST	Bond et al. 2003

Local Scale Variables

	Semi-monthly (observed)	Source
ALONG	Alongshore Wind Index	
UPWELL	Upwelling-favorable Wind Index	Stabeno et al. 2004
MIXING	Wind Mixing Index (wind speed cubed)	
SSTanom	Normalized SST anomalies, Shelikof, based on 1950-2003 mean	NOAA / NCEP Reanalysis
	Seasonal (observed)	
T90	Shelikof temperature below 90 m, Feb-Apr mean	NOAA/AFSC; Jennifer Boldt
	Semi-monthly (model-derived)	
FLOWKL8	Flow through Line 8, Kodiak side	Hermann and Stabeno 1996; Computed from the SPEM model
RI	Retention Index (Percent particles released in upper 100m of study area not lost to advection in 14 days)	Hermann and Stabeno 1996; Computed from the SPEM model

Table 10. Late spring (May 16-June 6) time series of normalized larval fish abundance anomalies (column one) and significant environmental variables in best fit GAMs (with R^2 (adj.)>0.50) of late spring larval abundance versus time-lagged independent variables (columns two and three). Best fit GAMS were selected based on the following objective criteria; an R^2 (adj.) value >0.50 in combination with the highest percentage of deviance explained, and the lowest P-values for the individual variables in the model. Empty cells denote variables that did not emerge in the best fit GAMs.

Basin-Scale Variables

Northern lampfish

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI			Neg		P>0.05		Neg
FRESH			Neg				Neg
SST1			Neg	P<0.05			Neg
SST2			Pos				
PDOm						No model run	No model run
NPI					Pos		
MEI			P<0.05				P>0.05
PDOw		No model run					P<0.05
VICw							Neg

Pacific cod

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI		P<0.05	P<0.05				
FRESH			P>0.05	Neg			
SST1	Neg						
SST2							Pos
PDOm			Neg			No model run	
NPI		P<0.05	P<0.05	P<0.05			
MEI							
PDOw	No model run						Neg
VICw							P>0.05

Walleye pollock

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI						P<0.05	P<0.05
FRESH						Neg	P>0.05
SST1		Neg	P<0.05			P<0.05	
SST2							P<0.05
PDOm						No model run	
NPI			P>0.05			P<0.05	
MEI		P<0.05					
PDOw	No model run						Neg
VICw							Neg

Rockfish

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI	P>0.05						
FRESH							
SST1		P<0.05	Pos				P<0.05
SST2							
PDOm			P<0.05			No model run	
NPI			P<0.05	P<0.05			P>0.05
MEI							
PDOw	No model run						P<0.05
VICw							

Ronquils

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI	P<0.05		P<0.05		Neg		P<0.05
FRESH			Pos		Neg		Pos
SST1	P>0.05		Pos				
SST2	P>0.05		P>0.05		Neg	Neg	
PDOm	Pos		P>0.05		P<0.05		
NPI	P<0.05						
MEI	P<0.05						
PDOw	No model run					Pos	
VICw						P>0.05	P>0.05

Local-Scale Variables

Northern lampfish

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG			Pos			
UPWELL			Pos			
MIXING			Neg			
SSTanom						
T90					No model run	No model run
FLOWKL8						
RI			P>0.05			

Pacific cod

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG		P<0.05	Pos	P>0.05		P<0.05
UPWELL						
MIXING				P<0.05		
SSTanom	Neg	Neg		P<0.05	No model run	
T90	P>0.05	Neg				
FLOWKL8	P<0.05			Neg		
RI		Pos	Pos			P<0.05

Walleye pollock

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG		Neg		Pos		
UPWELL			Neg	Pos		
MIXING		P<0.05		Pos		
SSTanom					No model run	No model run
T90						
FLOWKL8	Neg	P>0.05	P<0.05			
RI			P<0.05			

Rockfish

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG						
UPWELL						
MIXING						
SSTanom						
T90					No model run	No model run
FLOWKL8						
RI						

Ronquils

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG				Pos		
UPWELL		Neg	P>0.05	Pos		
MIXING						
SSTanom		Pos		P>0.05		
T90		Pos			No model run	
FLOWKL8			P>0.05	P<0.05		
RI			P<0.05			

Pos — Positive response apparent
Neg — Negative response apparent
No model run
P<0.05
P>0.05

Feb2 and Mar2: PDOw and VICw replace PDOm and NPI in the model runs

Table 10 continued.

Basin-Scale Variables

Pacific sandlance

	Jan	Feb	Mar	Apr	May		Feb2	Mar2
CUI								
FRESH		■	■				■	
SST1		■					■	
SST2			Neg					
PDOm								
NPI			Neg					
MEI		■					■	
PDOw								
VICw								

Arrowtooth flounder

	Jan	Feb	Mar	Apr	May		Feb2	Mar2
CUI		■	■				■	
FRESH				Neg				
SST1			■				Neg	
SST2		■	■				Pos	Pos
PDOm		■	■	■				
NPI				Neg				
MEI		■	■					
PDOw							■	■
VICw								

Flathead sole

	Jan	Feb	Mar	Apr	May		Feb2	Mar2
CUI								
FRESH		Pos					Pos	
SST1								
SST2							Neg	
PDOm								
NPI								
MEI		■					■	
PDOw								
VICw								

Starry flounder

	Jan	Feb	Mar	Apr	May		Feb2	Mar2
CUI				■				
FRESH		■					■	
SST1				Pos				
SST2								
PDOm								
NPI								
MEI		■		■				
PDOw								
VICw								

Pacific halibut

	Jan	Feb	Mar	Apr	May		Feb2	Mar2
CUI				■				
FRESH		Neg						
SST1				■				
SST2								
PDOm								
NPI		■						
MEI				Neg				
PDOw								
VICw								

Southern rocksole

	Jan	Feb	Mar	Apr	May		Feb2	Mar2
CUI		Pos		■	■		Pos	
FRESH								
SST1				Pos				
SST2		Pos	Pos				Pos	
PDOm			Neg					
NPI				Neg				
MEI								
PDOw								
VICw								

Northern rocksole

	Jan	Feb	Mar	Apr	May		Feb2	Mar2
CUI		Pos	Neg					Neg
FRESH								
SST1		Neg	Neg					Neg
SST2								
PDOm								
NPI		Pos						
MEI								
PDOw								
VICw								

Local-Scale Variables

Pacific sandlance

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG		Neg				
UPWELL		Neg			Neg	
MIXING		Pos			Pos	
SSTanom						
T90						
FLOWKL8						
RI					Pos	

Arrowtooth flounder

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG	■	■	■		Neg	
UPWELL					Neg	
MIXING					Pos	
SSTanom						
T90						
FLOWKL8	Pos				■	
RI	Pos				■	

Flathead sole

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG						■
UPWELL						
MIXING					Neg	
SSTanom						
T90						
FLOWKL8					Neg	
RI						■

Starry flounder

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG						Neg
UPWELL		■	■			Neg
MIXING						■
SSTanom		■	Pos			
T90						
FLOWKL8						
RI						

Pacific halibut

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG			■			
UPWELL						
MIXING						
SSTanom	■					
T90						
FLOWKL8	Pos		Pos			
RI	Pos		Pos			

Southern rocksole

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG		■				■
UPWELL						■
MIXING						
SSTanom						
T90		Pos				
FLOWKL8						■
RI						

Northern rocksole

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG	■		Pos			■
UPWELL	■	Neg		Neg		
MIXING	Pos					
SSTanom				■		■
T90	Neg	Neg				
FLOWKL8			Pos	Pos		Pos
RI			Pos	Pos		

Pacific sandlance

Arrowtooth flounder

Flathead sole

Starry flounder

Pacific halibut

Southern rocksole

Northern rocksole

1985   1990   1995   2000

Distribution, diet, and energy density of age-0 walleye pollock, *Theragra chalcogramma*, in the Bering Sea and Chukchi Sea, Alaska

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Last updated: November 2004

This study examines large-scale distribution, energy density and diet of age-0 pollock in the Eastern Bering Sea and Chukchi Sea during US BASIS (Bering-Aleutian Salmon International Survey) surveys conducted in August-October, 2003. Distribution data were divided into three geographic regions: Bristol Bay (between 162°W and 166°W), Bering Sea shelf (between 58°N and 63°N), and Chukchi Sea (between 64°N and 68° N).

Age-0 pollock were distributed throughout all geographic areas, with the highest concentration in the middle domain of Bristol Bay (Figure 42). There was a significant difference in energy density between geographic areas (P < 0.00001). Pair-wise tests indicated that pollock from the Chukchi Sea and Bristol Bay had significantly greater energy densities than pollock from the Bering Sea shelf (4226 J/g, 3985 J/g, and 3340 J/g, respectively), and there was no difference in energy density between the Chukchi Sea and Bristol Bay (Figure 43). Stomach content analysis indicated that age-0 pollock from Bristol Bay had a more cosmopolitan diet dominated by calanoid copepods (49%) and euphausids (23%), where as pollock from the Bering Sea shelf had a less varied diet dominated by calanoid copepods (65%; Figure 44).

Figure 42. Age-0 pollock distribution in the Bering Sea and Chukchi Sea. X indicates no pollock were caught and the largest brown circle indicates 300,000 fish caught.

The lower energy density of fish from the Bering Sea shelf could be due to the presence of a coccolithophore bloom in that region during the summer of 2003 (Saitoh and Iida unpublished data), which might have reduced the fish's reactive distance, thus resulting in diminished ingestion rates. 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 investigated.

Figure 43. Average energy density (J/g wet weight) of age-0 pollock at each survey location, with 95% confidence intervals.
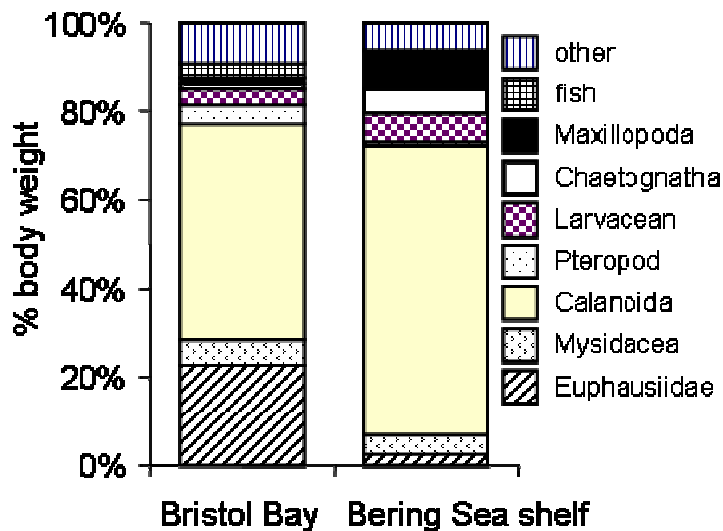
Figure 44. Diet composition by % body weight for age-0 pollock from Bristol Bay and the Bering Sea shelf.

Variations in juvenile sockeye and age -0 pollock distribution during fall 2000-2004 in the eastern Bering Sea- BASIS
Lisa Eisner, Ed Farley, Jim Murphy, Auke Bay Laboratory, NMFS
Last updated: September 2005

Oceanographic and fisheries data have been collected in the Eastern Bering Sea (EBS) during fall 2000-2004 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 15-30 km resolution,

although spatial coverage varied by region and by year. Bristol Bay stations were sampled from mid August to early September during all five years. While, stations in the central and northern Eastern Bering Sea were generally sampled from mid September to mid October. Forage fish were captured with a surface net trawl and oceanographic data were obtained from vertical conductivity-temperature-depth (CTD) profiles and laboratory analyses of discrete water samples at select depths (2003 and 2004 only). 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 45 and see Figure 31 from the *Physical Environment* section of this report). Juvenile sockeye distributions were bordered by the Inner Front in Bristol Bay in 2002-2004 and were located further south in Bristol Bay in 2000 and 2001. The overlap of age-0 pollock and juvenile sockeye distribution (most evident in 2003-2004) may improve the survival of juvenile sockeye, since age-0 pollock are an important prey species (composed 60-75 % wet weight in 2003 and 2004). Additional data collection and analyses are required to further characterize the interannual variability in oceanography and fisheries distributions in the EBS.
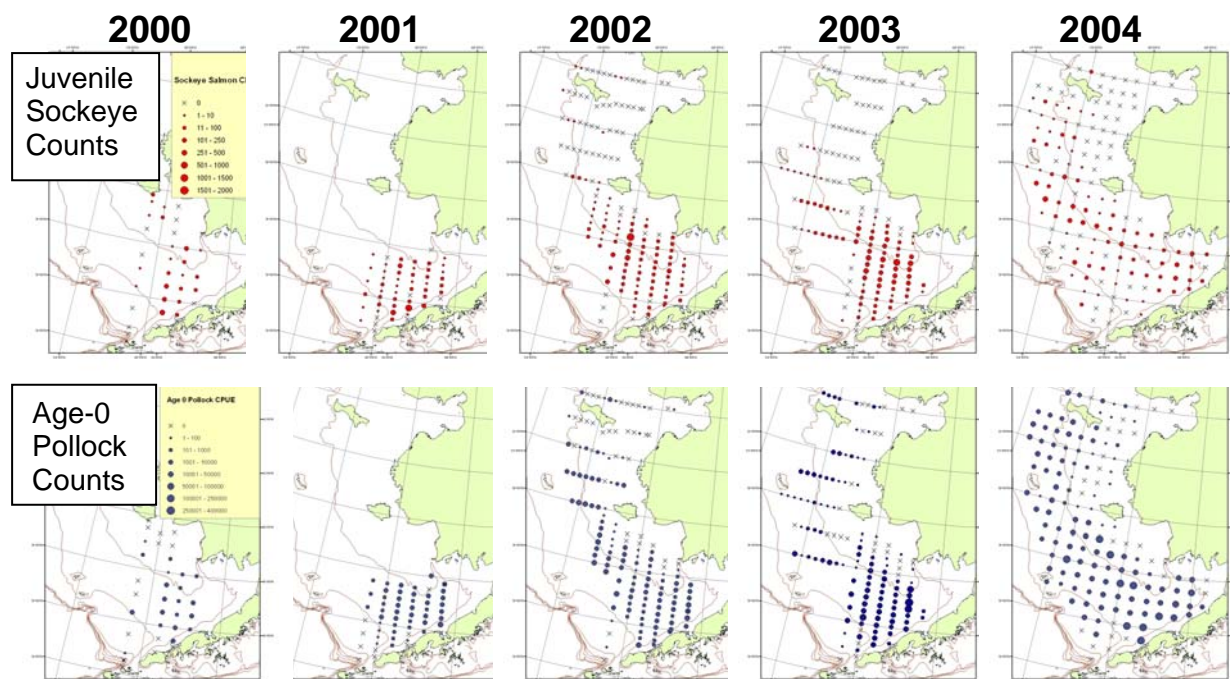
Figure 45. Juvenile sockeye and age-0 pollock abundance (CPUE) during fall in the EBS, 2000-2004.

Forage – Gulf of Alaska
Contributed by Michael Martin
AFSC, RACE Division (michael.martin@noaa.gov)
Last updated: November 2005

Several groups have been defined as forage species by the North Pacific Fishery Management Council for management purposes in the Gulf of Alaska. These groups include gunnels, lanternfish, sandfish, sandlance, smelts, stichaeids, and euphausiids. Several of these groups are captured incidentally in the 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 46).
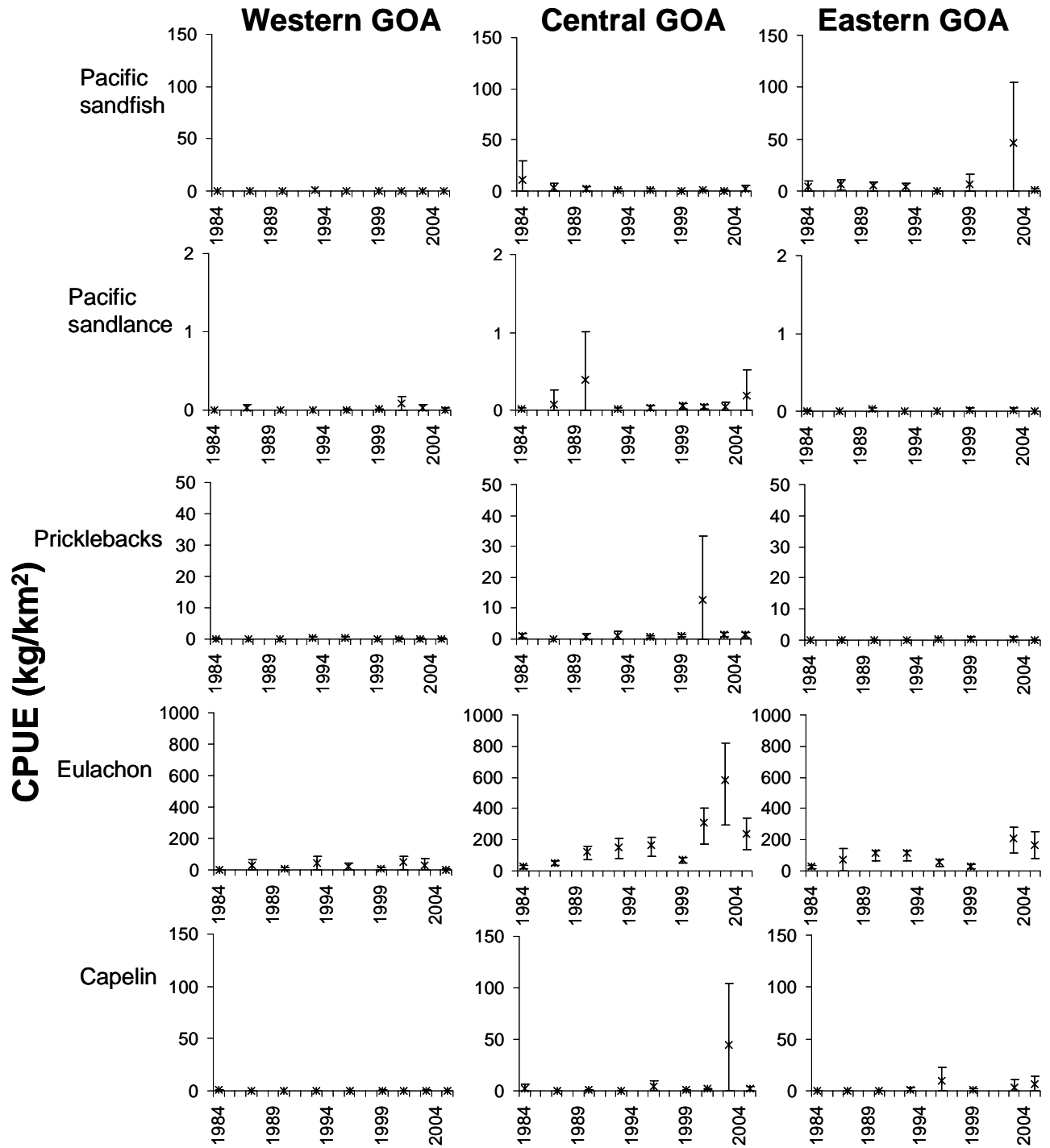
Figure 46. CPUE of forage fish from the Gulf of Alaska biennial survey from 1984 through 2005. Error bars represent 95% confidence intervals.

Forage – Eastern Bering Sea
Contributed by Bob Lauth, Alaska Fisheries Science Center
Last updated: November 2005

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 47). Sandfish are generally in low abundance in the trawl surveys and are usually caught in high abundance in only a few hauls at the shallower stations (Figure 47).   Stichaeids, which likely 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 lowest from 1999 to 2003, but appeared to increase slightly after 2003. Sandlance biomass appeared to be increasing in survey catches in the 1990s, but has been very low since 1999. Eulachon catch per unit effort (CPUE) appeared to be relatively stable in the 1990s but may have declined in more recent years. Capelin catches in the survey have been relatively stable with the exception of one year (1993) when CPUE was very high (Figure 47).
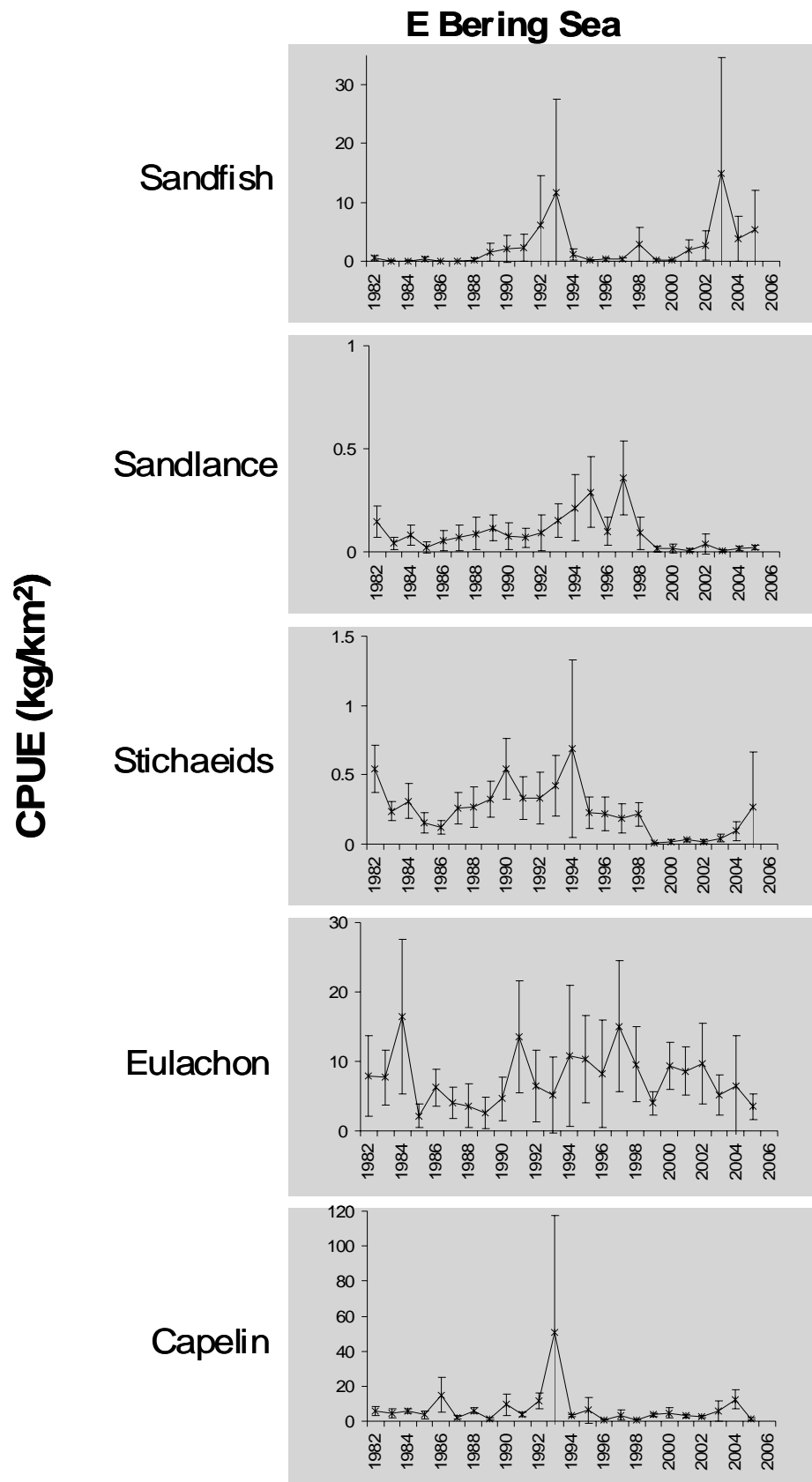
Figure 47. Catch per unit effort (CPUE) of several forage fish groups from the eastern Bering Sea summer bottom trawl survey, 1982-2005. 95% confidence intervals are shown.

Forage – Aleutian Islands
Contributed by Eric Brown, Alaska Fisheries Science Center
Last updated: November 2004

Several groups have been defined as forage species by the North Pacific Fishery Management Council 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 48). This survey is not designed to assess these organisms and further detailed examinations of these results are needed to assess whether there are meaningful trends.

The Aleutian Islands forage species appear only sparingly in survey catches with occasional higher than normal catches. The spike of Pacific sandfish seen in the western Aleutian Islands in 1986 is a result of only 4 individuals appearing in one catch. Similarly, the highest catch rates for pricklebacks, eulachon and capelin are driven by only two to three unusually high 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.

The results of the 2002 survey indicated an apparent three-fold increase in the abundance of Pacific sandfish in the southern Bering Sea; however, over all surveys including the 2004 survey, Pacific sandfish densities have consistently been low, never exceeding 1 kg/km^2 and a frequency of occurrence greater than 2%. Other changes in 2004 include a sharp increase of Pacific sandlance in the Western Aleutians (a large increase from 2002) and a decrease in the central Aleutian Islands. Capelin abundance decreased (southern BS and eastern AI) or remained zero (central and western AI) in 2004. The abundance of pricklebacks in 2004 increased slightly in all areas except the eastern AI, where it decreased relative to 2002.
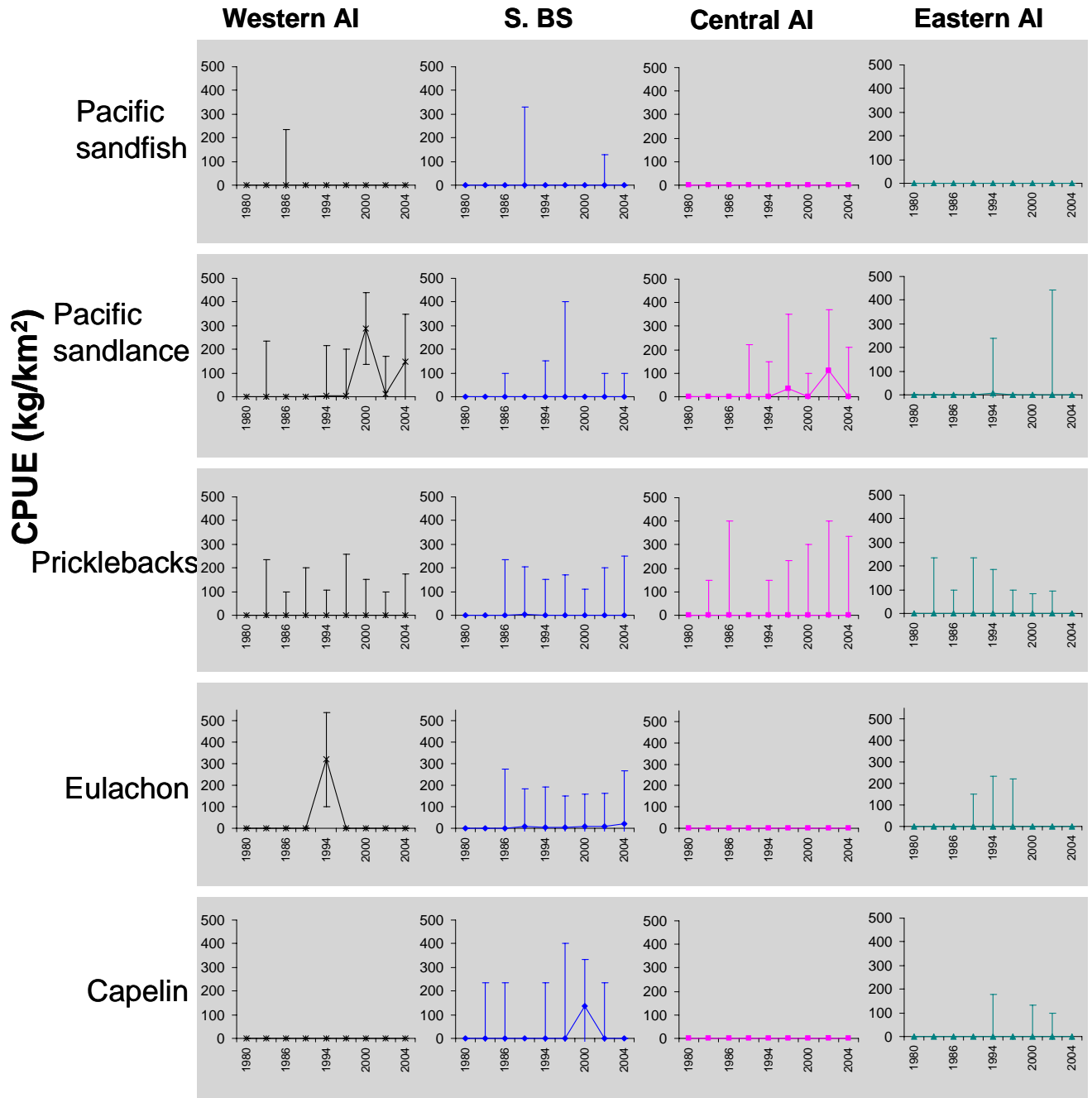
Figure 48. Catch per unit effort of forage fish per unit area in the western Aleutian Islands (AI), southern Bering Sea (BS), central AI, and eastern AI, in bottom trawl surveys conducted between 1980 and 2004. 95% confidence intervals are shown.

Herring

Prince William Sound Pacific herring
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Last updated: November 2005

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 have 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 49). 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 50). 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 – 2005) 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 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 13 years). The fishery is also closed for the fall 2005 and spring 2006 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 this may cause increased mortality in the older age classes. The age-structured assessment model currently used by ADF&G was selected among several models that include disease information (Marty et al. 2004).
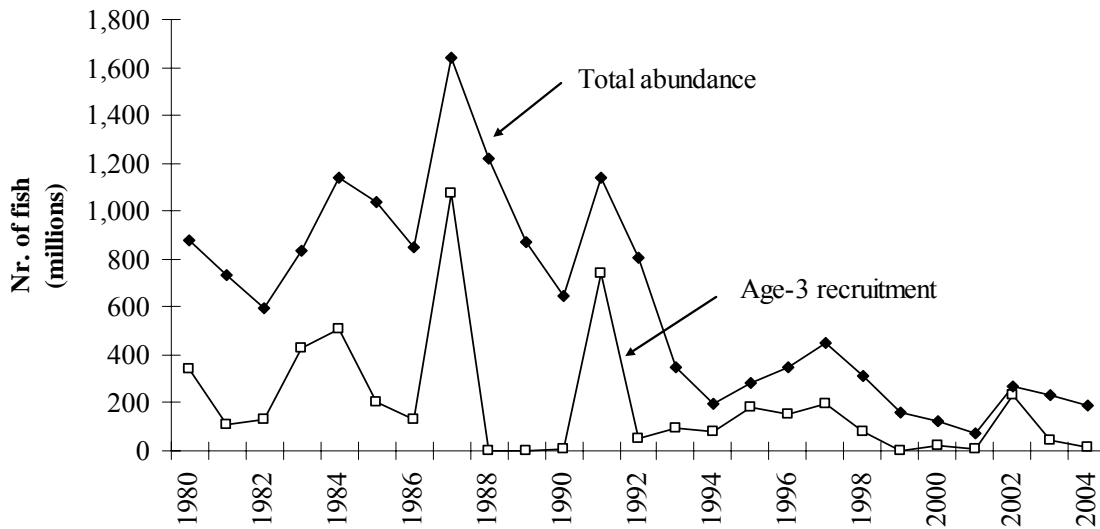
Figure 49. Age-3 recruitment and total prefishery abundance of Pacific herring in Prince William Sound, 1980-2004. The abundance values are outputs of the age-structured model used to produce the 2005 projections.
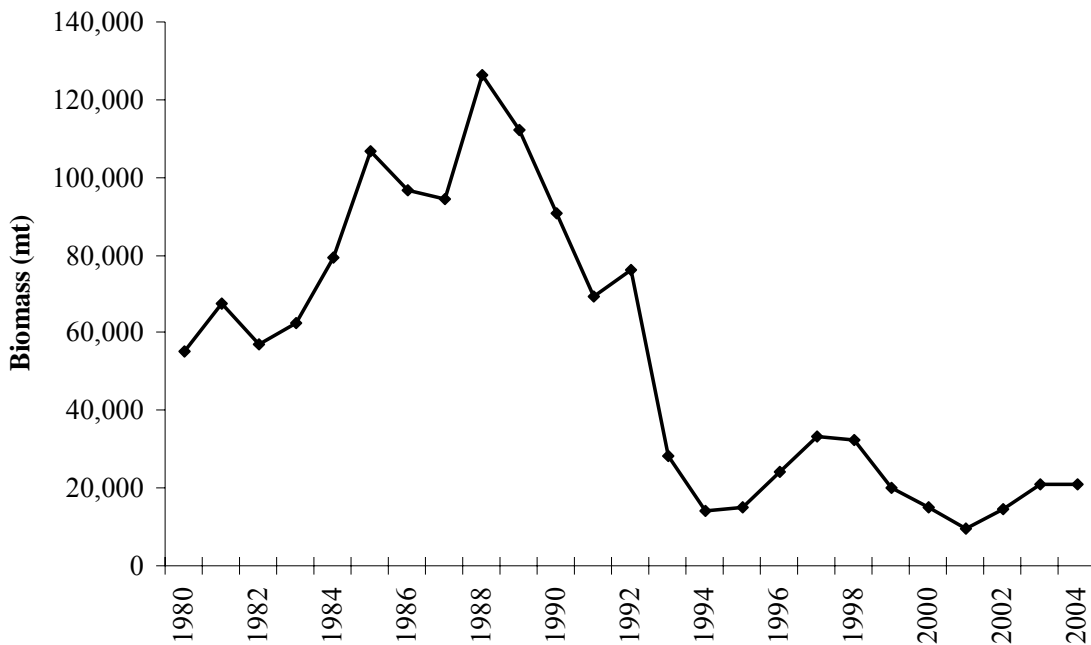
Figure 50. Prefishery run biomass (metric tons) of adult Pacific herring in Prince William Sound, 1980-2004. The biomass values are calculated from the age-structured model used to produce the 2005 projections.

Southeast Alaska Herring

Sherri Dressel, Kyle Hebert, Marc Pritchett, and David Carlile – Alaska Dept. of Fish & Game –(907) 465-6146; sherri_dressel@fishgame.state.ak.us
Last updated: November 2004

Herring stock assessments have been conducted each fall by the Alaska Department of Fish and Game at nine spawning areas in Southeast 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 22 years. More limited spawning occurs at other locales throughout S.E. 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 S.E. Alaska in any given year.

Herring spawning biomass in S.E. Alaska often changes markedly from year to year, rarely exhibiting consistent, monotonic trends (Figure 51). Since 1980 seven of the nine primary locations have exhibited long term trends of at least slightly increasing biomass, one area (Craig) has not shown any long term trend, and biomass in one area (Kah Shakes/Cat Island) has had a pronounced downward trend. There have been major fluctuations around these long-term trends with periods of both increasing and decreasing trends over the shorter term. Since 1997, southeast Alaska spawning herring biomass has been above the long-term median of 75,299 tons (1980-2003; Figure 51). The 2001 and 2003 estimates of spawning biomass were the highest of the 24-year time series (Figure 51). Since 1980 herring biomass at Sitka has contributed 37 to 64% (median: 56%) of the total annual biomass among the nine spawning locations. Excluding the Sitka biomass from a combined estimate, S.E. Alaska herring biomass has generally been above the 24-year median since 1997 (except in 2000).

There does not appear to be clear decadal-scale variability of age-3 herring recruit abundance, in the three widely recognized climate-regimes in the North Pacific: 1978-1988, 1989-1998 and post-1998. The number of age-3 recruits has been estimated for Kah Shakes-Cat Island, Craig, Seymour Canal, Sitka, and Tenakee Inlet for most years since 1980. The number of age-3 recruits has been estimated for West Behm Canal, Ernest Sound, Hobart Bay-Port Houghton and Hoonah Sound for most years since 1995. Overall recruit abundances were highest in 1980, 1987, 1991, and 1996; however, this pattern was not consistent across all spawning locations, and recruit estimates were not available for all areas in all years. Only one stock, Kah Shakes/Cat Island, showed a distinct decreasing trend in recruit abundance over time. The recruit abundance of Sitka herring, the stock with the greatest annual recruit abundance, was above the 24-year median in 8 out of the last 9 years.

There has been some speculation and debate about the extent to which commercial harvests may have contributed to marked declines in abundance and/or localized changes in herring spawning sites in a few areas in S.E. 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 S.E. 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 (Figure 51).
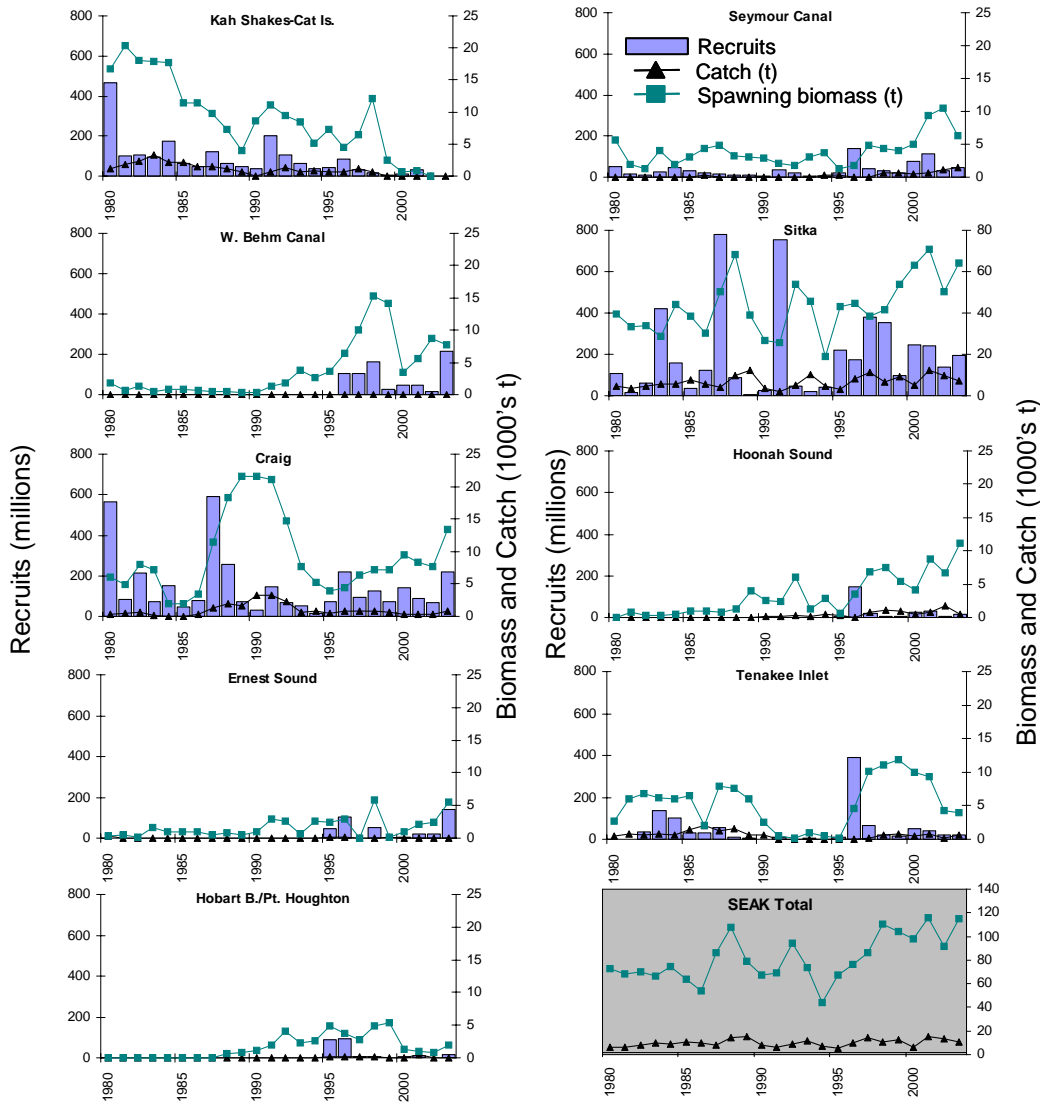
Figure 51. Estimated herring spawning biomass (tons), catch (tons), and age-3 recruits (millions of fish) in nine areas of S.E. Alaska, 1980-2003. Total biomass and catch for southeast Alaska (SEAK) is shown (bottom right panel). Recruits were not estimated in all years in all areas; therefore, missing values may not be zero estimates.

Togiak Herring Population Trends

Contribution by Fred West, Alaska Department of Fish and Game
Last updated: November 2004

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 52). Beginning in 1983, total abundance steadily declined until modest recruitment events occurred in 1991 and 1992 from the 1987 and 1988 year classes. We are currently seeing moderately strong recruitment from the 1996 and 1997 year classes that recruited into the fishery in 2000 and 2001. 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 52).

The high abundance estimates in the early 1980's 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. This has not yet been resolved, but 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".

Figure 52. Total abundance, age-4 recruits, mature biomass, and total harvest of Pacific herring in the Togiak District of Bristol Bay, 1978 – 2004.
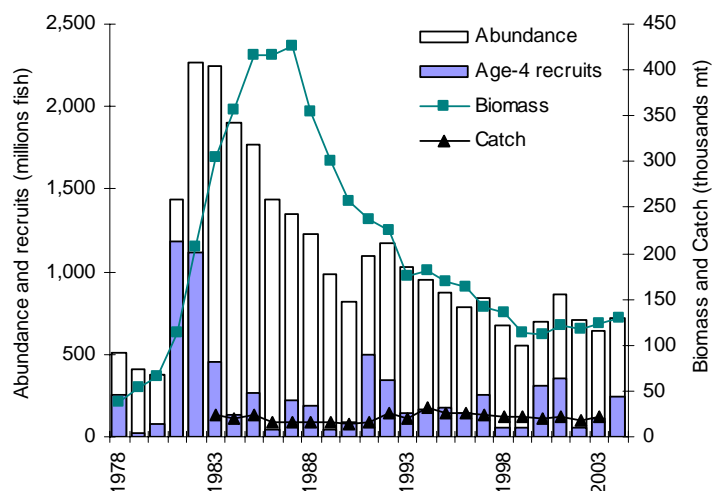
Pacific herring recruitment trends are highly variable, with large year classes occurring occasionally at regular intervals of approximately every 9-10 years (Figure 52). These large recruitment events drive the Togiak herring population. Environmental conditions may be the critical factor that influences 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.

Salmon

Historical trends in Alaskan salmon

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With contributions from Lowell Fair (ADFG) and Tom Kline (PWSSC).
Last updated: November 2004

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 53). 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 53. The four fishery management regions of the Alaska Department of Fish and Game, Division of Commercial Fisheries.

Generally, Alaskan salmon stocks have been at high levels of abundance in the last 20 years (Figure 54, Figure 56, and Figures 58-60). Asian stocks have shown similar trends as Alaskan salmon. Salmon stocks in the Pacific Northwest and British Columbia were at lower levels in the 1980's and 1990's; however, since 1999 survival of some salmon stocks has improved. In Alaska, during the last decade, there have been some weak runs observed, particularly in certain areas of western Alaska, due to weak recruitment events. Notable examples include Yukon River fall chum, Yukon River summer chum, Yukon River chinook, and Kvichak River sockeye salmon. Observed weak yearclass strengths, however, have not been observed for most other Alaskan salmon stocks. For example, recruitment for most Bristol Bay sockeye salmon stocks other than Kvichak has been moderate to strong during this period, and most Bristol Bay stocks increased in 2003. 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's to early 1970's. 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 data 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).

SOCKEYE

Abundance of sockeye salmon in all areas increased from the mid 1970s to the 1980s (Figure 54). Since then the increased abundance has been stable and at high levels. Recruitment for most Bristol Bay sockeye salmon stocks other than Kvichak has been moderate to strong in the last decade (Figure 55). 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 1970's. 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. Recent ocean temperatures and returns to Bristol Bay in 1999 and 2003 suggest that returns in 2004 may be more characteristic of the 1978-95 period (Fair 2004).

PINK

Pink salmon catches increased in the late 1970's to the mid-1990's and have generally remained high in all regions in the last decade (Figure 56). 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 regime shifts (Figure 57). 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 57).

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 58). 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 58). 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 has been lower than the previous decade, but still above catches in the 1960's and 1970's (Figure 59).

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 have been declining in recent years 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 60). 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-1970's to the late 1990's 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 61). The decreasing trend observed in other species and areas generally appears to have leveled off within the last decade (Figure 61).
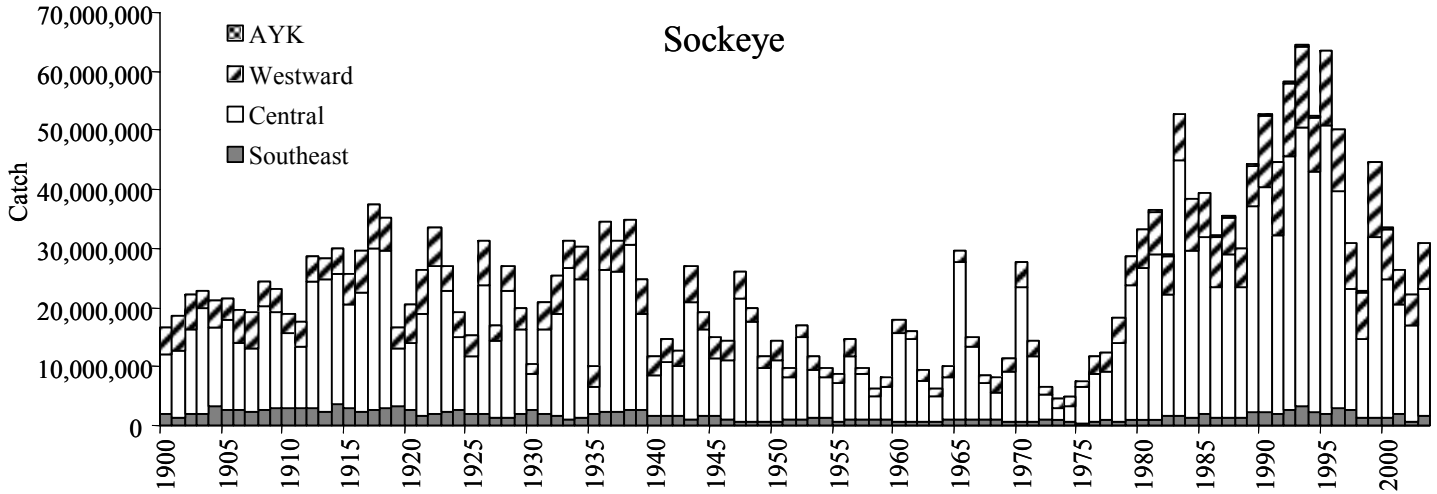
Figure 54. Historical catch of sockeye salmon by area in Alaska, 1900-2003.
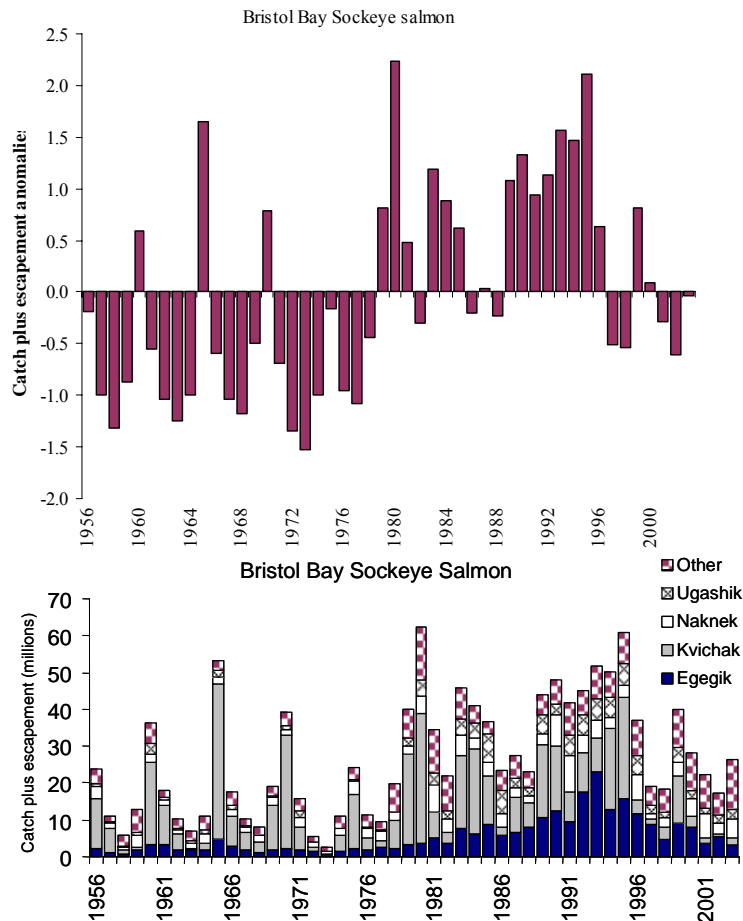
Figure 55. Historical catch plus escapement anomalies of Bristol Bay sockeye salmon, 1900-2003 (top panel). Bristol Bay sockeye salmon catch plus escapement by stock, 1900-2003 (bottom panel). Data provided by Lowell Fair (Alaska Department of Fish and Game).
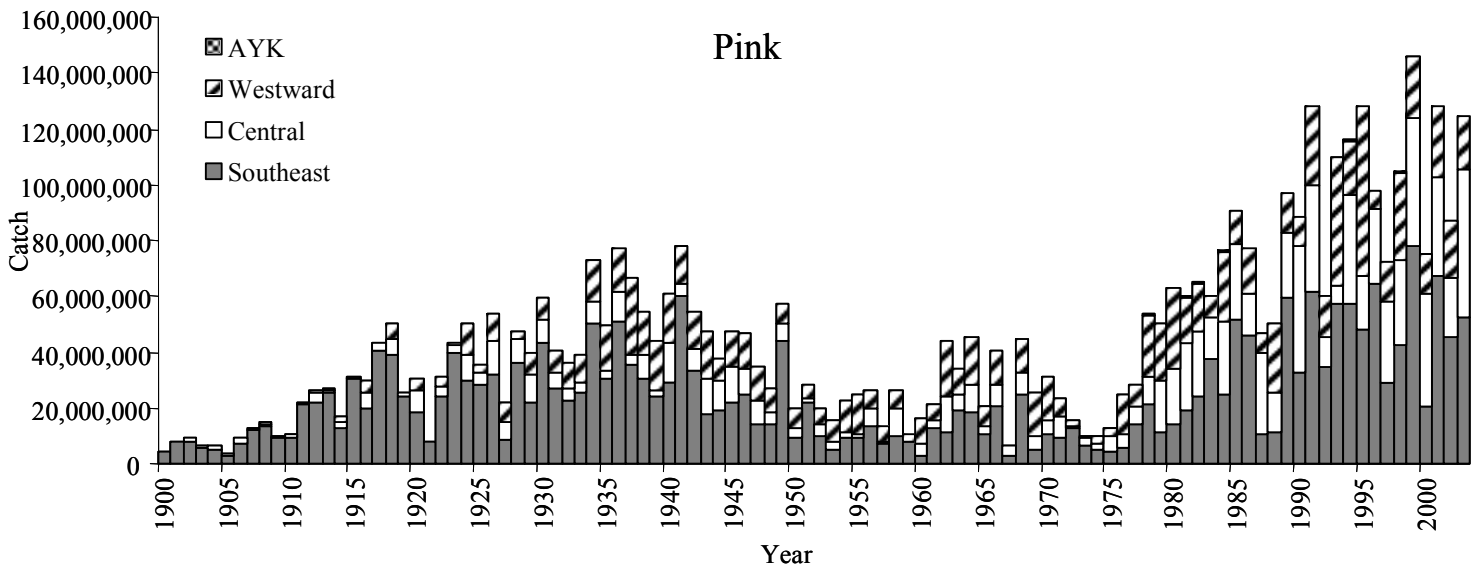
Figure 56. Historical catch of pink salmon by area in Alaska, 1900-2003.
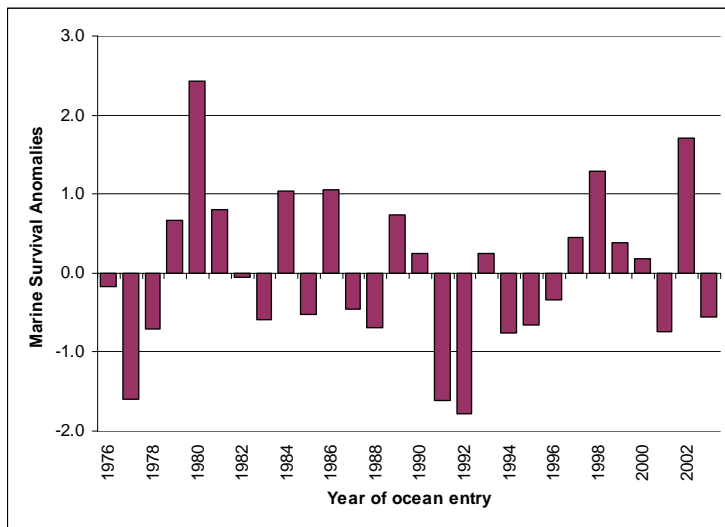
Figure 57. Marine survival of Prince William Sound hatchery pink salmon by year of ocean entry (release year). Data from 1977-2002 taken from Gray et al. (2002); 2003 data from Gray (Alaska Department of Fish and Game, personal communication) and from Tom Kline (Prince William Sound Science Center, personal communication).
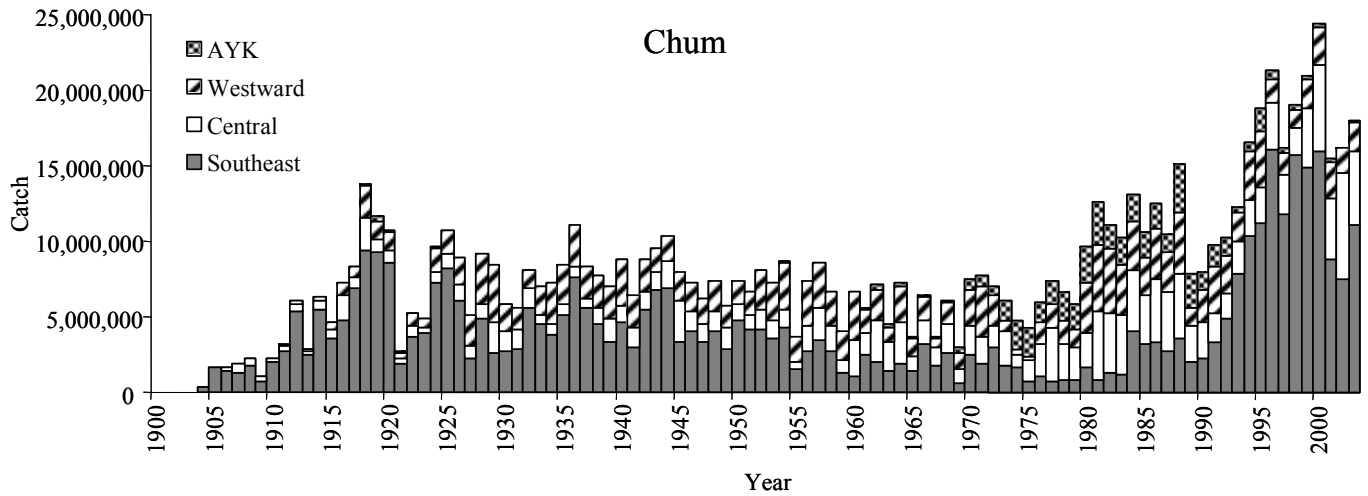
Figure 58. Historical catch of chum salmon by area in Alaska, 1900-2003.
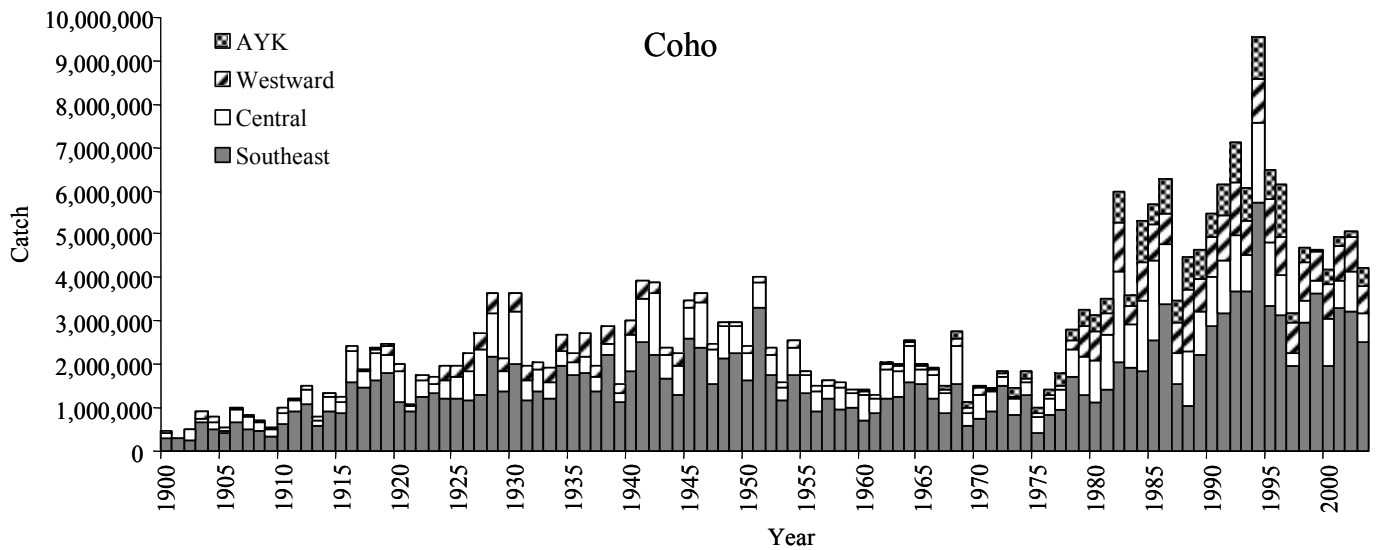
Figure 59. Historical catch of coho salmon by area in Alaska, 1900-2003.
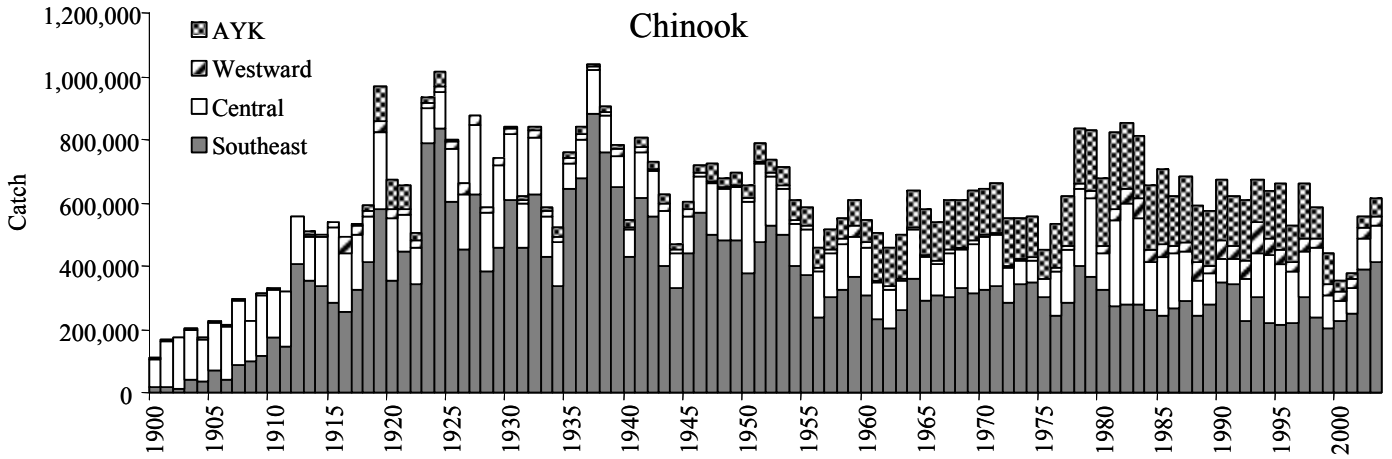
Figure 60. Historical catch of chinook salmon by area in Alaska, 1900-2003.
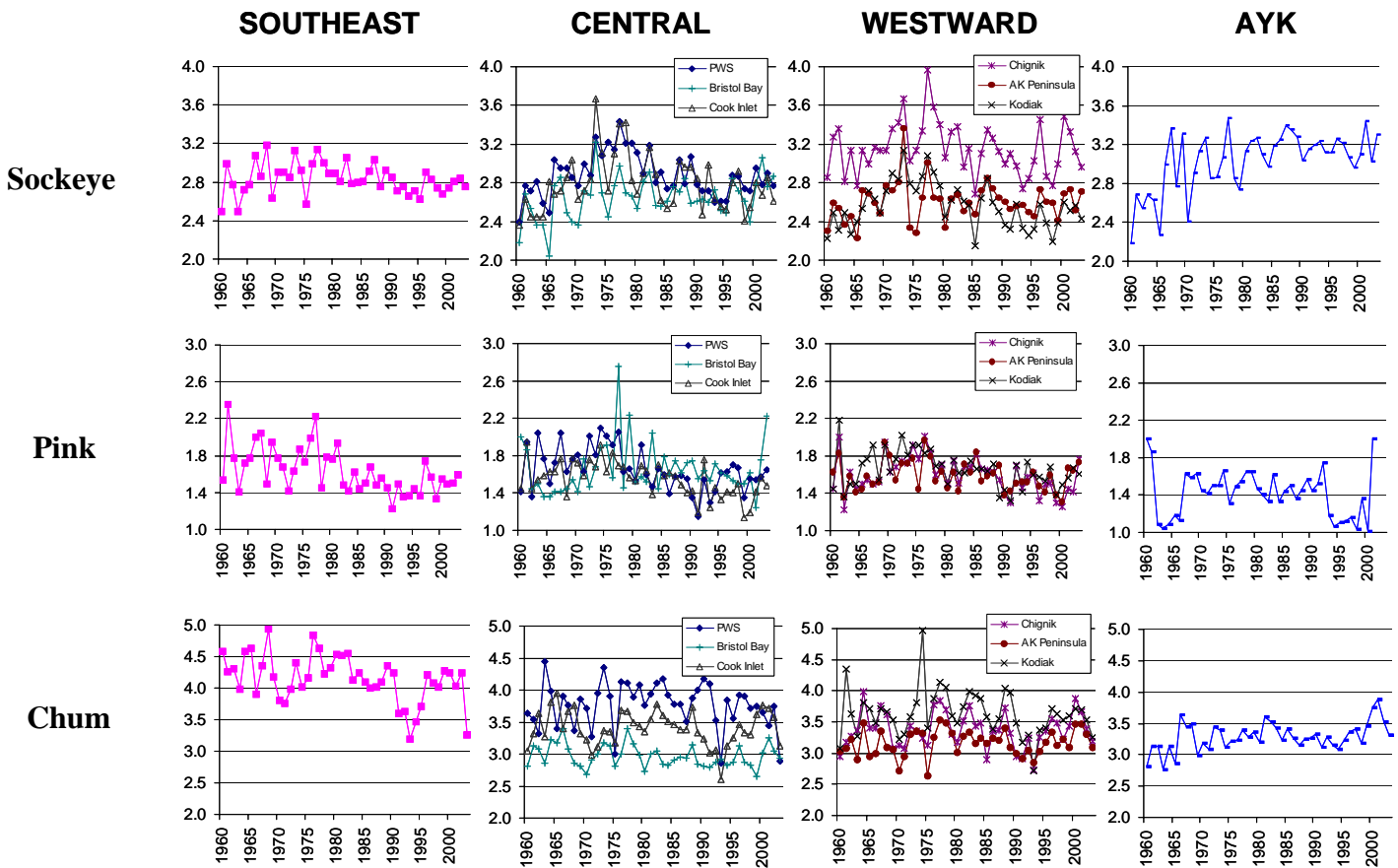
Figure 61. Average weight (kg) of sockeye, pink, and chum salmon in commercial fishery catch by
management area, 1960-2003. Data for years 1960-1976 from INPFC (1979). Data for later
years from the ADF&G fish ticket system.

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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 62). 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 (Figure 63 and Figure 64). Relative survival of juvenile Bristol Bay sockeye salmon was lowest during 2001 and highest during 2002 (Table 11). 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 11. 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.
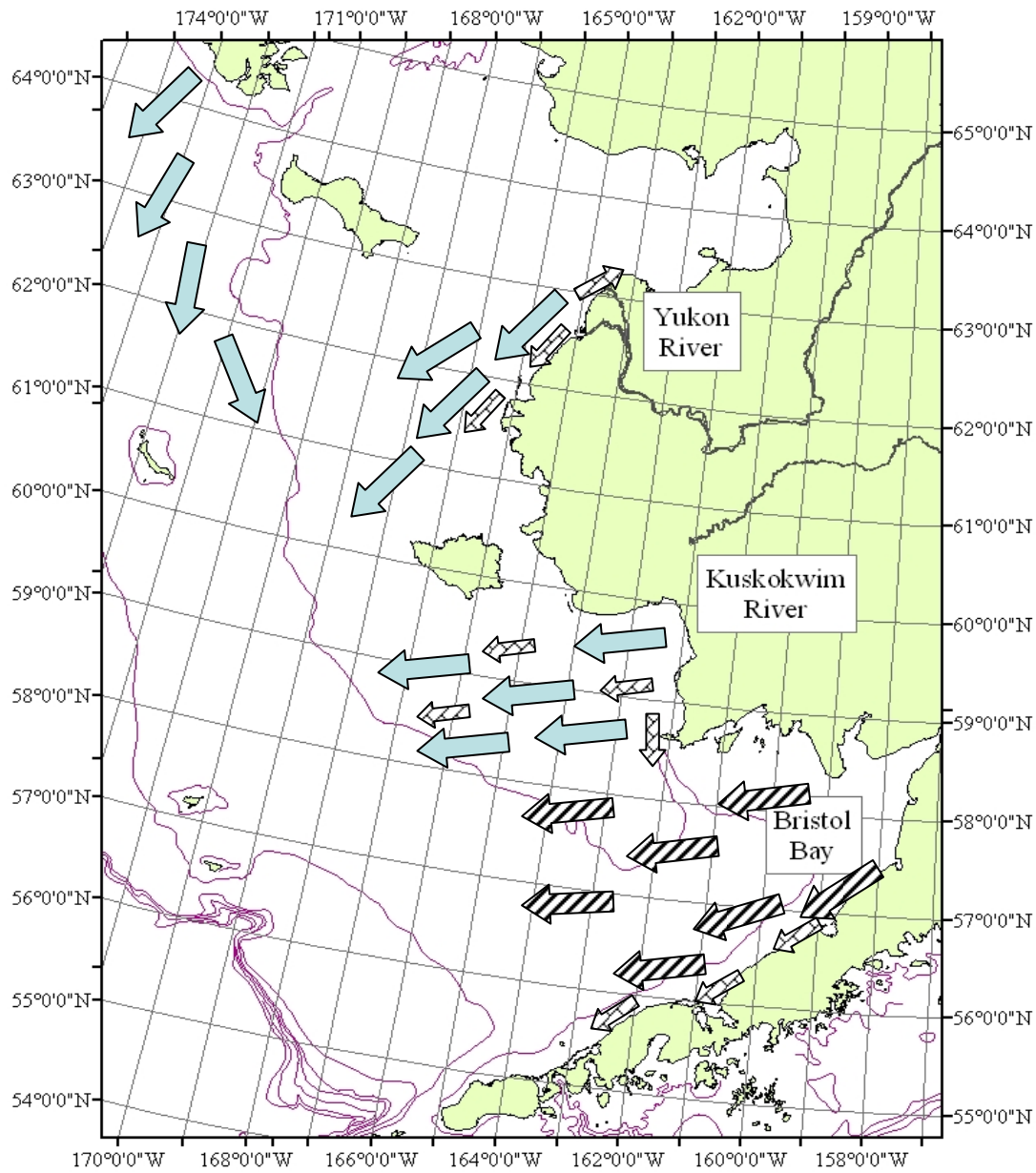
Figure 62. Seaward migration pathways for juvenile chum (solid arrow), sockeye (slashed line arrow), coho, and chinook (boxed line arrow) salmon along the eastern Bering Sea shelf, August through October.
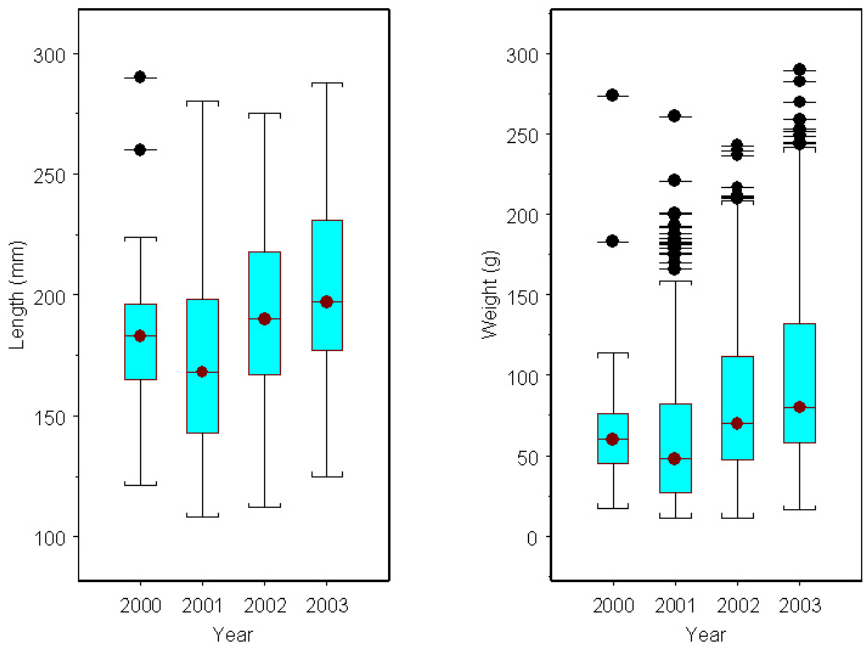
Figure 63. Box plots of juvenile Bristol Bay sockeye salmon fork length (mm) and weight (g) collected along the eastern Bering Sea shelf, August–September of 2000–2003.
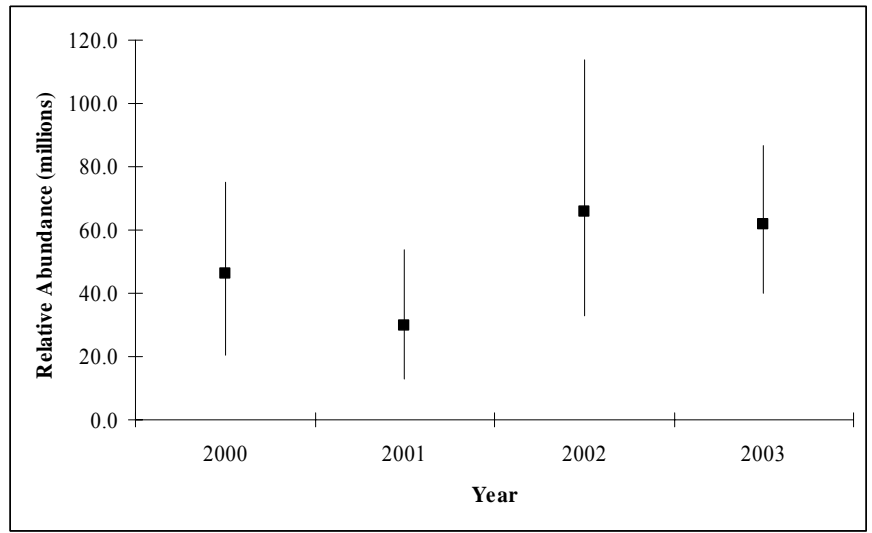
Figure 64. Relative abundance (millions) and 95% confidence intervals of juvenile Bristol Bay sockeye salmon collected along the eastern Bering Sea shelf, August–September of 2000–2003.

Groundfish

Trends in Groundfish Biomass and Recruits per Spawning Biomass
By Jennifer Boldt, Julie Pearce and the Alaska Fisheries Science Center Stock Assessment Staff
Last updated: April 2005

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 (Figure 65). The assessment information is available in the NPFMC stock assessment and fishery evaluation reports (2004 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 1970's but increased in the early 1980's 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 65). 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 65) are different from those in the BSAI. Although biomass increased in the early 1980's, 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 2003 IPHC stock assessment of halibut, ages 6 and older, for the GOA (areas 2C, 3A, and 3B) indicates halibut biomass
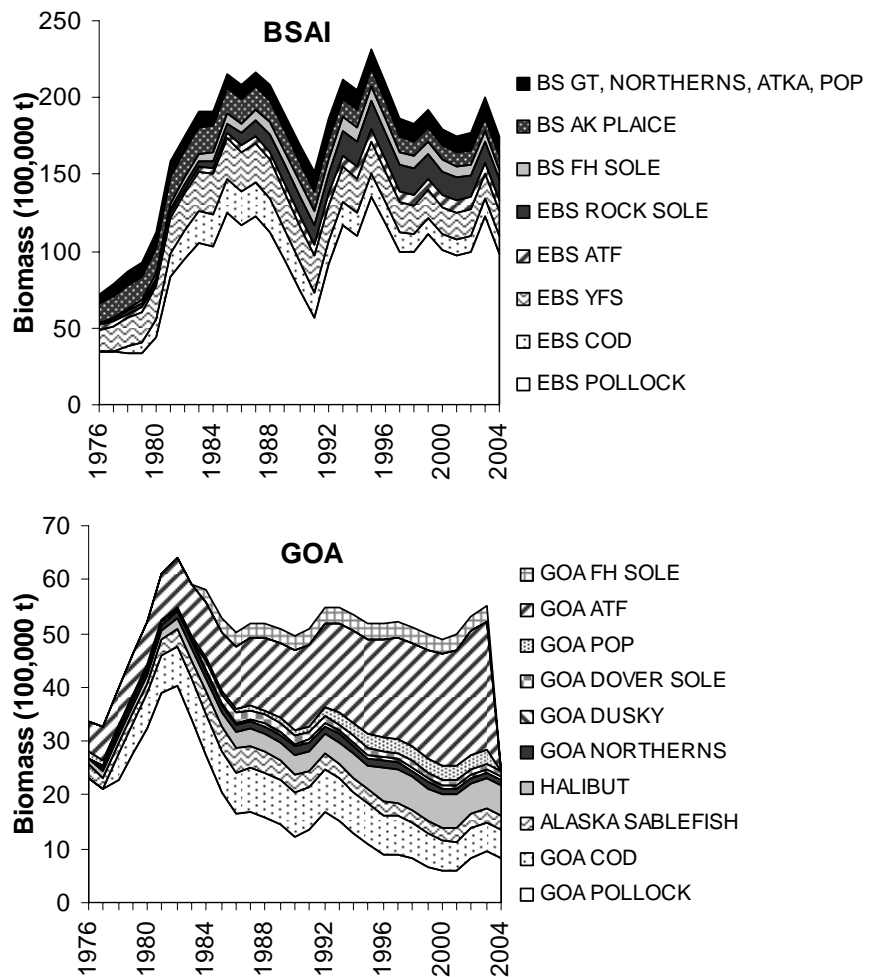
Figure 65. Groundfish biomass trends (metric tons) in the BSAI and GOA from 1978-2004, as determined from age-structured models of the Alaska Fisheries Science Center reported by NPFMC (2004 a, b). GOA FH Sole, GOA ATF, and GOA POP biomass time series do not include estimates for 2004. Halibut data provided by the IPHC (S. Hare, personal communication).

increased from 1978 to 1996 and declined slightly during 1997-2003. Biomass levels in 2003 were still well above the 1978-present average.

RECRUIT PER SPAWNING BIOMASS

Methods
Median recruit per spawning biomass (RS) anomalies were calculated for each species to provide an index of survival (Figure 66 and Figure 67). 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. Recruit abundance of 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 (Figure 66 and Figure 67). 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 (this report) examines 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
Approximately half the stocks examined displayed a significant shift in RS anomalies in the late 1970s or late 1980's (Table 12). All shifts observed in the late-1980s were negative. Five stocks potentially had shifts in 1998/99 and five stocks showed other or no shifts.

With the exception of a negative 1980-shift in GOA pollock RS anomalies which followed the late-1970s regime shift, roundfish typically did not show the 1976-77 or 1988-89 regime shifts in the BSAI or GOA. Instead, regime shifts were observed in the early to mid-1980s and potential shifts were identified in 1998-2001.

BSAI winter spawning flatfish RS anomalies had a negative shift in the late-1980s, and two of these stocks (flathead sole and rock sole) also had another negative shift in 1994. Similarly, GOA flathead sole also showed a negative shift in 1993. None of the GOA winter spawning flatfish, however, showed the late-1980's shift. BSAI Greenland turbot RS anomalies also showed the negative late -1980s shift. Yellowfin sole, however, shifted in the late 1970s, not the late 1980s.   Arrowtooth flounder RS anomalies showed a positive shift in 1969 and a negative shift in 1984.

Rockfish generally showed positive shifts in the late 1970s and negative shifts in the late 1980s. BSAI Northern (positive shift in 1994) and GOA dusky (negative shift in 1999) rockfish were the exceptions.

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 68). Aleutian Island pollock and Atka mackerel (not included in this analysis) also show similar patterns in recruitment (Figure 68; 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) show 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; Figure 69). 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 (Figure 69). The pattern of springtime wind changed to an off-shore direction during the 1990s which coincided with below-average recruitment.

Rockfish 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. Results from analyses of rockfish recruits do not show the late 1970s shift.

Table 12. Years and direction of regime shifts observed in groundfish recruit per spawning biomass time series in the Bering Sea/Aleutian Islands and Gulf of Alaska. These are results from the STARS analysis, using a cutoff value of 10 years and a p-value of 0.10. Light-colored text indicates potential shifts near the end of the time series.

Fish Type		Area	Species	Years of regime shifts		
Roundfish		Bering Sea/Aleutian Islands	Pollock	-1983		
			Cod	-1983	1998	
			Atka mackerel	1998		
		Gulf of Alaska	Sablefish	2000		
			Pollock	-1980	1999	
			Cod	-1985	-2001	
Flatfish	Winter spawning	Bering Sea/Aleutian Islands	Arrowtooth flounder	-1989		
			Flathead sole	-1986	-1994	
			Rock sole	-1988	-1994	
	Winter spawning	Gulf of Alaska	Arrowtooth flounder	1969	-1980	
			Flathead sole	-1993		
			Dover sole	1994		
	Other	Bering Sea/Aleutian Islands	Yellowfin sole	-1977	-1984	-1997
			Greenland turbot	-1987	2000	
			Alaska plaice	-1982	1999	
Rockfish		Bering Sea/Aleutian Islands	Pacific Ocean Perch	1975	-1987	
			Northern rockfish	1994		
		Gulf of Alaska	Pacific Ocean Perch	1977	-1989	
			Northern rockfish	-1989		
			Thornyhead rockfish	1980	-1991	
			Dusky rockfish	-1999		
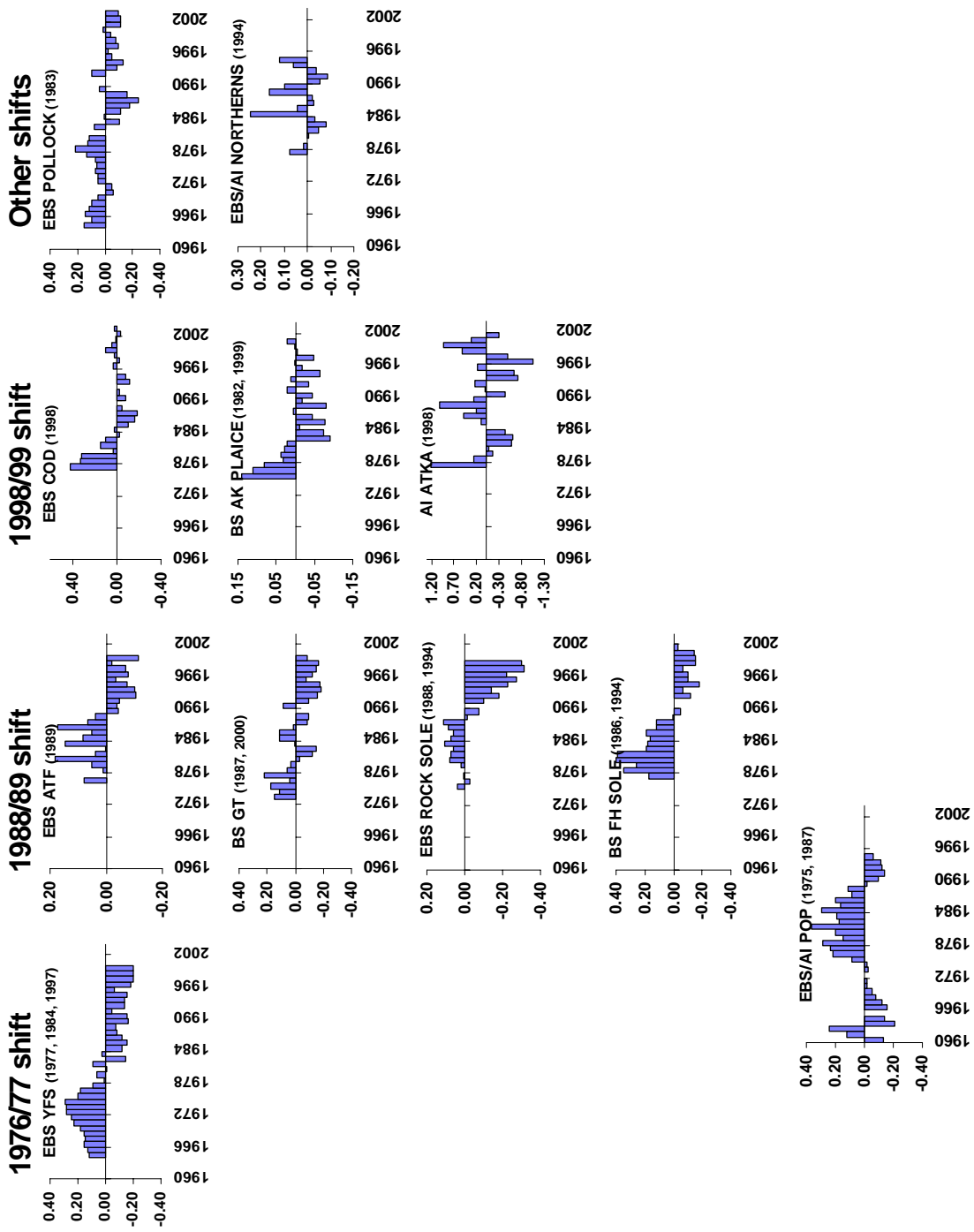
Figure 66. Median recruit per spawning biomass anomalies for BSAI groundfish species assessed with age- or size-structured models, 1960-2003. Stocks are generally sorted according to known regime shifts. Years of regime shifts are shown in parentheses, since some stocks had more than one shift. EBS = Eastern Bering Sea, BS = Bering Sea, AI = Aleutian Islands, YFS = yellowfin sole, ATF = arrowtooth flounder, FH sole = flathead sole, POP = Pacific ocean perch, GT = Greenland turbot, Atka = Atka mackerel.
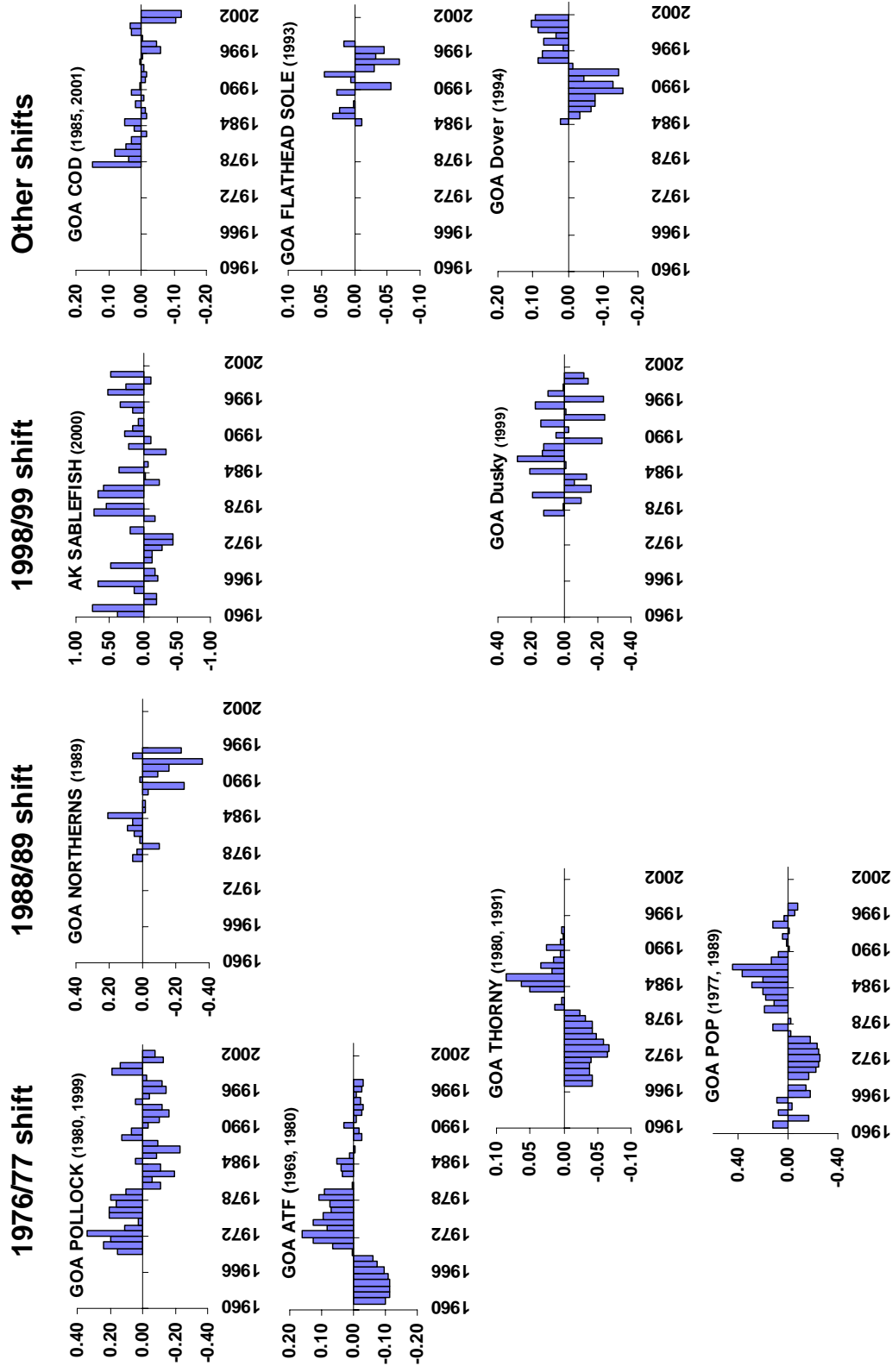
Figure 67. Median recruit per spawning biomass anomalies for GOA groundfish species assessed with age- or size-structured models and Thornyhead rockfish, 1960-2003. Stocks are generally sorted according to known regime shifts. Years of regime shifts are shown in parentheses, since some stocks had more than one shift. GOA = Gulf of Alaska, ATF = arrowtooth flounder, POP = Pacific Ocean perch, Sable = sablefish, Thorny = Thornyhead rockfish, Dusky = Dusky rockfish, Dover = Dover sole.

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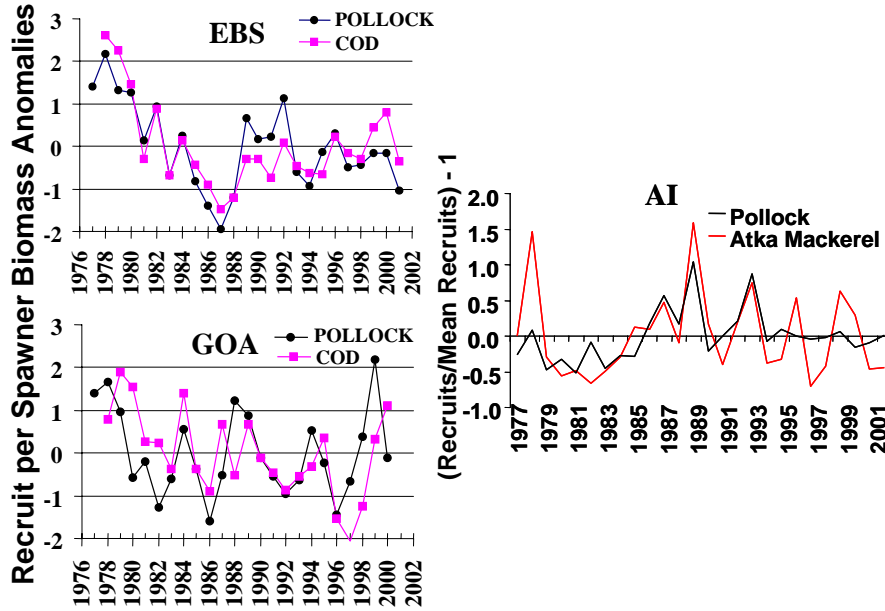
Figure 68. Recruit per spawner anomalies of BSAI and GOA pollock and cod and Aleutian Islands pollock and
Atka mackerel (lagged back one year) recruits expressed as a proportion of mean recruits. Atka mackerel
spawn in the summer and pollock spawn in the winter; therefore, the Atka mackerel were lagged by one
year, to match the yearclasses that experienced similar conditions (modified from Barbeaux et al. 2003)
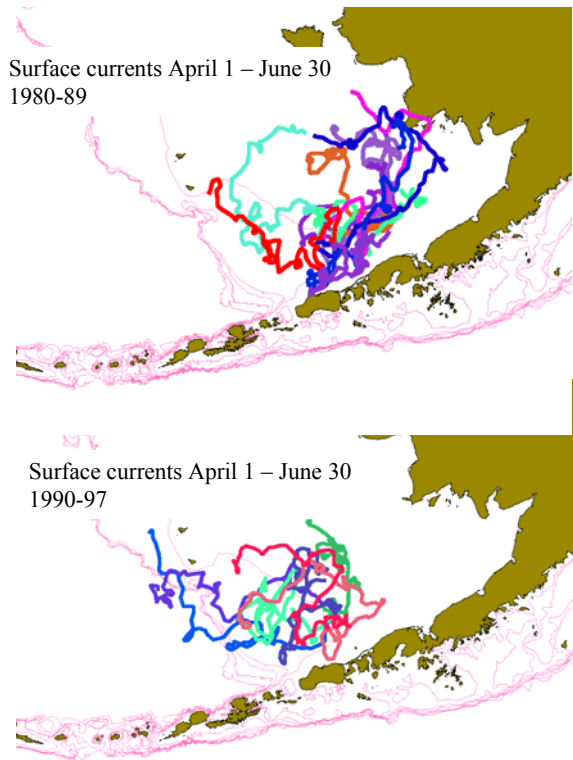
Figure 69. OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56° N, 164° W
from April 1 – June 30 for the 1980's (upper panel) and 1990-96 (lower panel). Figure adapted from
Wilderbuer et al. (2002).

Update on EBS winter spawning flatfish recruitment and wind forcing
Contributed by Jim Ingraham and Tom Wilderbuer, AFSC

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. The time series is updated (2000-2005; Figure 70) for the last 6 years.

Five out of six OSCURS runs for 1998-2004 were consistent with those which produced above-average recruitment in the original analysis, 2000 being the exception. The north-northeast drift pattern suggests that larvae may have 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. The end point of the drift trajectory in 2005 was the furthest offshore of any since 2000; therefore, recruitment strength for the 2005 yearclass of winter spawning flatfish may be weak.
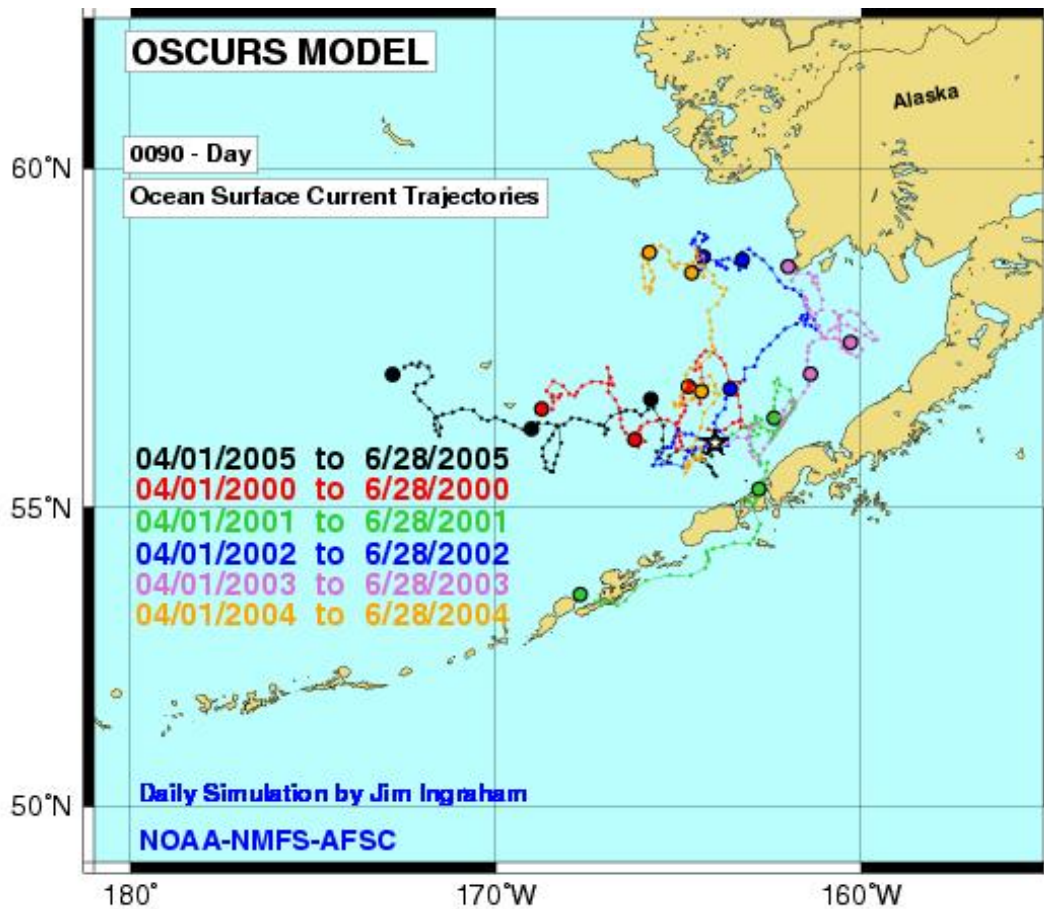
Figure 70. OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56° N, 164° W from April 1-June 30 for 2000-2005.

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

Principal Investigator – Paul Spencer (Alaska Fisheries Science Center – REFM)
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 $< 2 \degree C$) 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 71a). 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 71b).

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 72). 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.
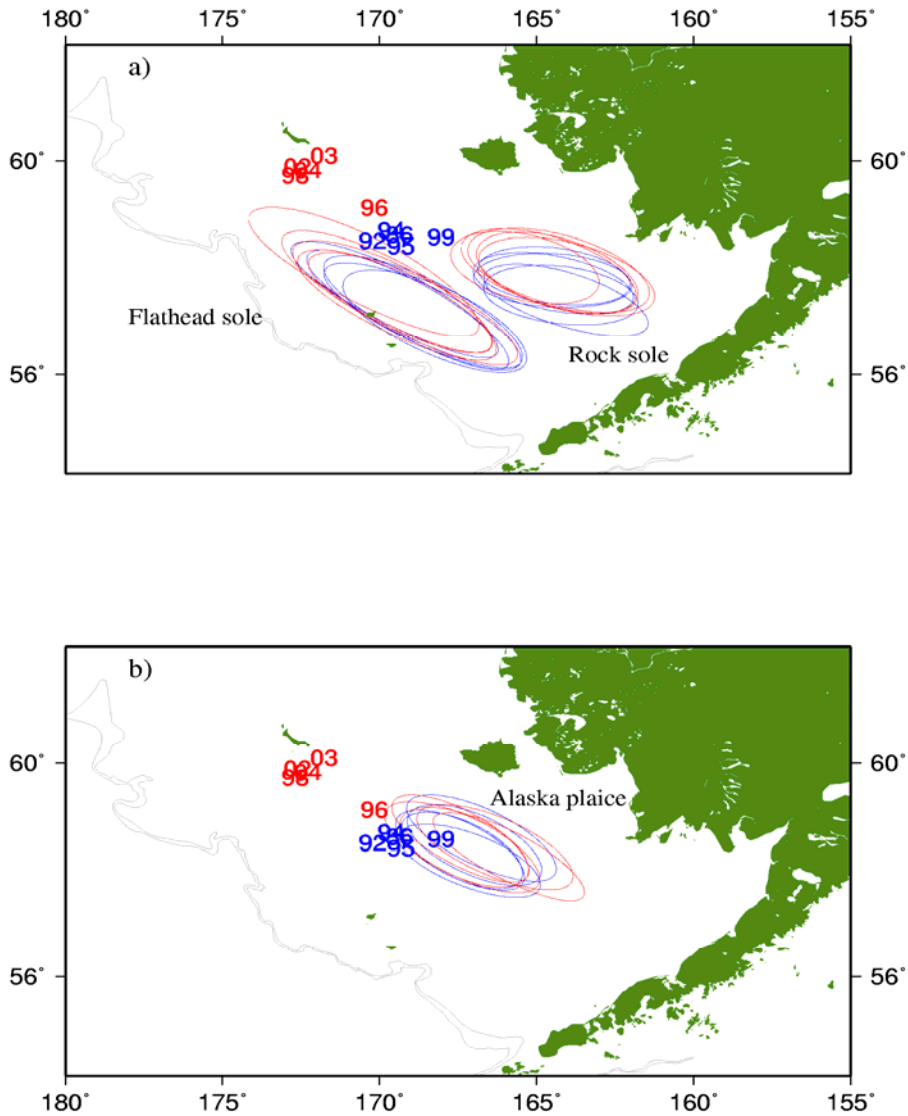
Figure 71. Centers of the cold pool, label by year, from the five warmest (red) and coldest (blue) years observed from 1982-2004, and the distributional ellipses encompassing a probability of 50% for a bivariate normal distribution (based upon EBS shelf survey CPUE data) for flathead sole and rock sole (a) and Alaska plaice (b).
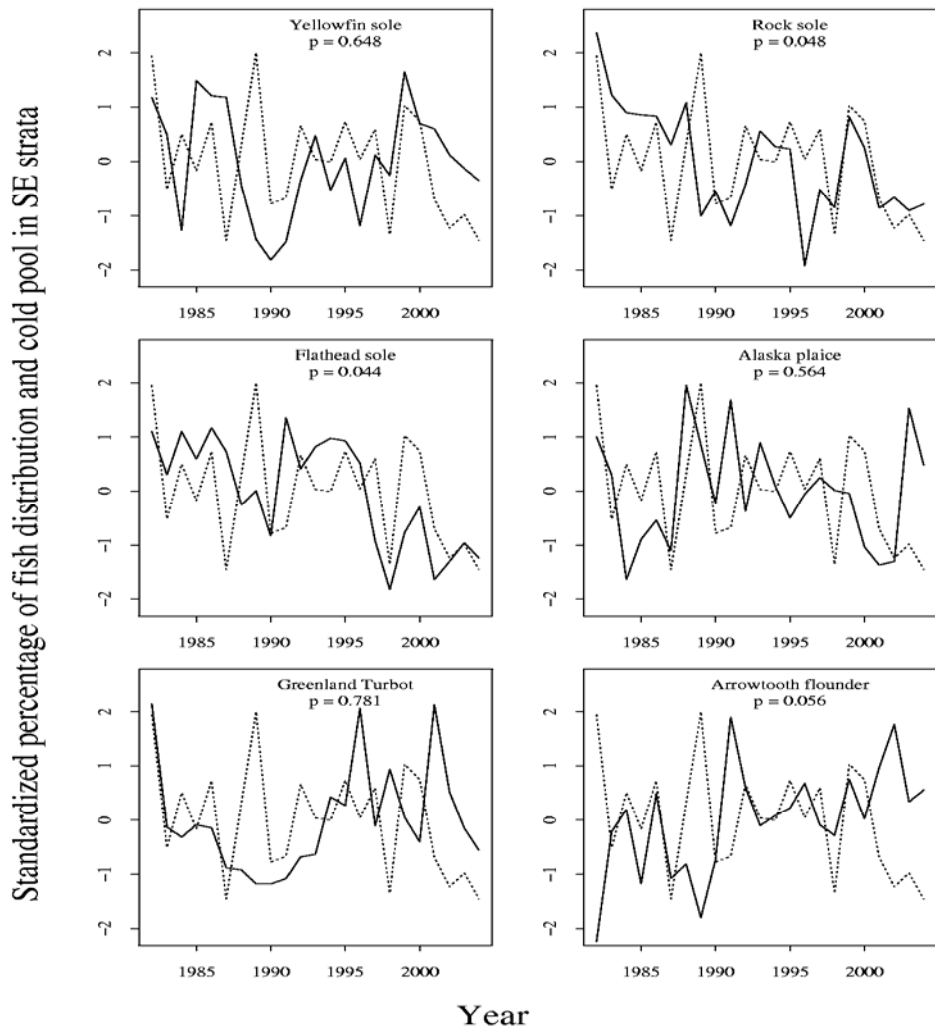
Figure 72. Time series of the standardized proportions of fish populations (solid lines) and proportion of the cold pool (dashed lines) located in the southeast EBS shelf survey strata. Data were standardized by subtracting the mean and dividing by the standard deviation; positive values indicate relatively higher percent with the SE survey strata.

Benthic Communities and Non-target Fish Species

ADF&G Gulf of Alaska Trawl Survey

Contributed by Dan Urban, Alaska Department of Fish and Game, 211 Mission Road, Kodiak, Alaska, 99615, Ph. 907-486-1849; dan_urban@fishgame.state.ak.us
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The Alaska Department of Fish and Game continued its trawl survey for crab and groundfish in 2005. 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 73) are broadly representative of the survey results across the region. These areas have been surveyed continuously since 1984, and Ugak Bay was also the subject of an intensive trawl survey in 1976 (Blackburn 1977). Ugak Bay continues to be a very different place than it was in 1976. Red king crabs were once a main component of the catch, but now are nearly non-existent. Tanner crab, flathead sole, and walleye pollock catch rates have all increased roughly 10-fold.

Arrowtooth flounder are the main component of the offshore catches, while flathead sole comprise the largest catch in the bays (Figure 74). Tanner crab catch increased in the offshore stations, despite a commercial fishery in the area for the last 5 years. Tanner crab catch in the bays declined by 50% despite the fact Ugak and Kiliuda were closed for the January 2004 fishery and Ugak Bay was closed for the 2005 fishery. The 2005 gadid catch (94% walleye pollock) declined in Barnabas Gully but is still the highest catch since 1989.
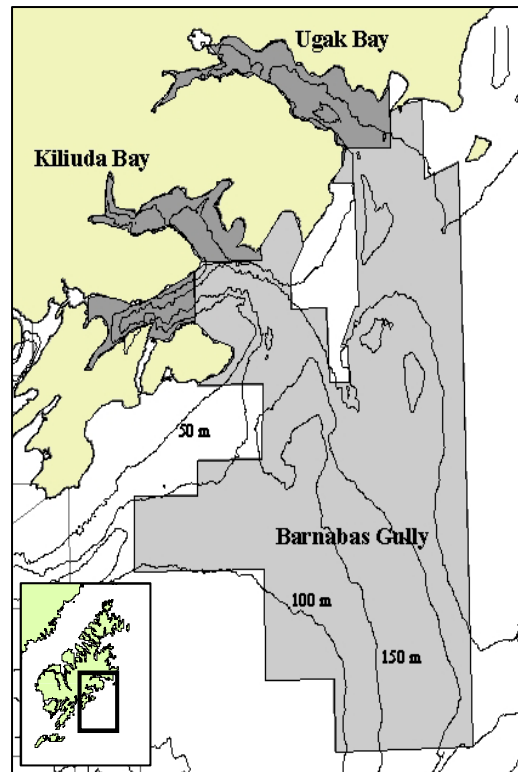
Figure 73. Adjoining survey areas on the east side of Kodiak Island used to characterize nearshore (dark gray, 14 stations) and offshore (light gray, 35 stations) trawl survey results. The 50, 100, and 150 m depth contours are shown.

Barnabas Gully

Kiliuda and Ugak Bays
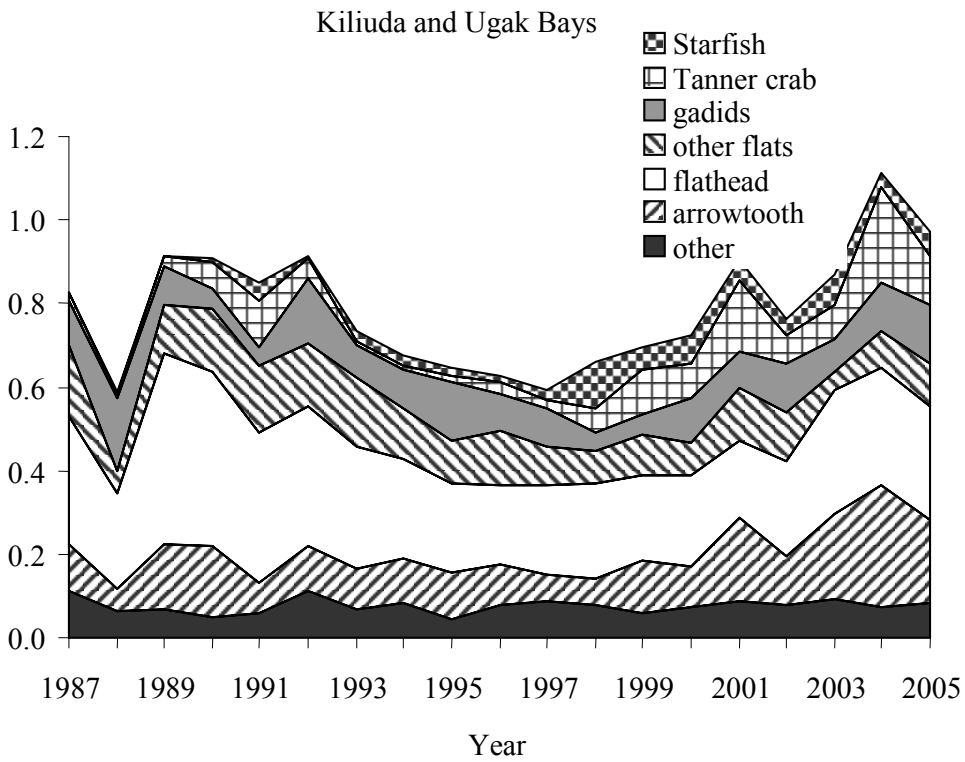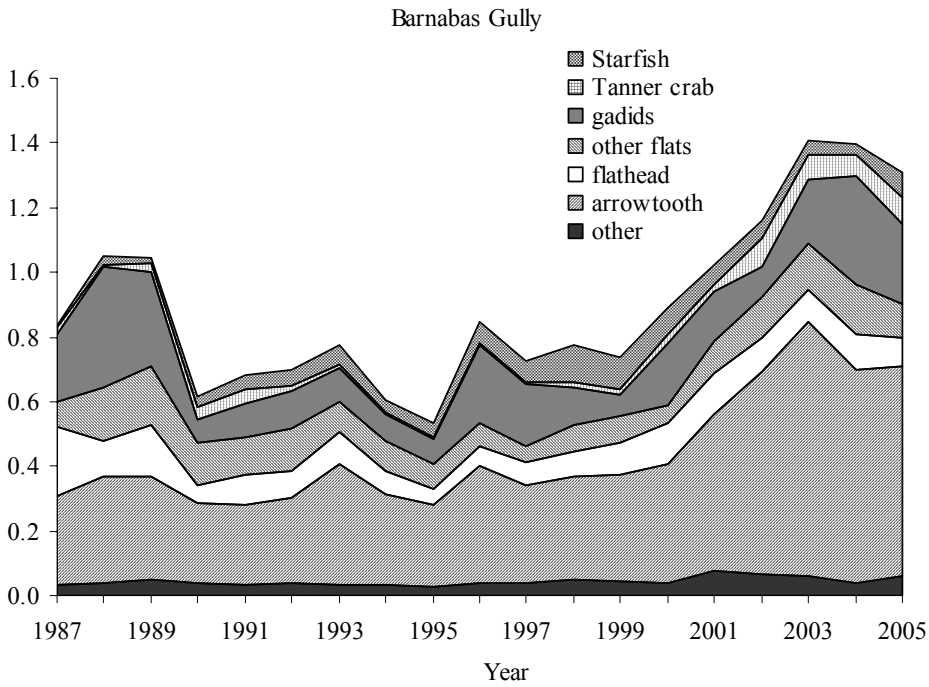
Figure 74. Metric tons per kilometer caught from 1987 to 2005 during the ADF&G large mesh trawl
survey from adjacent areas off the east side of Kodiak Island.

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Gulf of Alaska Small Mesh Trawl Survey Trends
Contributed by Mike Litzow, Alaska Fisheries Science Center
Last updated: September 2005

Small mesh shrimp trawl surveys have been conducted with standard methods in the Gulf of Alaska by the Alaska Department of Fish and Game and National Marine Fisheries Service since 1972 (n = 8,083 hauls). This data set has been particularly valuable in documenting the ecological reorganization that occurred following the 1976-1977 shift from a cold state of the Pacific Decadal Oscillation to a warm state (Piatt & Anderson 1996; Anderson & Piatt 1999). During 2004, sampling occurred in Marmot and Chiniak Bays, Shelikof Strait, and along the Alaska Peninsula coast between Wide and Pavlof Bays (n = 114 hauls). Several authors have suggested that another climate regime shift may have occurred in 1998-99 (Bond et al. 2003; Peterson and Schwing 2003), and increases in CPUE of Pandalid shrimp and eulachon *Thaleichthys pacificus* in small mesh trawls following 1998 have suggested the possibility of incipient climate-mediated community reorganization in the Gulf (Anderson 2004). The goal of this contribution is to assess the evidence for current ecological reorganization in small mesh survey data.

Community trends
Analysis of the data set is complicated by seasonal variability (i.e., sampling in different months during different years) and spatial variability (sampling of different bays in different years). In order to control these effects, analysis of variability in catch composition was limited to hauls set from July to October in the seven best-sampled bays on Kodiak Island and the Alaska Peninsula (Marmot, Kiliuda, Two-Headed Gully, Alitak, Chignik/Castle, Kuiukta and Pavlof; n = 1,744 hauls). Only one bay (Pavlof) was sampled each year, and the others were sampled between 14 and 18 of the 33 years. Nonmetric multidimensional scaling (NMDS) was used to summarize variability in the 30 most common taxa, which made up 98.8% of the total catch. NMDS summarizes variability in community composition in a restricted number of variables. This method is conceptually similar to principal components analysis, but is more robust to the presence of large numbers of zero catches that characterize trawl survey data (see Mueter and Norcross 1999, 2000 for detailed methods). The first three NMDS axes explained 34%, 24% and 20% of variability in catch composition, respectively. Only the first axis showed coherent temporal variability, while axis 2 primarily varied among bays and axis 3 primarily varied with depth. Axis 1 positively weighted taxa that increased after the 76-77 regime shift (jellyfish [Scyphozoa], arrowtooth flounder *Atheresthes stomias*, walleye pollock *Theragra chalcogramma*, flathead sole *Hippoglossoides elassodon*) and negatively weighted taxa that declined following the regime shift (Pandalid shrimp, capelin, Pacific sandfish *Trichodon trichodon*, red king crab *Paralithodes camtschaticus*, sculpins [Cottidae, Psychrolutidae, Hemitripteridae]; Figure 75). Similar results were obtained in a previous analysis of small mesh data from Kodiak Island bays (Mueter and Norcross 2000).
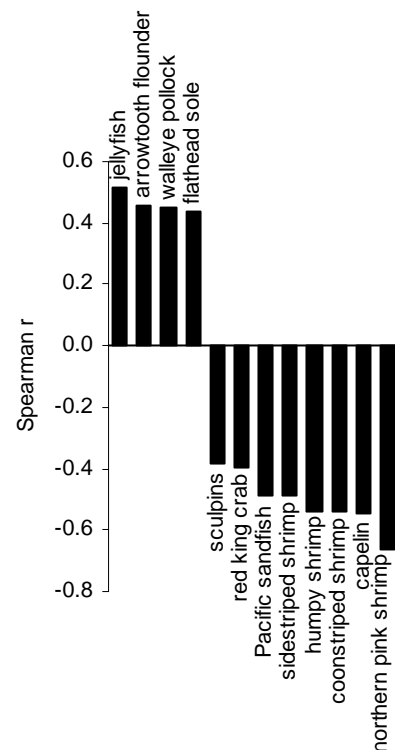
Figure 75. Associations between individual taxa and NMDS axis 1 in Gulf of Alaska small mesh trawls. Taxa with |r| > 0.35 are shown. Taxa with positive correlations increase in CPUE when axis 1 increases, taxa with negative correlations decrease when axis 1 increases.

In order to overcome the bias due to different bays being sampled in different years, bay-year values for axis 1 were estimated as the mean axis 1 score from every haul in a bay during a given year. Separate autoregressive error models (which account for the autocorrelation among errors that is present in time series data) were run for each bay time series. Predicted axis 1 values from the autoregressive models were used to estimate missing bay-year values, resulting in seven complete time series. Pavlof Bay was the only bay sampled in 1972, with two other time series (Chignik-Castle and Kuiukta) beginning in 1973 and the remainder beginning in 1976. Two averaged time series were therefore constructed, one beginning in 1973 (mean axis 1 scores from Pavlof, Chignik-Castle and Kuiukta), and another beginning in 1976 (mean axis 1 scores from all seven bays). An index of local climate was also calculated as the first principal component of five measures of local climate: winter and summer sea level pressure averaged over seven 1º x 1º blocks centered on the seven sampled bays (Pacific Fisheries Environmental Laboratory 2005), winter and summer sea surface temperature in a 5º x 5º block centered on Kodiak Island (Climatic Research Unit 2005), and summer GAK1 250 m temperature (Institute of Marine Science 2005).
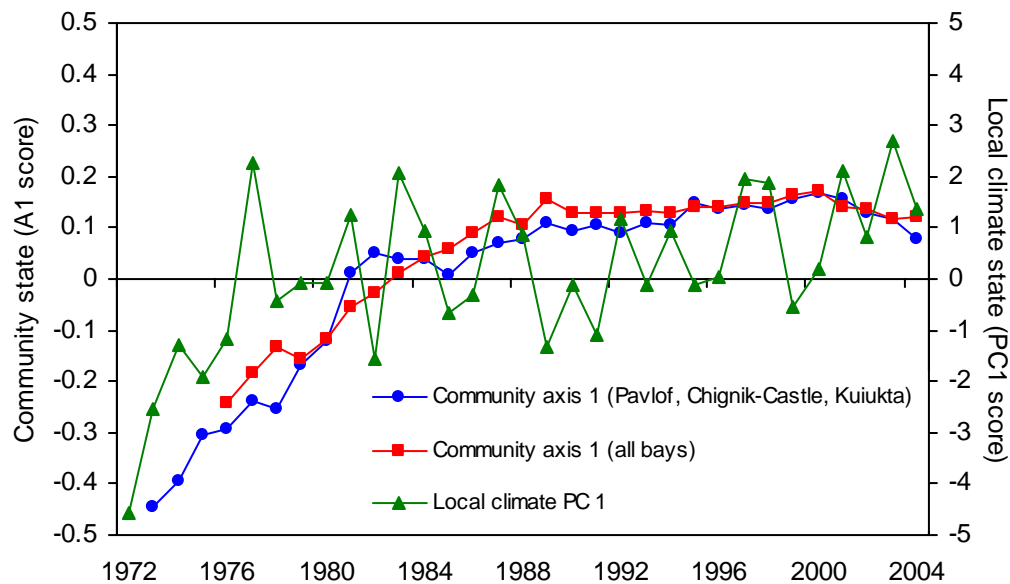
Figure 76. Trends in Gulf of Alaska community composition (NMDS axis 1 of small mesh trawl catches) and local climate (first principal component of summer and winter sea level pressure, summer and winter surface temperature and summer GAK1 250 m temperature). Trawl data are from seven bays on Kodiak Island and Alaska Peninsula during July-October, and have been corrected for effect of sampling different bays in different years. Two time series are presented, one for three bays that have been sampled since 1973, and another for all bays, beginning in 1976, the first year that all bays in the time series were sampled. See Figure 75 for interpretation of axis 1 scores.

All three time series showed a logarithmic increase with year (axis 1 for Pavlof, Chignik-Castle and Kuiukta, $r^2 = 0.92$; axis 1 for all bays, $r^2 = 0.88$; local climate PC1, $r^2 = 0.45$). This logarithmic pattern is consistent with a sudden climate shift in 76-77, a resulting sudden community transition following the 76-77 regime shift, and the completion of the transition to the current ecological state in the early 1980s (Figure 76). Axis 1 was positively correlated with local climate PC1 for the longer Pavlof/Chignik-Castle/Kuiukta time series ($r = 0.48$), but not for the shorter time series for all bays ($r = 0.16$, Figure 76). Although axis 1 scores have declined since 1999-2000, these scores have remained within the range established after the early 1980s, and there is no evidence at this time of the kind of rapid community reorganization that followed the 1976-77 shift.

Trends in selected taxa

Although community-wide analysis shows no evidence of a current reorganization, changes in the three-year running mean CPUE of several taxa have been noted since 1998 (Anderson 2004). Calculation of running mean CPUE does not take into account seasonal and spatial differences in sampling among years, and this is an important caveat. Pavlof Bay has been sampled every year since 1972, while bays to the east of Pavlof on the Alaska Peninsula and Kodiak Island were sampled during triennial surveys in 1989, 1992, 1995 and 1998, and annually or biennially during 2001-2004. The increase in effort since 2001 has the effect of decreasing the contribution of Pavlof Bay to running mean CPUE estimates beginning in 2000 (the first year that includes 2001 data). Pavlof Bay shows consistent differences in CPUE from other sampled bays for a wide range of taxa, so annual differences in sampling distribution confound apparent temporal trends in running mean CPUE data.

In spite of these limitations in the data, increases in CPUE of some taxa (especially eulachon and spiny dogfish *Squalas acanthias*) are dramatic enough that they likely reflect significant changes in population size or distribution independent of changes in sampling distribution. CPUE data from selected taxa are presented here to provide insight into recent trends. Detailed 2004 catch data (excluding Pavlof Bay) are available elsewhere (Jackson 2005).

Pandalid shrimp CPUE in 2004 was generally similar to CPUE in recent years (northern pink shrimp *Pandalus borealis*, 22.0 ± 4.5 [SE] kg/km; humpy shrimp *P. goniurus*, 1.5 ± 0.7 kg/km; coonstriped shrimp *P. hypsinotus*, 0.02 ± 0.01 kg/km; sidestriped shrimp *Pandalopsis dispar* 1.4 ± 0.3 kg/km). The recent trend of dramatically higher eulachon catches continued, with 2004 CPUE of 11.6 ± 2.1 kg/km, the highest value ever observed in the time series. Capelin catches continued to be very low (0.02 ± 0.01 kg/km), following the trend since the 1980s of very low catches of this previously common species. Catches of Pacific sandfish continued at relatively high levels (2.1 ± 1.0 kg/km), similar to catches in the late 1970s and early 1980s, while longsnout pricklebacks *Lumpenella longirostris* continued to be caught at low levels (0.4 ± 0.2 kg/km) characteristic of their population levels since the 1970s. Recent trends of declining Gadid catches reversed in 2004. CPUE of both walleye pollock (192.7 ± 47.6 kg/km) and Pacific cod *Gadus macrocephalus* (22.7 ± 9.1 kg/km) were more than double values for 2001-2003. CPUE of two important flatfish species, arrowtooth flounder (35.8 ± 6.3 kg/km) and flathead sole (50.5 ± 8.6 kg/km), were similar to values for recent years, suggesting that populations of these species remain at high post-regime shift levels. Jellyfish CPUE (4.1 ± 0.8 kg/km) was one third of 2002-03 values, and an order of magnitude below 2001 CPUE. Finally, spiny dogfish CPUE (2.3 ± 0.4 kg/km) continued at unprecedented high levels that began in 1998.

Bering Sea Crabs
Contributed by Bob Otto and Jack Turnock, Alaska Fisheries Science Center
Last updated: November 2005

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 (Figure 77), and of six crab fisheries included in the FMP, 3 are open, 3 are closed, and 4 are at overfished levels of abundance. Rebuilding plans are in place for all overfished stocks. Fisheries will be managed in 2005 under the new eastern Bering Sea/Aleutian Islands crab rationalization regulations with individual quota shares for all eligible participants.

BRISTOL BAY RED KING CRAB.
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. The 2005 survey abundance index of legal males declined (-22%) relative to 2004, while that of pre-recruit males (+58 %) and mature females (+35%) increased. The survey index of mature biomass has been stable over the past three years and is at its highest level since the early 1980s (Figure 77). The 2005 fishery will open October 15 with a total allowable catch of 8,300 metric tons (18.3 million pounds) or about 10 % of the survey index of mature biomass.

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. The 2005 survey abundance index of large male crabs decreased by ca 69% relative to 2004 while that of mature females decreased by ca 129%. Almost no pre-recruit males were captured in either year's survey. 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. The fishery will remain closed in 2005.

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. Abundance of mature biomass continued to decrease in 2004 to the lowest on record and remains very low in 2005. Little or no recruitment is apparent in the population which has been declining continuously since 1995. Continued warm conditions in waters surrounding the Pribilof Islands may be contributing to the decline. The fishery will remain closed in 2005.

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. Legal male abundances decreased by 53% and while pre-recruit male increased by 159 % relative to 2004, both population segments remain at very low abundance. Indices of female crab abundances are not considered meaningful due to their preference for inshore, rocky, hence untrawlable habitat. The fishery will remain closed in 2005.

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. The 2005 mature biomass was above 50% MSY and at its highest levels since the mid-1990s (Figure 77). The abundance indices for mature portions of the stock, legal males (+112 %), pre-recruit males (+60 %) and mature females (+150 %) all increased substantially. There is some concern as to the validity of such

large increases due to imprecision of survey indices and because no such increases were anticipated from 2004 information. Under the terms of the rebuilding plan, a small fishery will be allowed in 2005 for the first time since 1996. The 2005 fishery will open October 15 with a total allowable catch of 730 metric tons (1.6 million pounds) or about 1 % of the survey index of mature biomass.

EASTERN BERING SEA SNOW CRAB.
Snow crab recruitment was higher during 1979-1987 than in other years (Figure 78). 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.

The mature biomass of Eastern Bering Sea snow crab was moderate to high in the early 1980s and from 1987-97 (Figure 77). The biomass declined sharply from 1998 to 1999 and the stock is considered overfished. Increases in abundance noted in 2004 continued but were more substantial in 2005, the abundance indices for commercial sized males (+5%) pre-recruit males (+236%) and mature females (+102%) all increased. A small fishery will be allowed under the terms of the rebuilding plan. The 2005 fishery will open October 15 with a total allowable catch of 16,900 metric tons (37.2 million pounds) or about 6 % of the survey index of mature biomass.
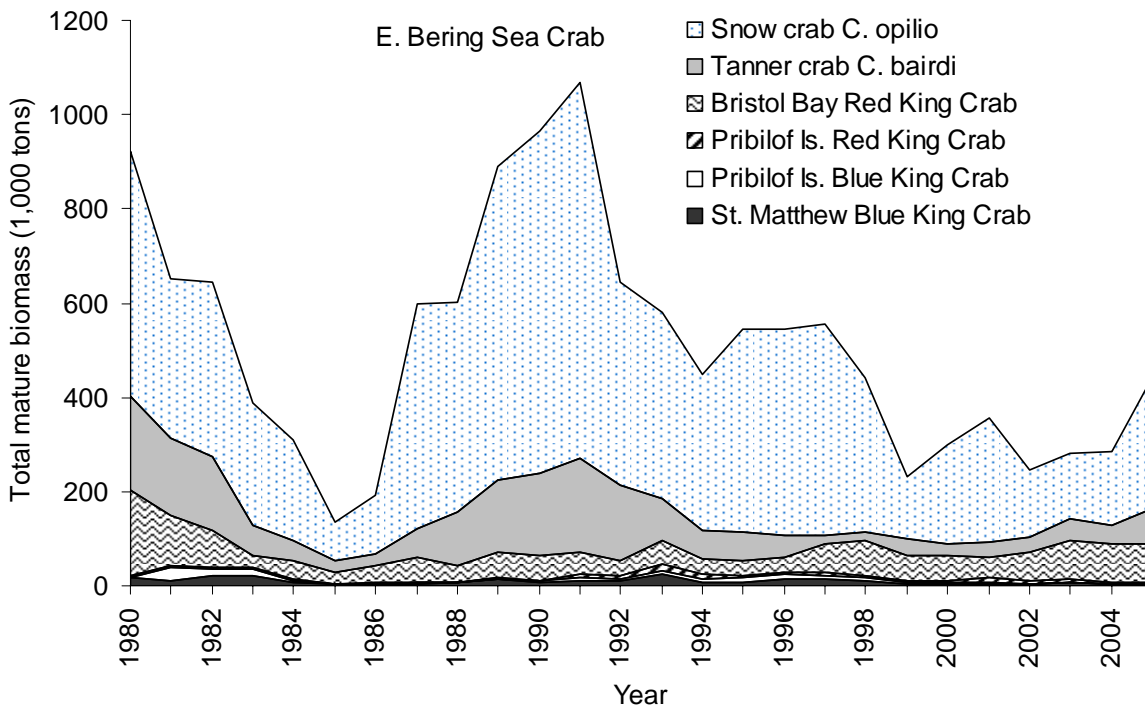
Figure 77. Total mature biomass of Eastern Bering Sea crab populations, 1980-2005.
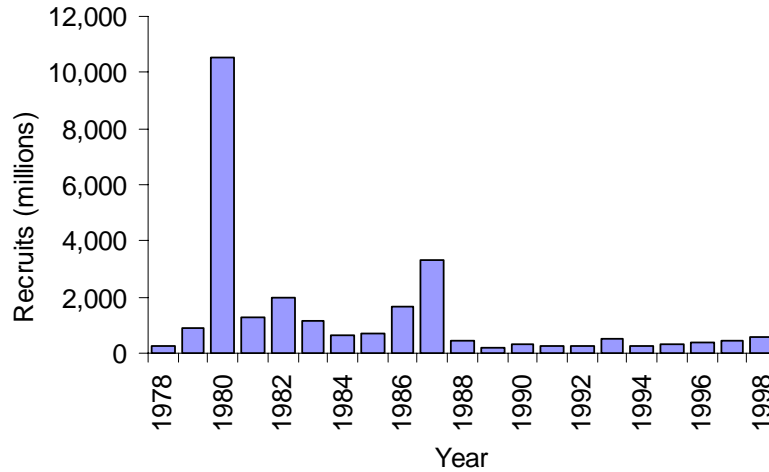
Figure 78. Snow crab recruitment from 1978 to 1998 in millions of crabs that are 25 mm to 50 mm in carapace width and lagged by 5 years (to fertilization year).

Stock-recruitment relationships for Bristol Bay red king crabs

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The results from a length-based model were used to develop stock-recruitment (S-R) relationships for Bristol Bay red king crabs, 1968-1997. 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 the mature female abundance was less than the male reproductive potential, then the 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 and 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:

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

and an autocorrelated Ricker curve:

$$R_t = SP_{t-k}\, e^{r2 - r3\, SP_{t-k} + v_t}, \tag{2}$$

where

$$v_t = \delta_t + a1\, v_{t-1},$$

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

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 79). 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 ($R^2 = 0.54$) was used to describe the density-dependent

relationship and the autocorrelated Ricker curve ($R^2 = 0.44$) was used to depict the autocorrelation effects. The recruitment trends of Bristol Bay red king crabs may partly relate to decadal shifts in physical oceanography: all strong year classes occurred before 1977 when the Aleutian Low was weak. The largest year class during the last 20 years, the 1989 brood year, was also coincidental with the weak Aleutian Low index during 1989-1991.
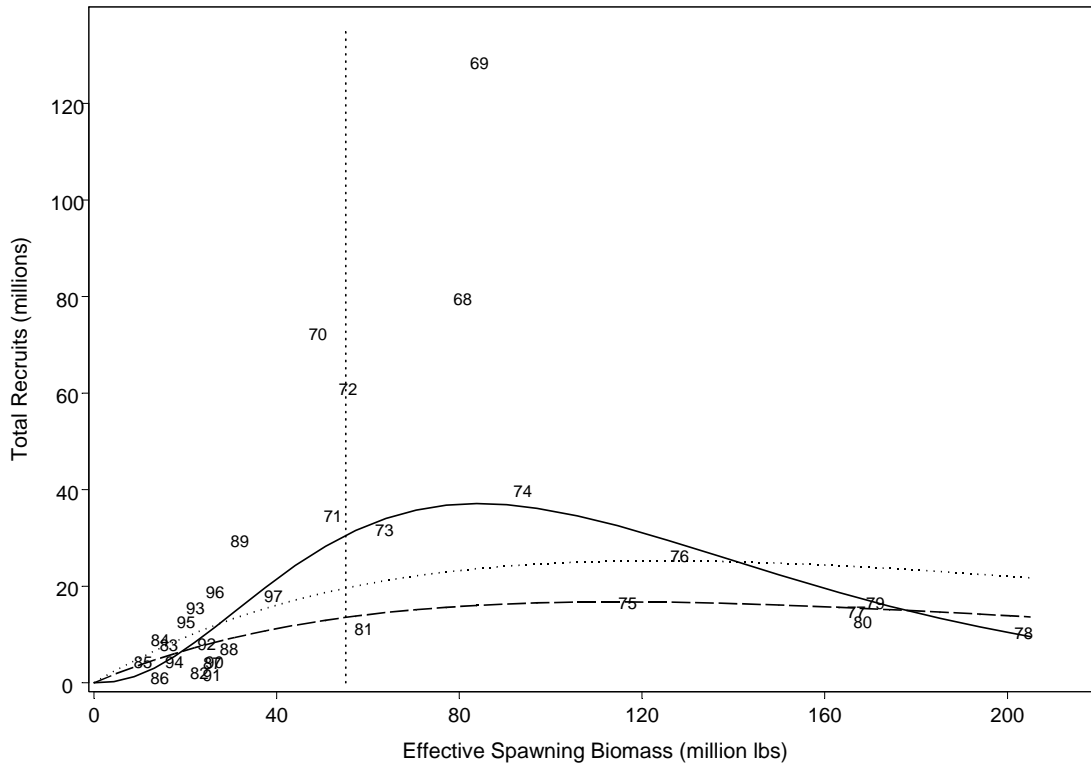
Figure 79. Relationships between effective spawning biomass and total recruits at age 7 (i.e., 8-year time lag) for Bristol Bay red king crabs, 1968-1997. Numerical labels are brood year (year of mating), the solid line is a general Ricker curve, the dotted line is an autocorrelated Ricker curve without υt values (equation 2), and the dashed line is a Ricker curve fit to recruitment data after 1974 brood year. The vertical dotted line is the targeted rebuilding level of 55 million lbs effective spawning biomass.

Miscellaneous Species – Gulf of Alaska
Contributed by Michael Martin
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Last updated: November 2005

Many other species of fish and invertebrates are encountered during the course of the biennial GOA survey. 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. A few general patterns of abundance can be discerned from the data. 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. Echinoderm abundances have generally been highest in the central GOA and their abundance appears to have generally increased over time in all areas. For the eelpouts (zoarcids) and poachers (agonids), definite abundance trends are difficult to discern as these species are rarely caught and the efficiency of the gear in capturing these fish is quite low due to their small size relative to the mesh size used on the biennial surveys (Figure 80).
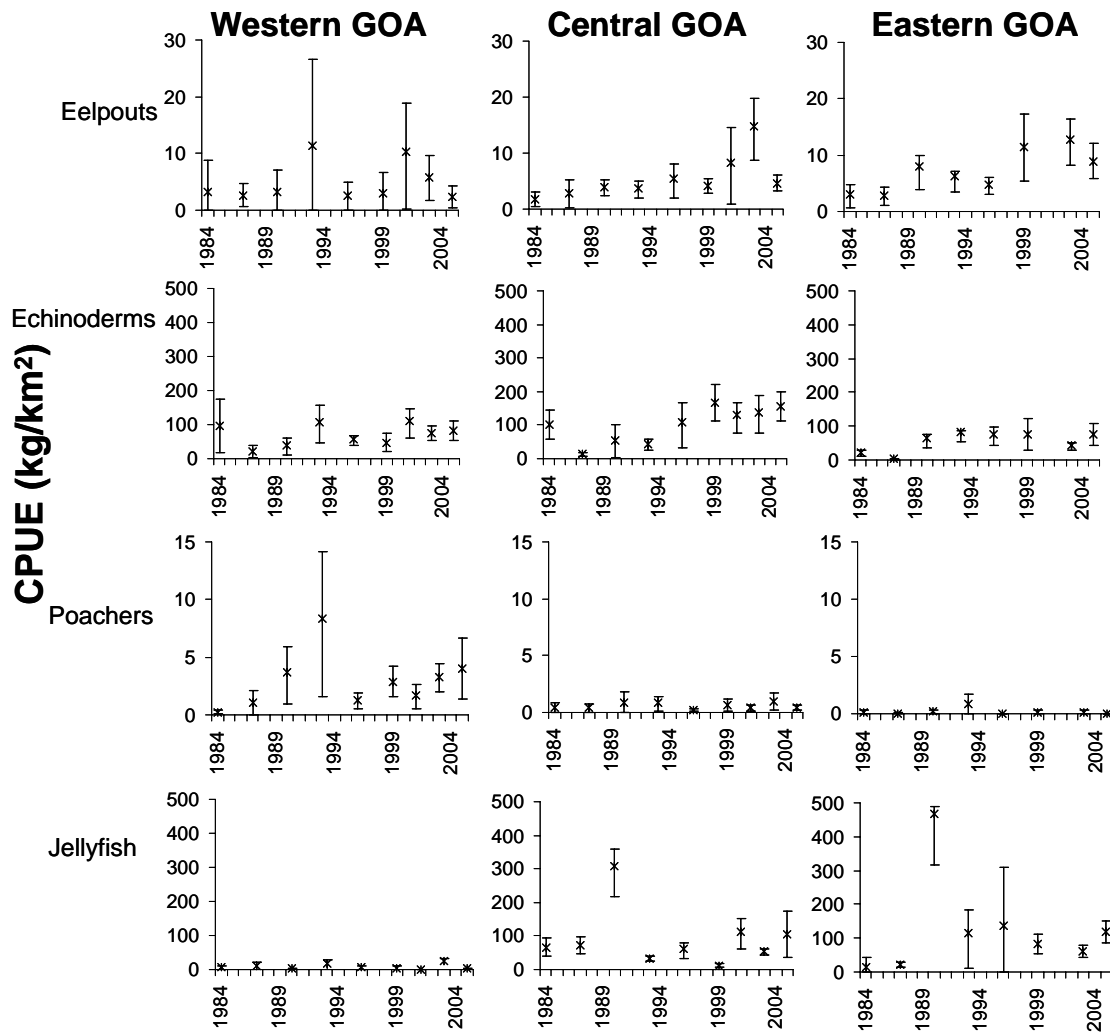
Figure 80. CPUE of miscellaneous species from the Gulf of Alaska biennial survey from 1984 through 2005. Error bars represent 95% confidence intervals.

Jellyfish – Eastern Bering Sea
Contributed by Robert Lauth, Alaska Fisheries Science Center
Last updated: November 2005

The time series of jellyfish caught as bycatch in the annual Bering Sea bottom trawl survey was updated to include data from 2005 (Figure 81). The increasing trend in abundance that began around 1989, reported by Brodeur et al. (1999), did not continue in 2001-2005. In fact, the 2001-2005 catches decreased dramatically and were close to levels seen in the 1980s and early 1990s. The overall area biomass index for 2005 is 68,082 t. It is unknown whether this decline is due to a change in availability or actual abundance.
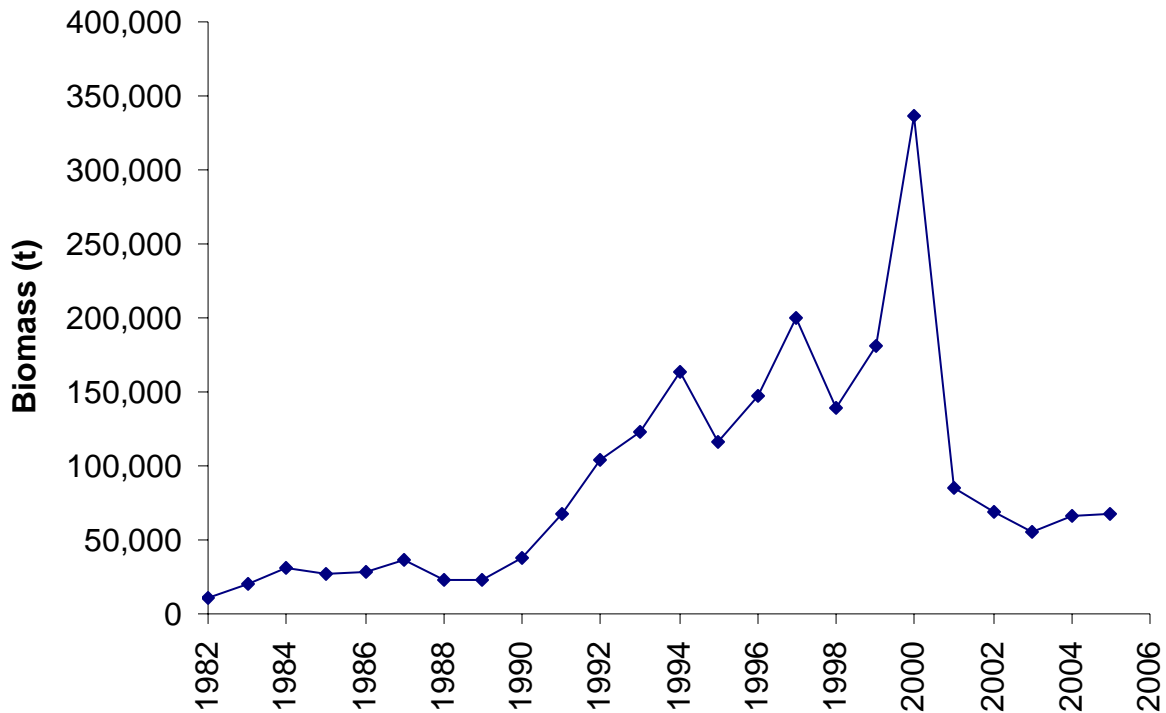
Figure 81. Index of large medusae biomass during the summer in the eastern Bering Sea from the NMFS bottom trawl survey, 1982-2005.

Miscellaneous species - Eastern Bering Sea
Contributed by Robert Lauth, Alaska Fisheries Science Center
Last updated: November 2005

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*). Total catch per unit effort (CPUE) of this group appeared higher in the early 1980s than in the late 1980s to the present (Figure 82). Although lower, CPUE appears to have been relatively stable in the recent time period. Further analyses are needed to examine CPUE trends at the species level. The CPUE of poachers, likely dominated by sturgeon poacher (*Podothecus acipenserinus*), was low in the early 1980s but increased in the late 1980s to the mid-1990s. Poacher CPUE appeared to increase in recent years and may have returned to levels

seen in the early 1990s (Figure 82). 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. CPUE values for this group on the shelf were higher from the mid 1980s to the present compared to the early 1980s. More research on the life history characteristics of non-target species is required to understand the possible reasons for these CPUE trends.
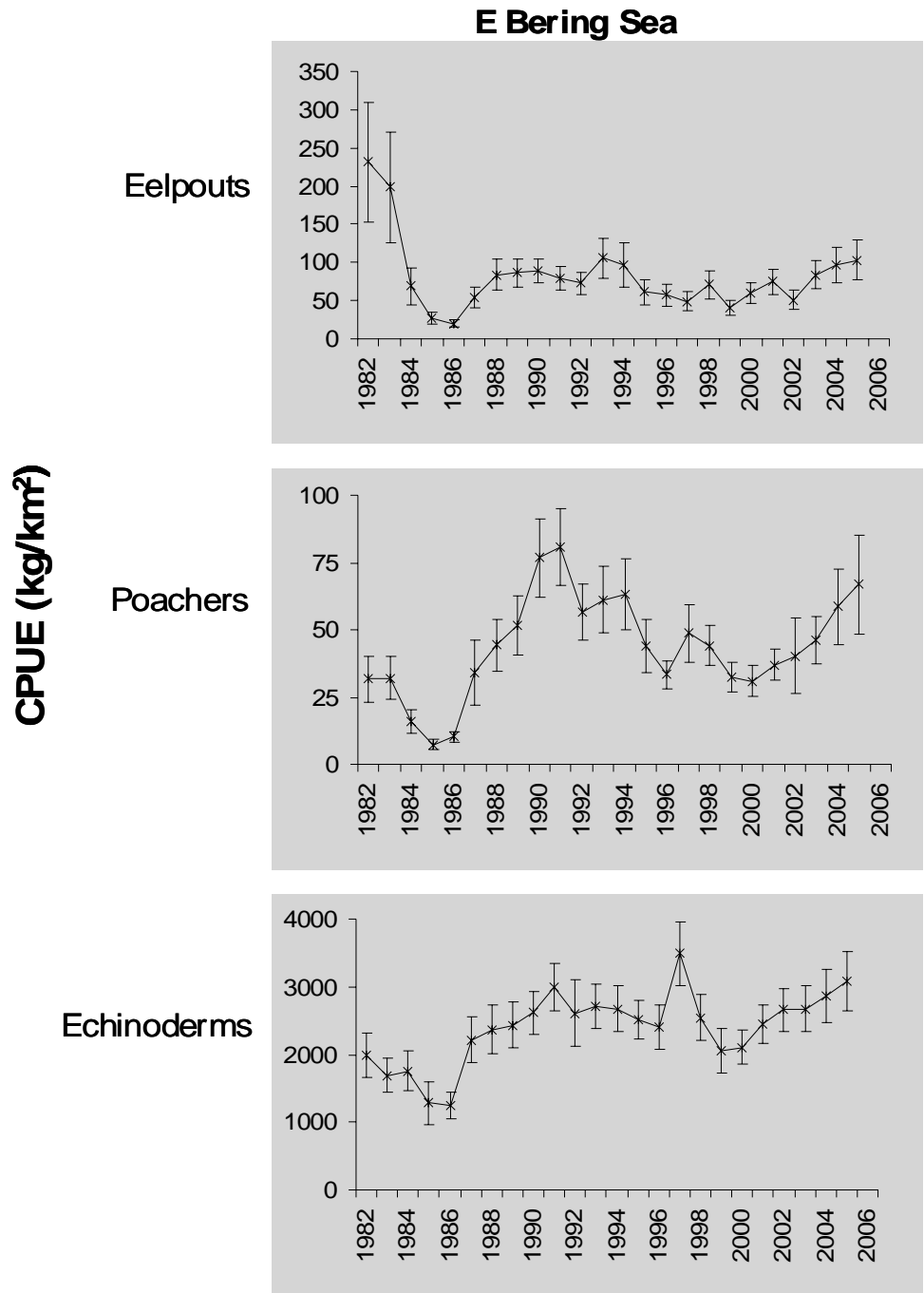
Figure 82. Catch per unit effort (CPUE) of miscellaneous species caught in the eastern Bering Sea summer bottom trawl survey, 1982-2005. Data points are shown with 95% confidence intervals.

Miscellaneous Species – Aleutian Islands
Contributed by Eric Brown, Alaska Fisheries Science Center
Last updated: November 2004

A variety of non-target species are seen in the RACE bottom trawl survey in the Aleutian Islands. It is possible that this survey may provide information about possible relative abundance changes in some of these species. Some initial results at summarizing these trends are shown (Figure 83). This survey is not designed to assess these organisms and further detailed examinations of these results are needed to assess whether there are meaningful trends.

Eelpouts and poachers are relatively common in trawl catches but generally occur at very low catch rates so that any apparent increases in abundance may be driven by one or two catches of only a few fish. Starfish and jellyfish are also quite common but exhibit much higher apparent abundance levels. As mentioned earlier, jellyfish may primarily occur higher in the water column and be caught during setting and retrieval of the trawl.

The 2004 survey showed an increase in abundance of eelpouts in all areas except the southern Bering Sea. Eelpout catches in all areas were the highest catches since at least 1991. Starfish catches in 2004 increased relative to 2002 in the western AI and southern BS and decreased in the central and eastern AI. Catches of poachers in 2004 showed a continued decreasing trend in all areas since the high catches in 2000 and 2002. In 2004, jellyfish catch rates increased dramatically and represented the highest or the second highest catches on record in all areas.
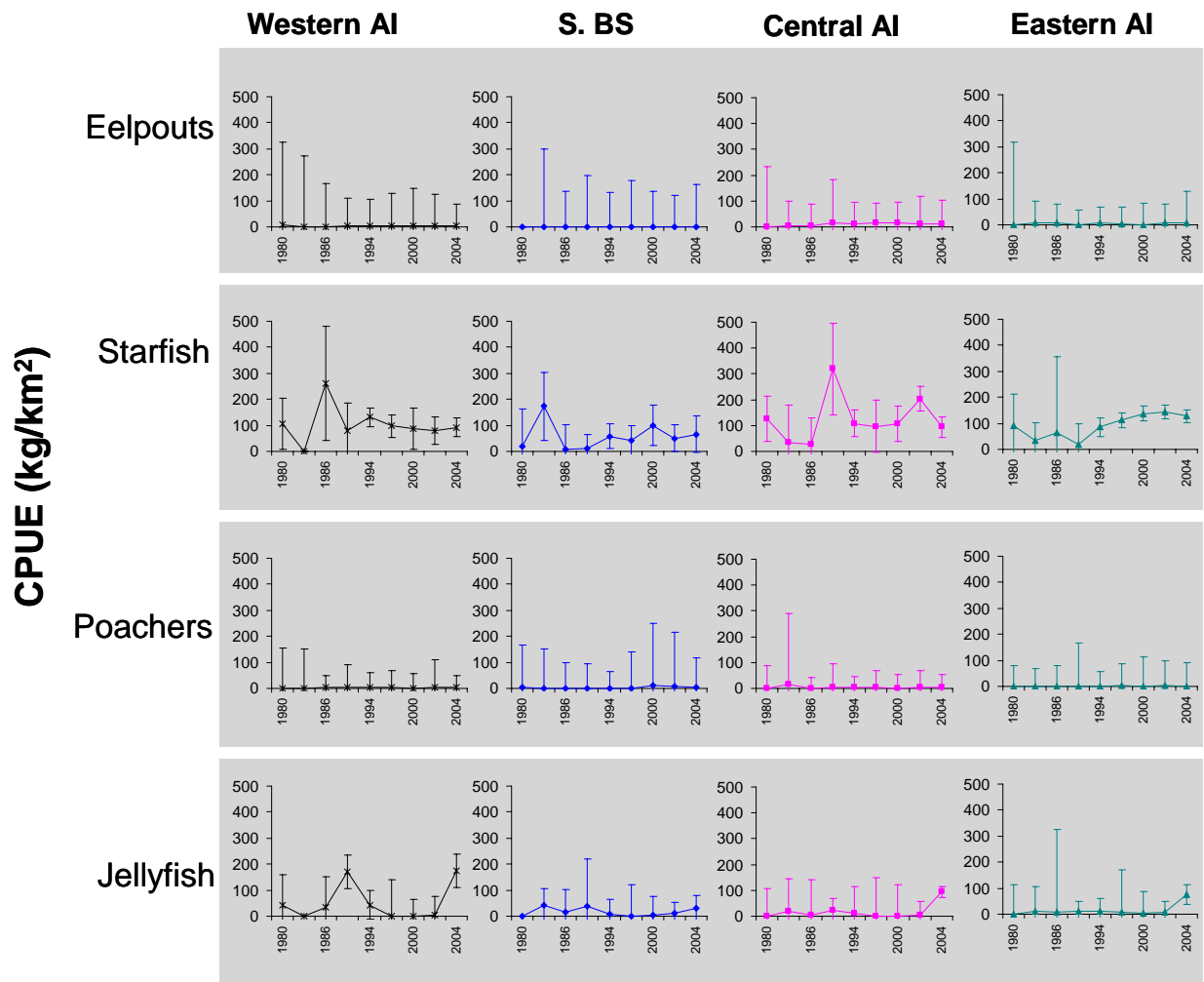
Figure 83. Catch per unit effort of miscellaneous species per unit area in the western Aleutian Islands (AI), southern Bering Sea (BS), central AI, and eastern AI, in bottom trawl surveys conducted between 1980 and 2004. 95% confidence intervals are shown.

Grenadiers in Alaska
David M. Clausen (Auke Bay Laboratory) and Sarah Gaichas (REFM - AFSC)
Last updated: November 2005

INTRODUCTION

Grenadiers (family Macrouridae) are deep-sea fishes related to hakes and cods that occur world-wide in all oceans (Eschmeyer et al. 1983). Also known as "rattails", they are especially abundant in waters of the continental slope, but some species are found at abyssal depths. At least seven species of grenadier are known to occur in Alaskan waters, but only three are commonly found at depths shallow enough to be encountered in commercial fishing operations or in fishery surveys: giant grenadier (*Albatrossia pectoralis*), Pacific grenadier (*Coryphaenoides acrolepis*), and popeye grenadier (*Coryphaenoides cinereus*) (Mecklenburg et al. 2002). Of these, giant grenadier has the shallowest depth distribution and the largest apparent biomass, and hence is by far the most frequent grenadier caught in Alaska. Because of this importance, this report will emphasize giant grenadier, but it will also discuss the other two species. The purpose of this report is to provide a synopsis of biological, fishery, and survey information on these three grenadier species in Alaska, and update the initial grenadier synopsis that was included in last year's Ecosystem Considerations document (Clausen and Gaichas 2004). There is a continued need for such a synopsis for the following reasons: 1) due to their abundance on the continental slope, grenadiers (especially giant grenadier) have an important role in the slope ecosystem; 2) giant grenadier are taken in large numbers as bycatch in longline fisheries; and 3) there was a small exploratory effort in 2005 at directed fishing for giant grenadiers in Alaska, and the potential exists for the development of a larger targeted fishery.

BIOLOGICAL INFORMATION

Geographic and Depth Range

Giant and Pacific grenadier both range from Baja California Mexico around the arc of the north Pacific to Japan, including the Bering Sea (Mecklenburg et al. 2002). Popeye grenadier have a similar range, but in the northeastern Pacific only extend south to Oregon. Depth ranges of the three species are summarized in the following table:

Species	Overall reported depth range (m)	Most abundant depth range in Alaska (m)
Giant	140-3,000[a,b]	400-900[d,e]
Pacific	620-3,000[c]	>800[d,e]
Popeye	225-2,832[a]	>800[d]

[a]Mecklenburg et al. 2002
[b]Tuponogov 1997
[c]Matsui et al. 1990
[d]Figure 84 and Figure 85, this report; see also discussion in "Survey Information" section
[e]Sasaki and Teshima 1988

It should be noted that although survey results for giant grenadier suggest its most abundant depth range is ~400-900 m, almost no sampling has been done >1,200 m, so that abundance in these deeper waters is unknown. A study of research longline catches off California reported that Pacific grenadier were most abundant at depths of about 1,300-1,700 m (Matsui et al. 1990).

Size

Maximum and average size of the three species is very different. Giant grenadier is the largest of all Macrourid species (Iwamoto and Stein 1974) and reaches a maximum total length (TL) of at least 150 cm (Mecklenburg et al. 2002). Pacific and popeye grenadier are much smaller and have maximum TLs of 95 cm (Matsui et al. 1990) and 56 cm (Mecklenburg et al. 2002), respectively. Most popeye are usually less than 45 cm TL (Mecklenburg et al. 2002). One problem with length measurements for all grenadiers is that their long, whip-like tails are frequently broken off when brought to the surface by fishing gear. This renders measurement of TL impossible. To remedy this situation, an alternative length measurement, called "pre-anal fin length" (PAFL), has now been adopted by most scientists when measuring grenadiers (Andrews et al. 1999). PAFL is defined as the length between the tip of the snout and the insertion of the first anal fin ray. Because many of the older measurements have been in TL, Burton (1999) computed a linear regression to describe the relationship between TL and PAFL for a sample of giant grenadier (males and females combined) collected off Kodiak Island, Alaska:

TL = 2.15(PAFL) +25.9, r^2 = 0.93, n = 136, where TL and PAFL are in cm.

The relationship between TL and PAFL for Pacific grenadier is only available for a sample collected off California, Oregon, and Washington (Andrews et al. 1999). The computed relationship (males and females combined) is:

TL = 2.53(PAFL) + 73.0, r^2 = 0.985, n = 128, where TL and PAFL are in mm.

Maximum weight of an individual giant grenadier in a recent Bering Sea trawl was 41.8 kg[1]. The following length-weight relationship has been computed for giant grenadier in the Gulf of Alaska (Britt and Martin 2001) based on data collected in a 1999 trawl survey:

W is weight in grams and PAFL is in mm:
males, $W = 6.033 \times 10^{-4}(PAFL^{2.723})$, n = 22
[2]female, $W = 1.332 \times 10^{-3}(PAFL^{2.597})$, n = 45
combined sexes, $W = 6.193 \times 10^{-4} (PAFL^{2.729})$, n = 67

The only length-weight relationship reported for Pacific grenadier is based on fish sampled off California (Matusi et al. 1990). This study used a different length measurement, anal length (AL), which is defined as the distance between the tip of the snout and the anus. As the anus in Pacific grenadier is located very close to the first anal fin ray, AL is a good approximation of PAFL for this species. The computed relationship is:

W is weight in grams and AL is in mm:
males, $W = 5.107 \times 10^{-6}(AL^{2.251})$, r^2 = 0.81, n = 141
female, $W = 8.879 \times 10^{-7}(AL^{2.579})$, r^2 = 0.92, n = 156

No relationships between TL and PAFL or between length and weight have been reported for popeye grenadier.

Age and Growth

Recent age information for Macrouridae species suggests that most are very long-lived. For example, the roundnose grenadier, *Coryphaenoides rupestris*, an important commercial species in the Atlantic, is

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[1] G. Hoff, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. March 2005.
[2] The reported length-weight relationship for female giant grenadier listed in Britt and Martin (2001) is incorrect. We have recalculated this female length-weight relationship based on the original data which is listed in the NMFS Alaska Fisheries Science Center's "Racebase" trawl survey database.

thought to live up to 70 years (Merrett and Haedrich 1997). Aging studies of giant and Pacific grenadier also indicate that these fish are long-lived.

For giant grenadier, the most recent and comprehensive aging study is that conducted by Burton (1999). This study used otoliths collected from 357 adult fish in the Aleutian Islands, Gulf of Alaska, and off Oregon and California to determine age. Results indicated ages ranged between 13 and 56 years. However, the otoliths were reported to be very difficult to age, and von Bertanlanffy growth curves yielded an unreasonable fit to the size and age data. No analysis was done to determine if ages differed by geographic area. Radiometric aging methods were also applied to the otoliths, and confirmed that giant grenadier live to at least 32 years.

No valid aging study has been done for Pacific grenadier in Alaska, but Andrews et al. (1999) conducted an aging study for this species off the U.S. west coast. Similar to giant grenadier, the study found that Pacific grenadier otoliths were extremely difficult to age. Both immature and adult fish were sampled, and ages ranged from 1 to 73 years. Von Bertanlanffy growth parameters were as follows:

	male	female	combined
L_{inf}	372	268	272
K	0.024	0.040	0.041
t_0	-1.79	0.20	0.25

Radiometric aging was used to confirm the ages in this study, and it verified that Pacific grenadier live to at least 56 years. Another study off California also found that Pacific grenadier are slow-growing and long-lived, and it reported a maximum age of 62 years (Matsui et al. 1990).

There is no reported age and growth information for popeye grenadier.

Life History, Habitat, and Ecological Relationships

Very little is known about the life history of giant grenadier. No fecundity studies have been done. The spawning period is thought to be protracted and may even extend throughout the year (Novikov 1970). Small, juvenile fish less than ~15-20 cm PAFL are virtually absent from bottom trawl catches (Novikov 1970; Ronholt et al. 1994; Hoff and Britt 2003), and juveniles may be pelagic in their distribution. Novikov (1970) states that sexual maturity is reached at about 56 cm TL (= 14 cm PAFL), when the fish assume a more benthic existence, but he gives no data as to how this value was determined or to which sex it applies. In contrast to Novikov's reported size of maturity, the senior author of the present report visually examined over 300 females giant grenadier ovaries in 2004 and 2005[3], and nearly all females less than ~27 cm PAFL were clearly immature. Bottom trawl studies indicate that females and males have different depth distributions, with females inhabiting shallower depths than males. For example, both Novikov (1970) and Britt and Martin (2001) found that nearly all fish <700 m depth were female, and the Novikov study was based on trawl sampling throughout the year. Presumably, some vertical migration of one or both sexes must occur for spawning purposes; Novikov (1970) speculates that females move to deeper water inhabited by males for spawning. Stock structure and migrational patterns of giant grenadier in Alaska are unknown, as no genetics studies have been done, and the fish cannot be tagged because all individuals die due to barotrauma when brought to the surface. One study in Russian waters, however,

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[3] These data were collected in the Gulf of Alaska during the 2004 and 2005 NMFS Alaska Longline Survey and are being analyzed by D. Clausen, National Marine Fisheries Service, Alaska Fisheries Science, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, AK 99801.

used indirect evidence to conclude that seasonal feeding and spawning migrations occur of up "to several hundred miles" (Tuponogov 1997).

The habitat and ecological relationships of giant grenadier are likewise little known and uncertain. Clearly, adults are often found in close association with the bottom, as evidenced by their large catches in bottom trawls. However, based on a study of the food habits of giant grenadier off the U.S. west coast, Drazen et al. (2001) concluded that the fish feeds primarily in the water column. Most of the prey items found in the stomachs were meso- or bathypelagic squids and fish, and there was little evidence of benthic feeding. The squids were primarily gonatids, and identifiable fish included viperfish, deep sea smelts, and myctophids. The study noted that the tissue composition of giant grenadier also suggests a midwater component to their lifestyle, as the muscle tissue of the fish is ~92% water, which would help maintain buoyancy during off bottom excursions. This hypothesis about the tendency of the fish to feed off bottom is supported by observations of sablefish longline fishermen, who report that their highest catches of giant grenadier often occur when the line has been inadvertently "clotheslined" between two pinnacles, rather than set directly on the bottom[4]. Furthermore, Drazen et al. (2001) conclude that giant grenadier is "at the top of the food web on the upper continental slope, and because of (its) abundance, may exert significant pressure on …prey populations". One study of giant grenadier food habits in the Aleutian Islands also found, similar to the Drazen et al. (2001) study, that the primary items consumed were squid and myctophids (Yang 2003).

Pacific sleeper sharks have been documented as predators on giant grenadier (Orlov and Moiseev 1999). According to this study, giant grenadier was ranked third in relative importance as a food item in the diet of these sharks.

Most of the information on Pacific grenadier life history, habitat, and ecological relationships is based on studies off the U.S. west coast. Fecundity of Pacific grenadier was reported to be 23,000-119,000 eggs for one study off Oregon (Stein and Pearcy 1982). Ripe females in this study were collected in April, September, and October. Although very few larvae and juveniles have been captured, they are apparently pelagic, as they have been caught in midwater plankton nets and trawls (Matsui et al. 1990). The juveniles settle to the bottom at a TL of ~80 mm (Stein and Pearcy 1982). Masui et al. (1990) indicate that length at maturity appears to be ~65 cm TL (= 22.8 cm PAFL) for females and ~50 cm TL (= 16.9 cm PAFL) for males. These values seem surprisingly high when one considers the average size of this species, and Stein and Pearcy (1982) report a much smaller size at maturity for females of 46 cm TL (= 15.3 cm PAFL). In contrast to giant grenadier, sexes of Pacific grenadier do not appear to be segregated by depth, and the ratio of males to females is around 1:1 (Stein and Pearcy 1982; Hoff and Britt 2003). No research has been done on stock structure or migrations of Pacific grenadier. Adult Pacific grenadier are believed to be mostly bottom oriented, but a few have been caught "thousands" of meters off the bottom (Mecklenburg et al. 2002). A food study of this species off the U.S. west coast supports the hypothesis that the fish are more benthic in their habitat than are giant grenadier (Drazen et al. 2001). Smaller Pacific grenadier (<20 cm PAFL) in particular fed more on bottom organisms such as polychaetes, cumaceans, mysids, and juvenile tanner crabs (*Chionoecetes* sp.). Larger individuals tended to consume a higher percentage of pelagic prey items such as squid, fish, and bathypelagic mysids, but there was still evidence of epifaunal prey and sediments in their stomachs. The study found that there was a significant difference in diet between Pacific and giant grenadier, which suggests that these species may occupy different ecological niches in the continental slope environment.

Life history, habitat, and ecological information on popeye grenadier is virtually nil. Males were found to be more common than females in a trawl survey of the eastern Bering Sea slope in 2002 (Hoff and Britt

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[4] D. Clausen, National Marine Fisheries Service, Alaska Fisheries Science, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, AK 99801. Pers. observ. October 2004.

2003). One of the reasons for the lack of information on popeye grenadier is that they are very infrequently caught on longlines, probably because of their small size. For example, a total of only 8 popeye grenadier were caught in a 2003 longline survey in Alaska that extensively sampled the continental slope[5]. Longline experiments or surveys are therefore not a useful data source for this species.

Natural Mortality Estimates

There are no published estimates of natural mortality rates for giant, Pacific, or popeye grenadier. To estimate natural mortality for giant and Pacific grenadier, we used the method of Hoenig (1983). This method uses the maximum age of a species in a regression equation to yield an estimate of total mortality. Assuming that stocks of giant and Pacific grenadier in Alaska are lightly fished, total mortality should approximately equal natural mortality. Based on a maximum age of 56 years for giant grenadier and 73 years for Pacific grenadier, (from the studies of Burton (1999) and Andrews et al. (1999), respectively, that were discussed above), Hoenig's method estimates the following natural mortality rates:
  Giant grenadier: 0.074
  Pacific grenadier: 0.057

FISHERY INFORMATION

A commercial fishery for grenadiers, especially roundnose grenadier, has existed for nearly 40 years in the North Atlantic (Merrett and Haedrich 1997). In the early years of this fishery, catches as high as 75,000 mt were taken, but landings quickly declined in later years even though exploitation appeared to be only moderate. Roundnose grenadier stocks appear to have become depleted and have shown little sign of recovery (Atkinson 1995). The history of the roundnose grenadier fishery supports the contention that, because of their longevity and slow growth, grenadiers may be especially vulnerable to fishing pressure, similar to the case for other long-lived species such as rockfish.

In the northeastern Pacific, the only substantial fishery for grenadiers has been directed at Pacific grenadier off California and Oregon. This fishery began around 1990, and catches as high as 1,500 mt were taken in 1996 (Andrews et al.1999). However, catches declined in subsequent years. Although the product recovery ratio for Pacific grenadier is relatively low because of its long, tapered body shape, the meat is firmly textured and has been rated as having a fairly good flavor (Matsui et al. 1990). The same study reported that giant grenadier flesh was rated very poorly because of its watery, soft texture. In Alaska, there have been only two known attempts to develop a fishery for grenadier. The first was an endeavor to process longline-caught giant grenadier for surimi at the port of Kodiak in 1998[6]. This small effort was apparently unsuccessful, as it ended in 1999. The second, also from the port of Kodiak, was a recent exploratory effort in 2005 using trawls to target giant grenadier and develop a fillet and roe market[7]. The success of this second venture, and whether it will continue, remains to be seen. Because of the large biomass of giant grenadier on the continental slope, however, research to develop marketable products from this species is ongoing (Crapo et al. 1999), and it is likely that Alaskan fishermen will continue their efforts at utilizing this species.

Although there has been almost no directed fishing for or retention of grenadiers in Alaska, grenadiers are taken as bycatch in other targeted fisheries and then discarded at sea. None of the discarded grenadiers

[5] C. Lunsford, National Marine Fisheries Service, Alaska Fisheries Science, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, AK 99801. Pers. commun. July 2004.
[6] J. Ferdinand, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. September 2004.
[7] T. Pearson, Kodiak Fisheries Research Center, National Marine Fisheries Service, Sustainable Fisheries, 302 Trident Way, Room 212, Kodiak AK 99615. Pers. commun. October 2005.

survive, as the pressure difference experienced by the fish when they are brought to the surface from deep water invariably causes death.

To determine whether the grenadier bycatch in Alaska is sufficiently high to be of management concern or a risk to stock abundance, an estimate of this bycatch is necessary. At present, all species of grenadier in Alaska are classified as "non-specified species" under the North Pacific Fishery Management Council's (NPFMC) fishery management plans, so there are no limitations on catch or retention, no reporting requirements, and no official tracking of grenadier catch by management. Thus, we had to devise our own method for estimating catches of grenadiers based largely on data from the Alaska Fishery Science Center's Fishery Observer Program. This method essentially was an attempt to simulate the catch estimation algorithm used by the NMFS Alaska Regional Office in what was formerly called their "blend catch estimation system". For details of our methodology, see Gaichas (2002). Results of our grenadier catch estimations are shown in Table 13 and Table 14. It should be noted that portions of the data in these tables were previously presented in NPFMC Stock Assessment and Fishery Evaluation Reports (Gaichas 2002; Gaichas 2003). Unfortunately, the data have to be presented as "grenadiers, all species combined", because observers were not instructed to identify individual grenadier species[8]. Also, one important caveat is that the catch estimates for the Bering Sea and Aleutian Islands (BSAI) may be more accurate than those for the Gulf of Alaska (GOA). In our catch estimation process, we assume that grenadier catch aboard observed vessels is representative of grenadier catch aboard unobserved vessels. This is a possible problem because observer coverage in the BSAI fisheries is considerably higher than those in the GOA. In general, smaller vessels fish in the GOA, especially in longline fisheries, and many of these vessels are not required to have observers, which could introduce a bias into the GOA estimates.

The estimated annual catches of grenadier in Alaska have been substantial in recent years (Table 13). Total annual catches have ranged between ~4,000-8,000 mt in the BSAI, and between ~10,000-15,000 mt in the GOA. To put these catches in perspective, the total annual sablefish catch in Alaska in the years 1996-2001 ranged from about 13,600 to 17,600 mt (Sigler et al. 2003). Thus, more grenadier were caught and discarded in these years than the amount of sablefish taken. The overwhelming majority of the grenadier catch (>90%) in each region and each year was apparently taken by longline gear, and the rest was mostly caught by bottom trawl (Table 13).

Unfortunately, we have not been able to estimate grenadier catches for years after 2002. This is because the NMFS Alaska Regional Office changed their catch-estimating algorithms in 2003, and the new methodology has not been amenable for estimating catches of non-target or non-specified species. These algorithms are presently being modified by Regional Office staff, and it is expected that catch estimates of non-target species will be available in future years[9].

Most of the grenadier catch in the GOA has been taken in the sablefish fishery, whereas in the BSAI, it has come from both the sablefish and the Greenland turbot fishery (Table 14). The sablefish and Greenland turbot fisheries in Alaska are predominately longline fisheries, which explains the large percentage of grenadier taken in longline gear that is shown in Table 13. Besides the sablefish and Greenland turbot fisheries, other targeted fisheries that have taken grenadier in much smaller amounts include fisheries for deepwater flatfish, Pacific cod, and Pacific ocean perch in the GOA, and for Pacific cod and Pacific ocean perch in the BSAI. Also, data presented in Gaichas (2002) and Gaichas (2003) for

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[8] This problem has been corrected for observations of giant grenadier in the 2005 fishery. Observers are now instructed to note catches of giant grenadier (an easy species to identify), although catches of Pacific and popeye grenadier will still be lumped together.
[9] M. Furuness, National Marine Fisheries Service, Alaska Regional Office, Sustainable Fisheries, 709 W. 9th St., Juneau AK 99802. Pers. commun. October 2005.

2000-2002 in the BSAI indicate that in the Aleutian Islands, most of the grenadier catch comes from the sablefish fishery, but in the eastern Bering Sea is taken predominately in the Greenland turbot fishery.

Although the species breakdown of the grenadier catch is unknown, we surmise that giant grenadier comprise by far the majority of the fish caught, for two reasons:

1. As indicated in Table 14, most of the grenadier catch in Alaska comes from the sablefish fishery. Although there are no data that summarize the depth distribution of this fishery, sablefish abundance in Alaska is usually low in depths >1,000 m[10], and it is likely that little or no commercial effort for sablefish occurs at these depths. Instead, the fishery is probably focused at depths of 400-800 m, where longline surveys have generally found the highest catch rates of sablefish (Zenger and Sigler 1992). Bottom trawl and longline surveys all show that very few Pacific and popeye grenadier are found shallower than 800 m deep, whereas giant grenadier are abundant in these depths (see "Survey Information" section in this report). Hence, we can use this indirect evidence to conclude that giant grenadier are the predominate species in the grenadier catch.

2. As indicated in Table 13, nearly all the grenadier catch is taken by longline gear. As mentioned previously, very few popeye grenadier are caught on longlines because of the small size of these fish. Therefore, we can rule out popeye grenadier as a significant component of the grenadier catch.

SURVEY INFORMATION

Fishery-independent surveys of the continental slope off Alaska have been conducted since the late 1970s using both bottom trawls and longlines. Area-wide biomass estimates are computed from the trawl surveys, whereas indices of abundance are computed from the longline surveys.

Trawl Surveys

There have been many NMFS trawl surveys in the eastern Bering Sea (EBS), Aleutian Islands (AI), and GOA since 1979, but relatively few have extended deep enough on the continental slope to yield meaningful biomass estimates for grenadier. For example, several surveys of the AI and GOA have sampled only to 500 m; thus, they barely entered the abundant depth range of giant grenadier and were well above the depths inhabited by Pacific and popeye grenadier. Giant grenadier biomass estimates for those surveys that have extended to 800 m or deeper are listed in Table 15. Prior to the early 1990s, it is believed that survey scientists did not always correctly identify Pacific and popeye grenadier in AI and GOA surveys, so biomass estimates for these species in these surveys have not been included in this report. Also, the earlier Bering Sea surveys (1979-1991) usually identified grenadiers only to the level of family, and it is these combined estimates that are listed in Table 15.

The biomass estimates indicate that sizeable populations of giant grenadier are found in each of the three regions surveyed, but the survey time series are too intermittent to show any trends in abundance. Highest estimates of giant grenadier biomass in each region were 667,000 mt in the EBS (2004), 601,000 mt in the AI (1986), and 587,000 mt in the GOA (2005). In the EBS, the biomass estimates for 1979-1991 appear to be unreasonably low compared to the biomass estimates in 2002 and 2004. Given the apparent longevity and slow growth of giant grenadier, it is unlikely that its biomass could have increased

[10] M. Sigler, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau AK 99801. Pers. commun. October 2004.

nearly six-fold from 74,000 mt in 1991 to 426,000 mt in 2002. The EBS slope surveys in 2002 and 2004 are considered to be better than their predecessors because they were the only ones specifically designed to sample the continental slope, they trawled deeper water (to 1,200 m) that encompassed more of the depth range of grenadiers, and they had good geographical coverage in all areas[11]. Also, in comparison to the steep and rocky slopes of the AI and GOA, the EBS slope is much easier to sample with a bottom trawl, which means a trawl survey in the latter region may yield more reliable results. Therefore, the biomass estimates in the EBS in 2002 and 2004 may be the most valid of any of the surveys in Table 15.

One factor that could have a significant effect on the biomass estimates is the extent that giant grenadier move off bottom. As discussed, there is indirect evidence from feeding studies that giant grenadier may be somewhat pelagic in their search for prey. If so, some of the population may be unavailable to the bottom trawl, which would result in an underestimate of biomass.

Results of the more recent trawl surveys in the EBS and GOA can be examined to determine the comparative biomass of the three grenadier species (Table 16; Figure 84). In the GOA in 1999 and 2005, giant grenadier was by far the most abundant species and comprised 94% and 96%, respectively, of the aggregate grenadier biomass. Next in abundance was popeye grenadier, followed by Pacific grenadier. In the EBS surveys in 2002 and 2004, giant grenadier also greatly predominated, comprising 89% and 93% of the aggregate biomass, respectively.   Similar to the GOA, popeye grenadier was second in biomass, followed by Pacific grenadier. Popeye grenadier biomass was considerably larger in both EBS surveys than in the GOA survey, which may be partially due to the fact that the EBS surveys sampled deeper water to 1,200 m, whereas the GOA survey only went to a maximum depth of 1,000 m.

The recent trawl surveys also provide information on the depth distribution of grenadiers in the EBS and GOA (Figure 84 and Figure 85). The surveys indicated that in both regions, giant grenadier accounted for nearly all the grenadier biomass at depths less than ~600-700 m, whereas Pacific and popeye grenadier did not become moderately abundant until deeper depths. The 2002 and 2004 EBS surveys showed giant grenadier biomass peaked at depths 400-1,000 m, and then declined at the 1,000-1,200 m depth stratum. Highest giant grenadier CPUE in the EBS surveys was at 600-1,000 m. The 1999 and 2005 GOA surveys were generally similar and indicated biomass and CPUE of giant grenadier was relatively high at depths 300-1,000 m, with a pronounced peak in CPUE at the 500-700 depth stratum. However, because the GOA surveys did not extend beyond 1,000 m, the abundance of giant grenadier in these deeper GOA waters is unknown.

Population size compositions for giant grenadier from the recent trawl surveys indicate that the fish are considerably larger in the EBS (Figure 86). For example, in the 2004 EBS survey, mean length was 28.1 cm, compared to 25.9 cm in the 2005 GOA survey. In the EBS, a much greater percentage of the population appears to consist of fish >30 cm in length.

Results of the trawl surveys emphasize the important ecological role of giant grenadier in Alaskan waters. In a ranking of all species caught in the 1999 GOA trawl survey, giant grenadier was the fifth most abundant species in terms of CPUE, after arrowtooth flounder, Pacific ocean perch, walleye pollock, and Pacific halibut (Britt and Martin 2001). It should be noted that this survey covered both the continental shelf and slope; if we consider just the slope deeper than 400 m, giant grenadier was the number one species in CPUE. Likewise, the EBS surveys in 2002 and 2004 (which sampled only the slope) both ranked giant grenadier first in biomass among all species caught (Hoff and Britt 2003; Footnote[12]).

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[11] G. Walters, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. October 2004.
[12] G. Walters, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. October 2004.

Longline surveys of the continental slope off Alaska have been conducted annually since 1979 (Sigler et al. 2004). The primary purpose of these surveys is the assessment of sablefish abundance, and the standard depth sampled is 200-1,000 m. An index of relative biomass, called the "relative population weight" (RPW), is computed for all the major species caught in the survey. However, RPW values for giant grenadier are only available for the years since 1990[13]. Other measures of giant grenadier abundance in the surveys have been computed for the years 1979-1989, including catch-per-unit-effort values and an index of abundance by number, called "relative population number". These data for the surveys before 1990 are presented in Sasaki and Teshima (1988) and Zenger and Sigler (1992), but will be not be discussed in this report.

In the GOA and AI, the longline gear used in the surveys is able to sample a high proportion of the steep and rocky habitat that characterizes the slope in these regions. This is in contrast to bottom trawls used on the trawl surveys, which are often limited to fishing on relatively smooth substrate. Because of this difference, the longline surveys may do a better job of monitoring abundance of giant grenadier on the slope, although they do not provide estimates of absolute biomass.

The RPWs provide a standardized time series of annual abundance for giant grenadier in the GOA for the period 1990-2005 and an intermittent series in the eastern AI and EBS (Table 17). The survey was expanded from the GOA into the eastern AI in 1996 and to the EBS in 1997, but these latter two regions have only been sampled in alternating years since. Therefore, the time series is much less complete for the eastern AI and EBS. In the GOA, definitive trends in RPW are difficult to discern. Generally, however, RPW decreased in the first three years to a low of 800,000, then increased to a high in 1997 of 1,420,000, and finally diminished again to a low of 900,000 in 2004. A rigorous analysis of the data will be required to determine whether the trends are statistically valid, such as the methods used by Sigler and Fujioka (1988) to analyze changes in the survey's RPWs for sablefish. The RPW values in Table 17 also indicate that giant grenadier are particularly abundant in the eastern AI; in 2000, 2002, and 2004, RPWs in this region were equal to or greater than those in the GOA, even though the area of the slope is much larger in the GOA.

Giant grenadier catch rates in the surveys can be used to examine the geographic distribution of abundance in more detail (Table 18). Highest catch rates are consistently seen in the eastern AI, Shumagin and Chirikof areas, and Bering areas 3 and 4, which are located NW of the Pribilof Islands. In the GOA, there appears to be a definite decline in catch rates as one progresses from the west (Shumagin area) to the east (Southeast area). The 1999 and 2005 GOA trawl surveys also showed a similar trend and found very low catch rates and biomass estimates in the eastern GOA (Britt and Martin 2001; Footnote[14]).

Population length frequency distributions for giant grenadier in the longline surveys were generally largest in the EBS, intermediate in the eastern AI, and smallest in the GOA (Figures 87-89). This difference in size between the EBS and the GOA agrees with that found in the recent trawl surveys of these two regions, which were discussed previously in this report. The length distributions of the longline surveys in the EBS tend to be spread over more lengths and include more large fish >35 cm PAFL (Figure 88). All three regions have shown a decline in size since about 2000, with the most recent surveys (2005 for the GOA and EBS and 2004 for the eastern AI) showing the smallest mean length for any year in the

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[13] C. Lunsford, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, AK 99801. Pers. commun. July 2004.

[14] Unpubl. data for 2005 GOA trawl survey in NMFS Alaska Fisheries Science Center's "Racebase" trawl survey database, Oct. 2005.

time series. In particular, the GOA distribution has become skewed toward smaller fish in recent years, and mean length has declined from 30.9 cm in 2000 to 27.9 cm in 2005 (Figure 87). Preliminary analysis of the longline survey data suggests that this decrease in size in the GOA has been mostly caused by increased numbers of small fish, although a decline in the numbers of large fish has also occurred[15]. Further analysis is needed, however, to better understand the reasons for this decrease.

A comparison between Figure 86 (size compositions for the GOA and EBS trawl surveys) and Figure 87 and Figure 88 (size compositions for the GOA and EBS longline surveys) reveals that the size distributions were consistently smaller for giant grenadier in the trawl surveys. For example, mean length in the 1999 GOA trawl survey was 24.9 cm, whereas it was 30.4 cm in that year's GOA longline survey. This indicates that there is a substantial difference in the size selectivity between the gear types used in each survey. It appears that the longline surveys are not sampling many of the smaller giant grenadiers less than ~25 cm PAFL that are taken in the trawl surveys.

The depth distribution of the RPW for giant grenadier was remarkably consistent in the last four GOA longline surveys (Figure 90). RPW was relatively high for each of the three deepest strata sampled in these surveys: 401-600 m, 601-800 m, and 801-1,000 m, with the peak at 801-1,000. These data indicate that additional sampling needs to be done at depths >1,000 m to determine where the abundance of giant grenadier begins to decline. The data also suggest that an unknown and perhaps significant portion of the giant grenadier population in the GOA may reside in depths beyond 1,000 m that are not currently surveyed. These depth results are similar to those depicted in Figure 84 for the 1999 GOA trawl survey, which also showed a large biomass of giant grenadier extending to at least 1,000 m. The longline depth distributions, however, are somewhat different than that seen in the 2005 GOA trawl survey, which indicated a considerable decline in biomass at depths >700 m.

A possible factor that may have influenced the survey's catch rates for giant grenadier is competition amongst species for baited hooks. Zenger and Sigler (1992) suggest that giant grenadier may be out-competed on the longline by more energetic fish such as sablefish. If sablefish are more quickly attracted to and caught on the hooks, or are able to drive away giant grenadier when both species are competing for the hooks, the survey's catch rates for giant grenadier would not be a true indicator of their abundance. This could be a partial explanation for the survey's high catch rates of giant grenadier in the EBS and eastern AI, as the relatively low abundance of sablefish in these two regions could result in a greater number of unoccupied hooks available for catching giant grenadier. To investigate the problem of possible competition for hooks in the longline survey, additional analysis and possibly experimental studies are needed.

CONCLUSIONS

Of the three common species of grenadier in Alaska, only giant grenadier appears to warrant management concern at present. Concern for the other two species, Pacific and popeye grenadier, could only arise if fishing operations develop in the future at depths >1,000 m, where nearly all the population of these two species live. Survey information indicates that giant grenadier are the most abundant fish on the continental slope at depths 400-1,000 m in all surveyed areas of Alaska except the eastern Gulf of Alaska. As such, they have a significant role in the slope ecosystem and are important predators in this habitat. Although there has been almost no directed fishing for giant grenadiers in Alaska, substantial numbers are taken as bycatch and discarded in the sablefish and Greenland turbot longline fisheries. Estimated annual catches of giant grenadier in Alaska may have ranged between 13,000 mt and 21,000 mt in the years 1997-2001. The large biomass of giant grenadier in Alaska may be able to support this level of catch, but

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[15] D. Clausen, National Marine Fisheries Service, Alaska Fisheries Science, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, AK 99801. Pers. observ. October 2005.

the reported longevity and slow growth of this species makes it susceptible to overfishing. Furthermore, a high proportion of the catch is likely female because mostly female giant grenadier live at the depths where the commercial fishery operates. Disproportionate removal of females by the fishery could put stocks of giant grenadier at greater risk. One possible mitigating factor that may protect giant grenadier from overfishing is that a substantial portion of its population may inhabit depths >1,000 m, where they are safe from any fishing pressure. These deep waters would act as a *de facto* reserve to replenish giant grenadier removed by the fishery in shallower water. Further analyses of fishery and survey data for giant grenadier are needed, as well as additional biological studies, to better determine the population dynamics of this species.

Table 13. Estimated commercial catch (mt) of grenadier (all species combined) in the eastern Bering Sea and Aleutian Islands and Gulf of Alaska, 1997-2002, by gear type. (n.a. = data not available).

Gear	1997	1998	1999	2000	2001	2002[a]
Eastern Bering Sea and Aleutian Islands						
Bottom trawl	214	241	132	359	198	242
Pelagic trawl	36	41	79	33	11	-
Pot	0	0	0	6	7	15
Longline	5,602	6,307	7,177	6,923	3,538	7,909
Total	5,852	6,589	7,388	7,321	3,754	8,166
Gulf of Alaska						
Bottom trawl	965	655	529	n.a.	n.a.	n.a.
Pelagic trawl	28	5	81	n.a.	n.a.	n.a.
Pot	0	0	0	n.a.	n.a.	n.a.
Longline	11,037	14,023	10,777	n.a.	n.a.	n.a.
Total	12,029	14,683	11,388	11,610	9,685	n.a.
All Alaska, All Gears Combined						
Grand Total	17,881	21,272	18,776	18,931	13,430	n.a.

[a]For the eastern Bering Sea and Aleutian Islands in 2002, the catch listed as "bottom trawl" includes bottom trawls and pelagic trawls combined.

Table 14. Estimated commercial catch (mt) of grenadier (all species combined) in the eastern Bering Sea/Aleutian Islands and Gulf of Alaska, 1997-1999, by target fishery.

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

Table 15. Estimated biomass (mt) of giant grenadier in NMFS trawl surveys in Alaska that sampled the upper continental slope.

Year	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska
1979	91,500[a]	-	-
1980	-	313,480	-
1981	90,500[a]	-	-
1982	104,700[a]	-	-
1983	-	349,538	-
1984	-	-	169,708
1985	107,600[a]	-	-
1986	-	600,656	-
1987	-	-	135,971
1988	61,400[a]	-	-
1989	-	-	-
1990	-	-	-
1991	73,520[a]	-	-
1992	-	-	-
1993	-	-	-
1994	-	-	-
1995	-	-	-
1996	-	-	-
1997	-	-	-
1998	-	-	-
1999	-	-	386,294
2000	-	-	-
2001	-	-	-
2002	426,397	-	-
2003	-	-	-
2004	666,508	-	-
2005	-	-	587,346

[a]Estimates are for all species of grenadiers combined

Notes and data sources:
a) Eastern Bering Sea: Depths sampled were to 1,000 m in 1979, 1981, 1982, and 1985; to 800 m in 1988 and 1991; and to 1,200 m in 2002 and 2004. Data sources: 1979 to 1988, Bakkala et al. (1992); 1991, Goddard and Zimmerman (1993); 2002, Hoff and Britt (2003); 2004, data on the Alaska Fisheries Science Center's "Racebase" trawl survey database, available from National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115.
b) Aleutian Islands: Depths sampled were to 900 m in each survey. Data source: Ronholt et al. (1994).
c) Gulf of Alaska: Depths sampled were to 1,000 m in each survey. Data sources: 1984, 1987, and 2005, data on the Alaska Fisheries Science Center's "Racebase" trawl survey database, available from the National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle, WA 98115; 1999, Britt and Martin (2001).

Table 16. Comparative biomass estimates (mt) for the three common grenadier species in recent NMFS trawl surveys in Alaska that sampled the upper continental slope.

Region	Year	Giant grenadier	Pacific grenadier	Popeye grenadier
Gulf of Alaska	1999	386,294	8,240	16,260
Gulf of Alaska	2005	587,346	2,252	21,297
Bering Sea	2002	426,397	2,461	50,329
Bering Sea	2004	666,508	4,039	44,361

Table 17. Giant grenadier relative population weight, by region, in NMFS longline surveys in Alaska, 1990-2005. Dashes indicate years that the eastern Bering Sea or eastern Aleutian Islands were not sampled by the survey. Gulf of Alaska values include data only for the upper continental slope and do not include continental shelf gullies sampled in the surveys.

Year	Eastern Bering Sea	Eastern Aleutians[a]	Gulf of Alaska
1990	-	-	1,069,723
1991	-	-	959,567
1992	-	-	805,356
1993	-	-	1,148,754
1994	-	-	1,133,409
1995	-	-	1,402,019
1996	-	879,550	1,251,843
1997	840,693	-	1,418,428
1998	-	910,625	1,185,404
1999	632,379	-	1,277,141
2000	-	1,214,191	1,230,161
2001	431,114	-	1,198,183
2002	-	1,233,988	1,011,721
2003	592,467	-	1,194,939
2004	-	1,202,491	903,906
2005	771,441	-	943,662

[a]Aleutian Islands east of 180° west longitude.

Table 18. Giant grenadier catch rates (number caught per 100 hooks), by area, in NMFS longline surveys in Alaska, 1990-2005. Dashes indicate areas or years in the Bering Sea and Aleutian Islands that were not sampled by the survey. Overall catch rates for combined areas or years are not available at this time.

Area	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Bering 4	-	-	-	-	-	-	-	26.1	-	22.3	-	8.0	-	13.3	-	25.9
Bering 3	-	-	-	-	-	-	-	27.0	-	23.0	-	14.5	-	26.5	-	28.4
Bering 2	-	-	-	-	-	-	-	10.7	-	7.7	-	7.0	-	7.2	-	10.2
Bering 1	-	-	-	-	-	-	-	1.9	-	0.2	-	1.6	-	1.3	-	1.6
NE Aleutians	-	-	-	-	-	-	12.8	-	10.2	-	17.8	-	21.0	-	25.3	-
SE Aleutians	-	-	-	-	-	-	22.8	-	25.3	-	28.2	-	27.9	-	24.6	-
Shumagin	22.1	21.8	19.4	24.2	25.5	30.1	21.5	27.9	31.6	24.4	24.7	26.5	28.3	26.6	27.6	25.4
Chirikof	22.1	17.8	19.3	21.8	20.4	28.4	27.4	28.3	17.1	22.2	21.0	24.4	15.4	26.6	16.7	19.7
Kodiak	10.4	8.4	6.5	7.6	10.9	13.8	16.1	16.9	11.7	17.5	13.4	13.1	11.6	15.4	8.2	14.5
W Yakutat	5.8	4.3	3.6	5.9	3.9	6.0	4.5	9.8	7.7	8.8	9.1	8.7	3.4	7.6	4.9	8.3
E Yakutat	2.4	3.2	2.3	3.3	2.0	4.0	4.1	3.2	4.1	3.9	3.3	3.6	4.6	5.1	3.8	4.0
Southeast	1.4	1.4	1.8	1.6	1.7	2.8	2.4	2.6	3.6	5.5	4.3	5.2	4.8	3.2	2.6	3.2
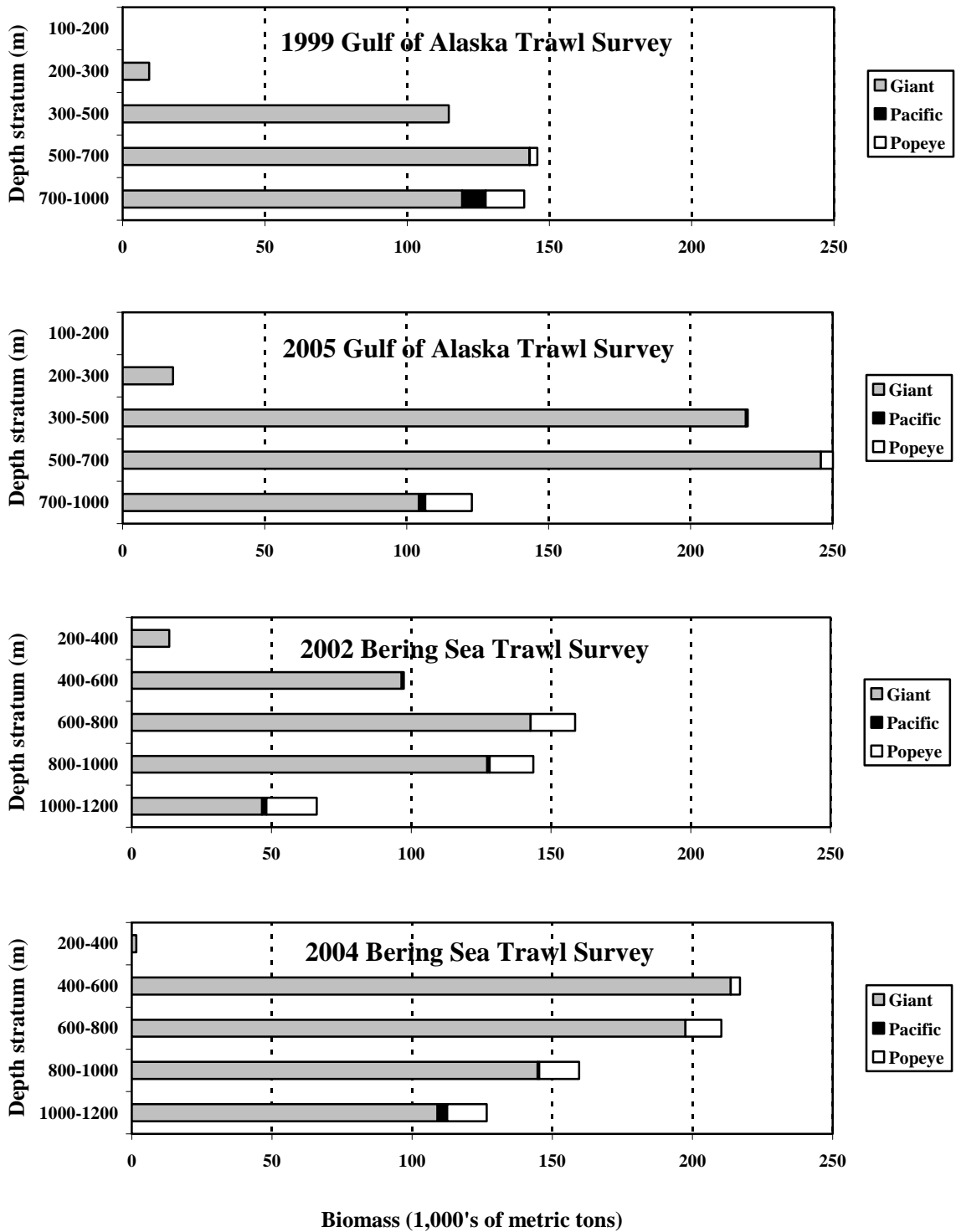
Figure 84. Depth distribution of giant, Pacific, and popeye grenadier biomass estimates in the 1999 and 2005 Gulf of Alaska trawl surveys and the 2002 and 2004 eastern Bering Sea slope trawl surveys. Note: depth strata shown for each survey are not the same because the surveys had different stratification schemes for depth.
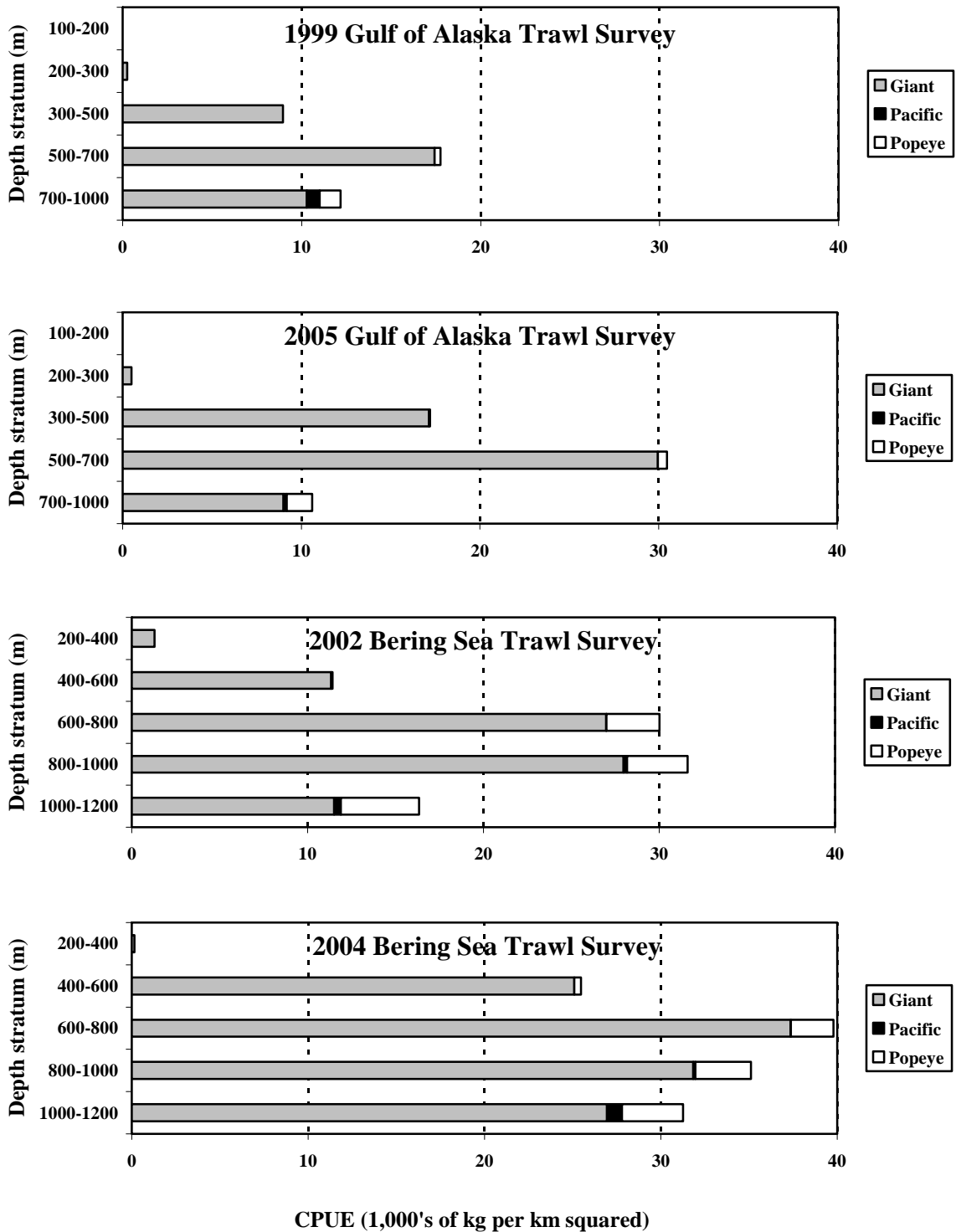
Figure 85. Depth distribution of giant, Pacific, and popeye grenadier catch per unit effort (CPUE) in the 1999 and 2005 Gulf of Alaska trawl surveys and the 2002 and 2004 eastern Bering Sea slope trawl surveys. Note: depth strata shown for each survey are not the same because the surveys had different stratification schemes for depth.
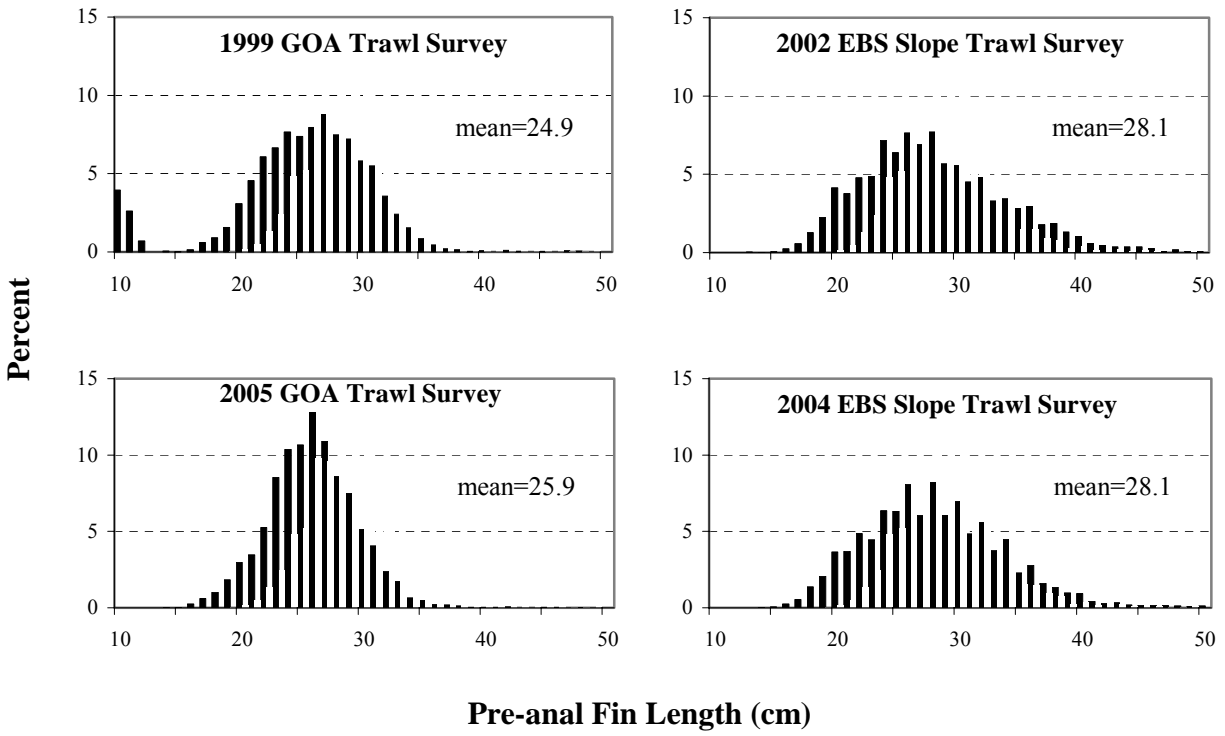
Figure 86. Estimated population size compositions for giant grenadier in recent Alaskan trawl surveys. (GOA = Gulf of Alaska and EBS = Eastern Bering Sea).

Pre-anal Fin Length (cm)
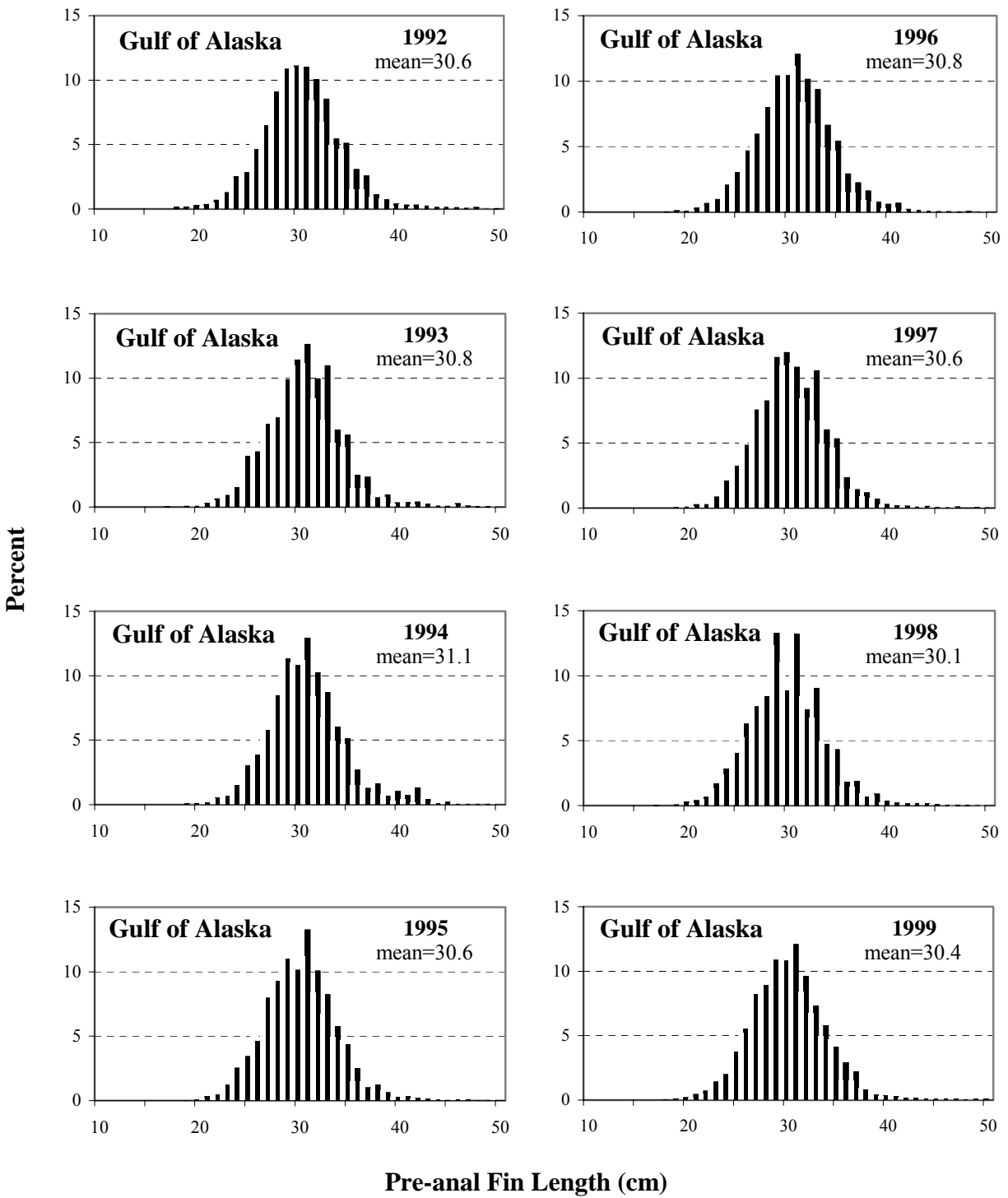
Figure 87. Estimated population size compositions for giant grenadier in the 1992-2005 longline surveys of the Gulf of Alaska. (Figure continued on next page).

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Percent (y-axis label)

Pre-anal Fin Length (cm)
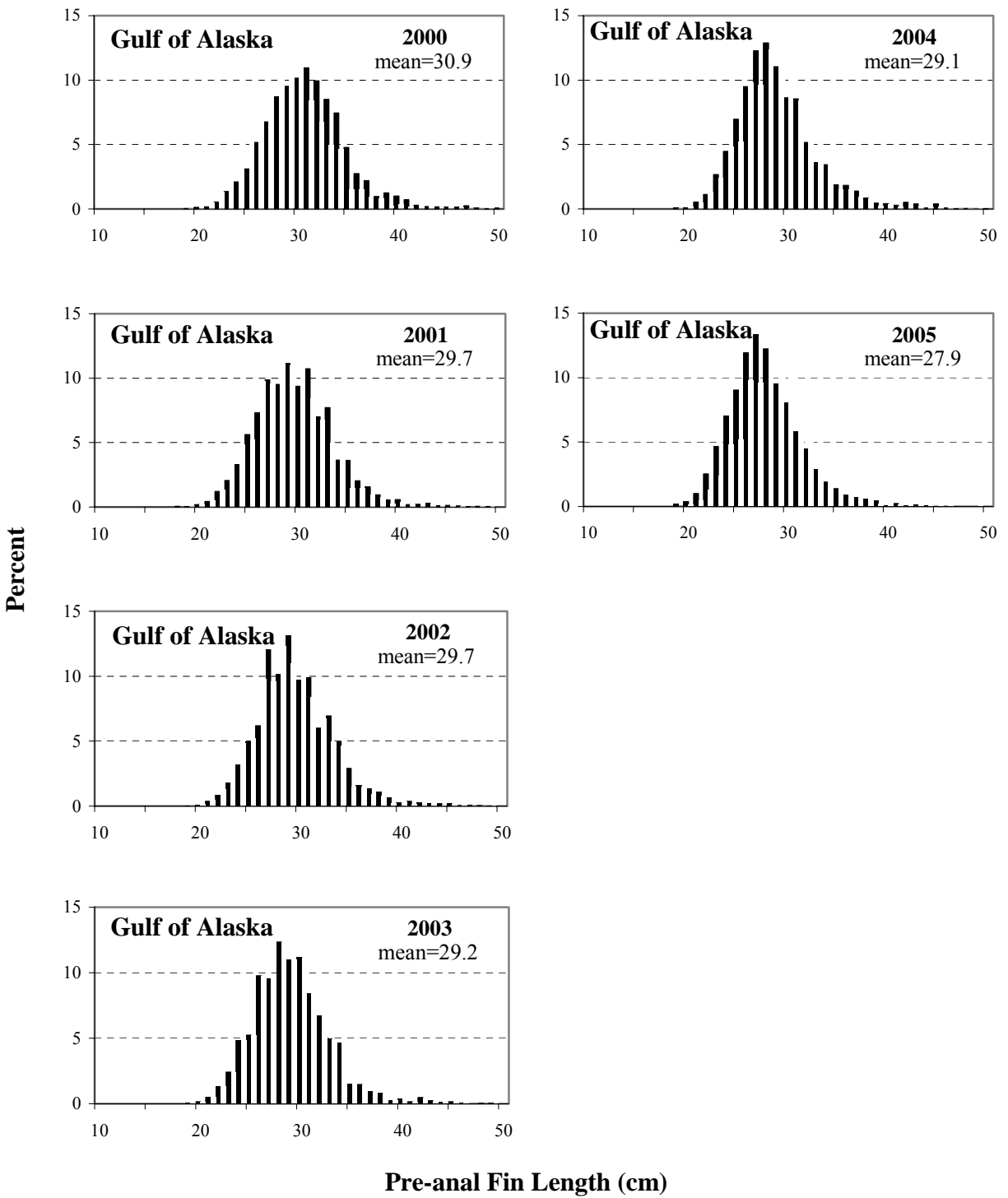
Figure 87. (continued from preceding page).

Percent

Pre-anal Fin Length (cm)
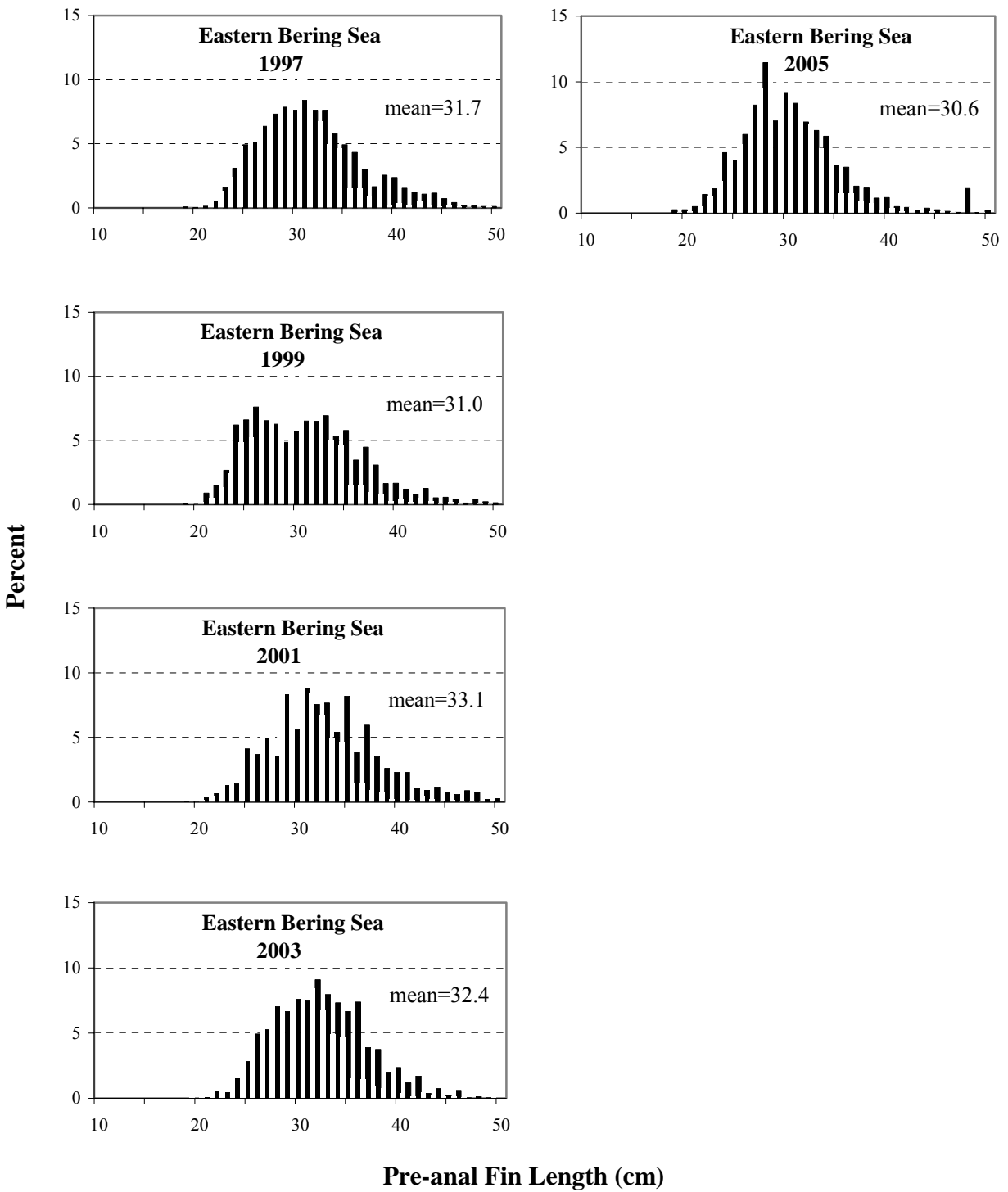
Figure 88. Estimated population size compositions for giant grenadier in the 1997-2005 longline surveys
    of the Eastern Bering Sea.
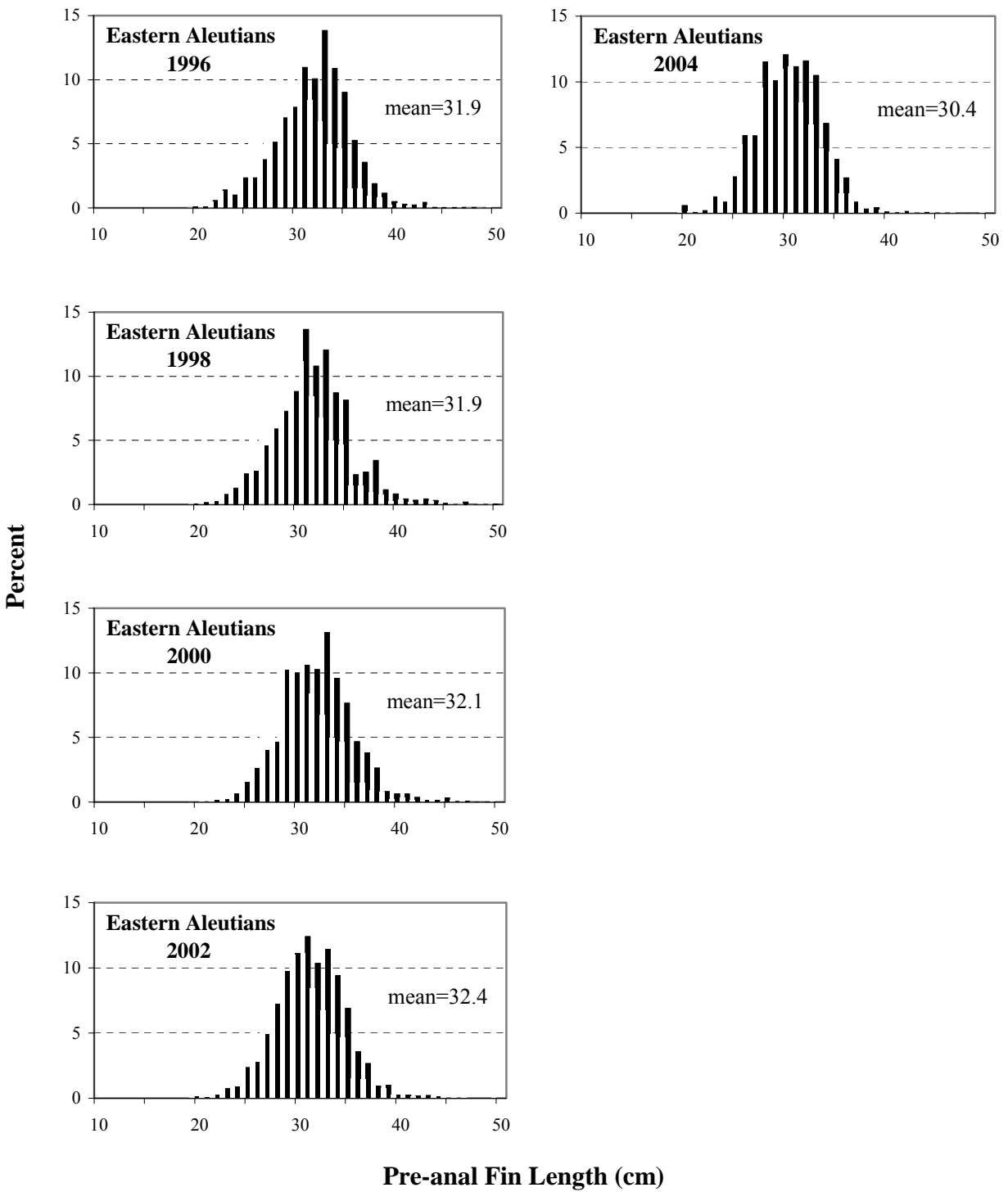
Figure 89. Estimated population size compositions for giant grenadier in the 1996-2004 longline surveys of the Eastern Aleutian Islands.

200
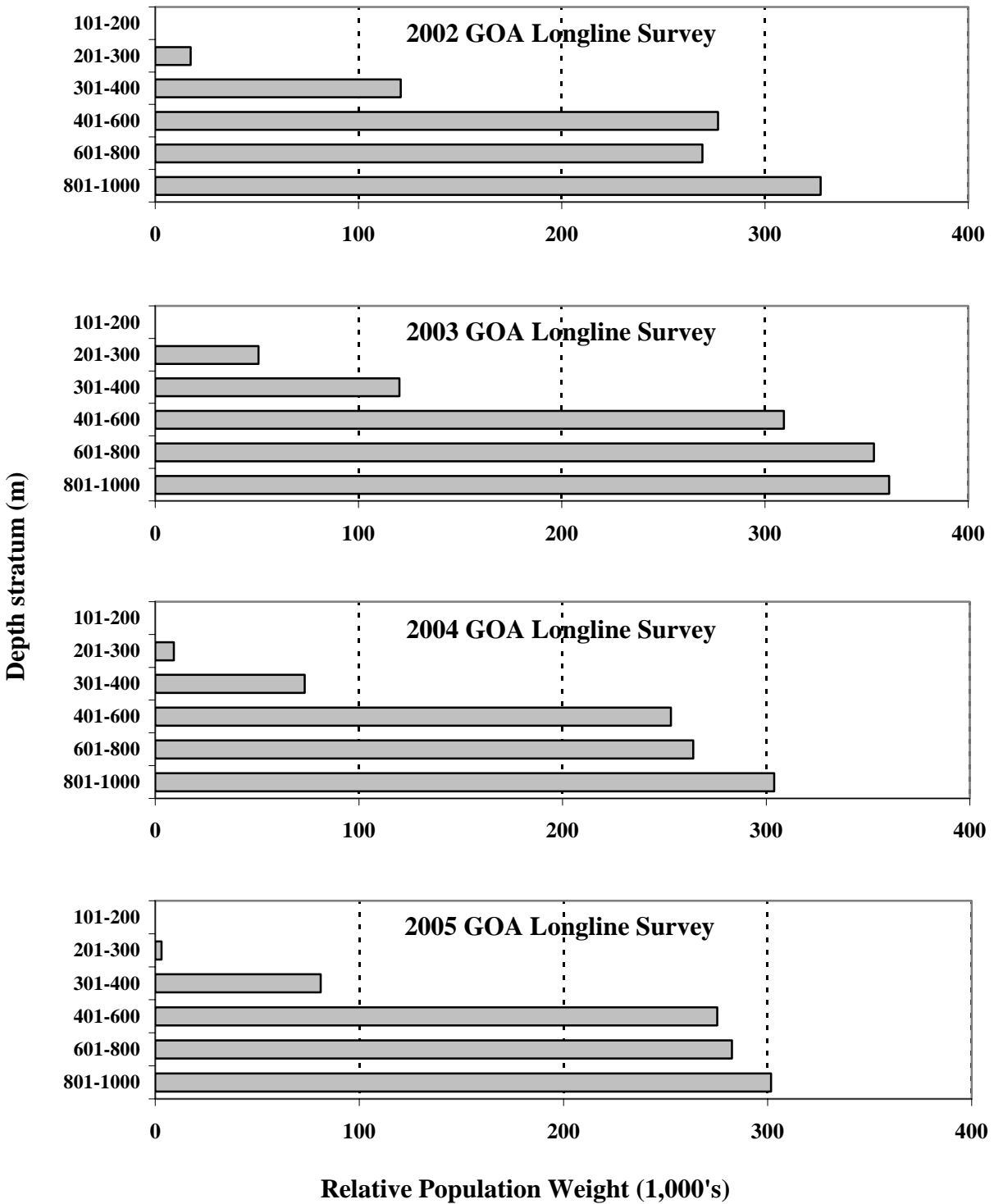
Figure 90. Depth distribution of giant grenadier relative population weight in the 2002-2005 longline surveys of the Gulf Alaska (GOA).

Marine Mammals
Contributed by NMFS National Marine Mammal Lab Staff, AFSC
Edited by E. Sinclair and J.W. Testa, NMFS, National Marine Mammal Lab
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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 2003 is provided.

PINNIPEDS
Steller sea lion (*Eumetopias jubatus*)

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 50% - 60% during the previous 10 – 15-year period. Several years later, 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 long. (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, remains classified as threatened. Population assessment for Steller sea lions is currently achieved by aerial surveys of non-pups and on-land pup counts.

An 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. This was the first complete survey conducted using medium format, vertical photogrammetric techniques. In previous years, counts of adult and juvenile (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 a series of 'trend' sites that have been consistently surveyed since the mid-1980s. The 2002 counts were made from 35 mm slides as opposed to the medium format photographic technique first used in 2004. Subtracting the 3-4% increase due to film format differences, NMFS estimates that the western Steller sea lion population increased approximately 6-7% from 2002 to 2004. This is similar to the rate of increase observed between 2000 and 2002 when standard 35mm slide techniques were used (Figure 91).

There were regional differences in the trends observed between 2002 and 2004. Trend site counts increased between 2002 and 2004 in the three Aleutian Islands sub-areas (Western, Central and Eastern) and in the western Gulf of Alaska, from the Shumagin Islands through Unimak Pass (Figure 91 and Figure 92). However, in the eastern portion of the range of the western Steller sea lion population, trend

site counts remained stable (near Prince William Sound in the eastern Gulf of Alaska) or decreased (around Kodiak Island in the central Gulf of Alaska).

A slightly different pattern of trends is revealed when a longer time series of sub-area counts since 1989 are examined (Table 19). 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 1989-2004, 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. Since then, counts increased in the Eastern Gulf of Alaska, but continued to decline, at a slower rate, in the Central Gulf of Alaska. 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 increases in the rate of predation by killer whales.
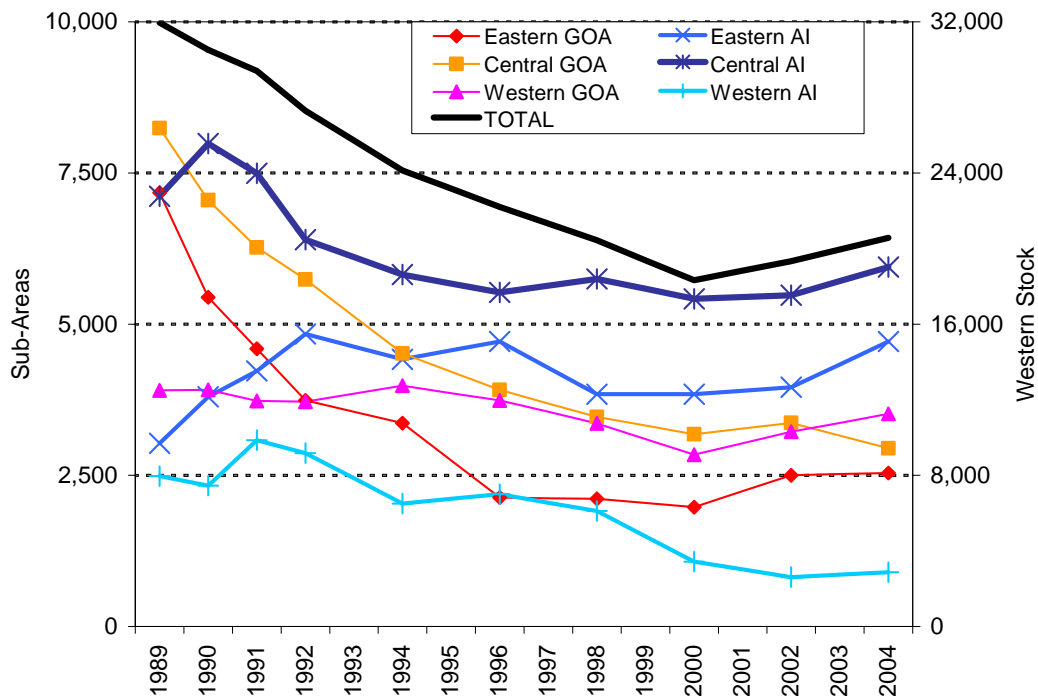
Figure 91. Counts of non-pup (adult and juvenile) Steller sea lions on rookery and haulout trend sites in the range of the western population from 1989-2004. Counts are aggregated by sub-area (left axis) in the Gulf of Alaska (GOA) and Aleutian Islands (AI) and for the entire western Alaskan population (TOTAL; right axis). Surveys in 1989-2002 used 35 mm oblique slides, while the 2004 survey used medium format vertical photographs. Counts in 2004 displayed above have been reduced 3.5% from the actual count to account for the format differences (see text).

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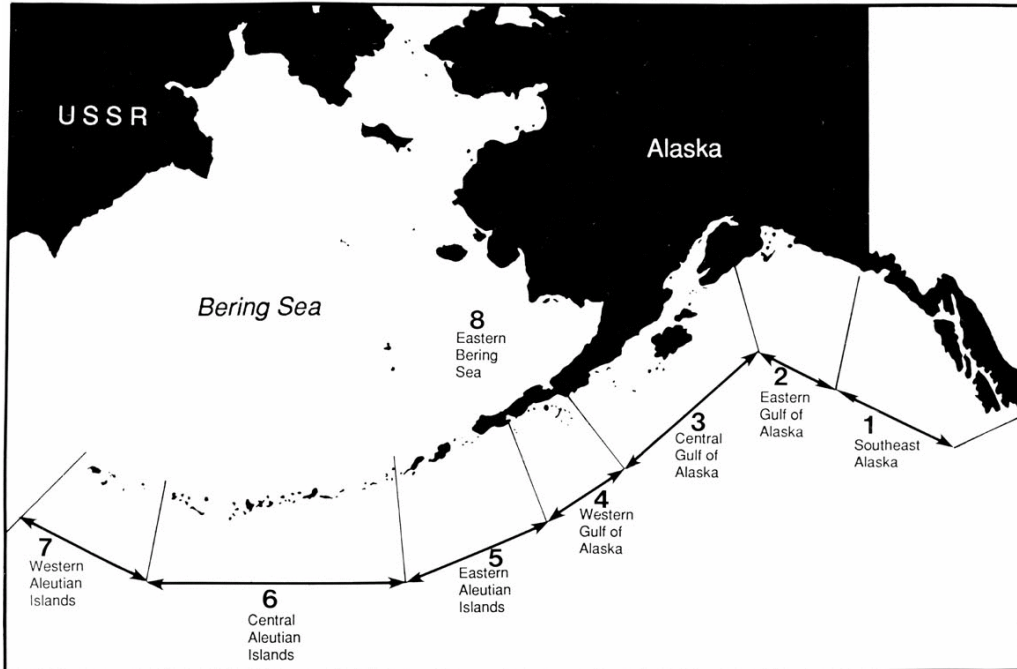
Figure 92. Map of Alaska showing areas within the range of the western Steller sea lion (subareas 2-7) surveyed in 2004.

Table 19. Counts of adult and juvenile (non-pup) Steller sea lions observed at rookery and haulout trend sites in six subareas of Alaska during June and July aerial surveys from 1989 to 2004, including overall percentage changes between 2002 and 2004, 2000 and 2002, and 1991 and 2004, and estimated annual rates of change from 1991-2004. Counts in 1989-2002 were made visually or from 35 mm slides shot obliquely out the side windows of aircraft. Counts in 2004 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. Both the corrected (2004[1]) and uncorrected (2004[2]) subarea trend site counts in 2004 are listed. Corrected 2004 counts were used to compute percentage changes and annual rates of change.

| | Gulf of Alaska | | | Aleutian Islands | | | Western |
Year	Eastern	Central	Western	Eastern	Central	Western	Stock
1989	7,175	8,243	3,908	3,032	7,114	2,486	31,958
1990	5,444	7,050	3,915	3,801	7,988	2,327	30,525
1991	4,596	6,270	3,732	4,228	7,496	3,083	29,405
1992	3,738	5,739	3,716	4,839	6,398	2,869	27,299
1994	3,365	4,516	3,981	4,419	5,820	2,035	24,136
1996	2,132	3,913	3,739	4,715	5,524	2,187	22,210
1998	2,110	3,467	3,360	3,841	5,749	1,911	20,438
2000	1,975	3,180	2,840	3,840	5,419	1,071	18,325
2002	2,500	3,366	3,221	3,956	5,480	817	19,340
2004[1]	2,540	2,948	3,517	4,714	5,944	899	20,563
2004[2]	2,632	3,055	3,645	4,885	6,160	932	21,309

Percentage Changes

2002-2004	1.6%	-12.4%	9.2%	19.2%	8.5%	10.1%	6.3%
2000-2002	26.6%	5.9%	13.4%	3.0%	1.1%	-23.7%	5.5%
1991-2004	-44.7%	-53.0%	-5.7%	11.5%	-20.7%	-70.8%	-30.1%

Annual Rates of Change 1991-2004

Annual Change	-4.7%	-5.6%	-1.4%	-0.6%	-1.5%	-10.6%	-3.1%
Upper 95%	-0.2%	-3.7%	0.4%	1.4%	0.2%	-7.3%	-1.5%
Lower 95%	-9.2%	-7.5%	-3.2%	-2.5%	-3.2%	-13.8%	-4.8%
P[3]	**0.0446**	**0.0004**	0.1032	0.4993	**0.0752**	**0.0002**	**0.0037**

[1] 2004 subarea and western stock counts made from medium format film; reduced by 3.5% to account for format differences. These data were used to calculate percentage changes and annual rates of change.
[2] 2004 subarea and western stock counts made from medium format film; uncorrected for format differences.
[3] Bold indicates P<0.10 (estimated annual rate of change significantly different from 0).

Northern fur seal (*Callorhinus ursinus*)

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 (Table 20 and Table 21). 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 93). 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 20. 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 21. 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**

St. Paul

St. George
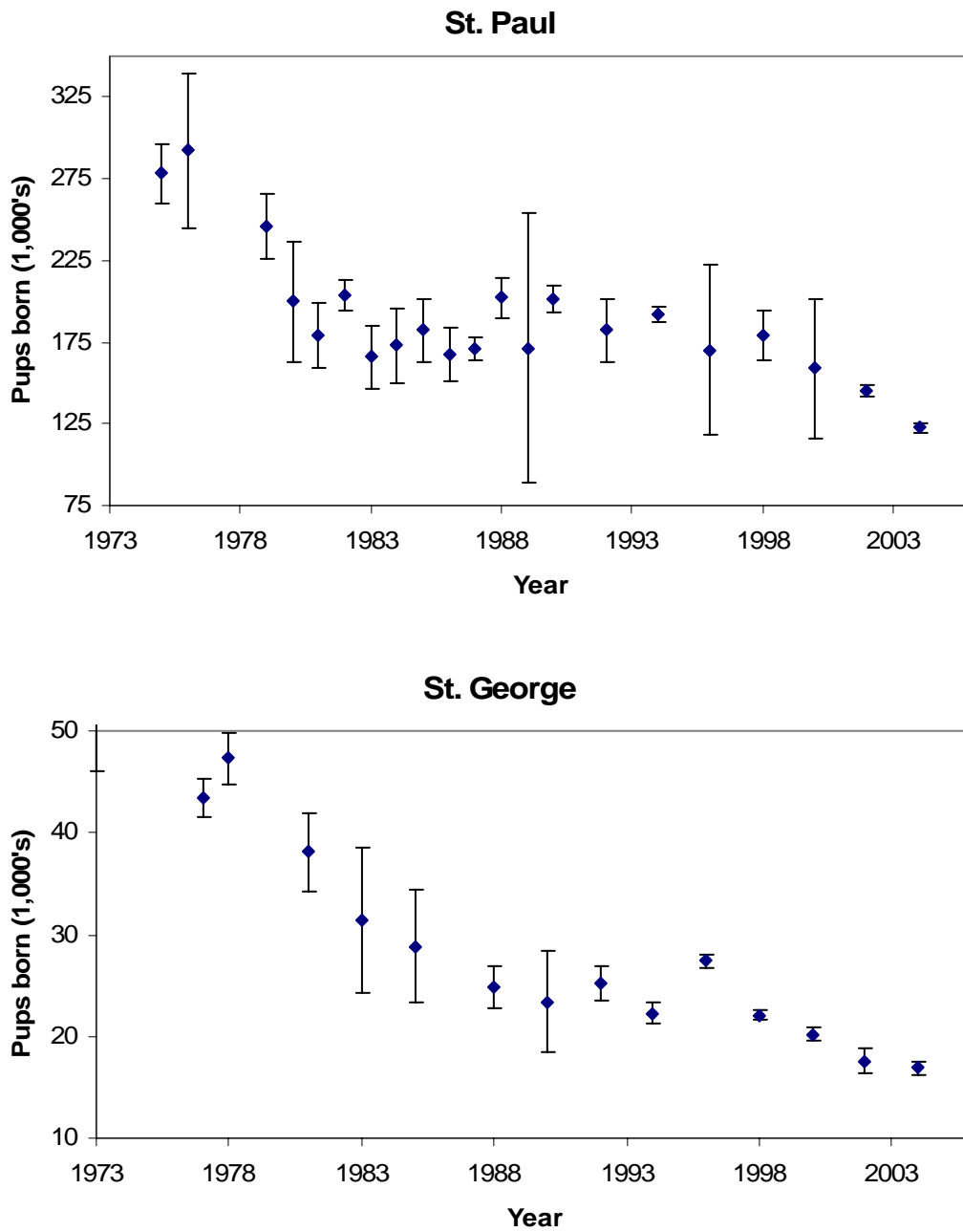
Figure 93. Northern fur seal pups born on the Pribilof Islands 1975-2004. Error bars are approximate 95% confidence intervals.

Harbor Seal (*Phoca vitulina*)

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 22). 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 22. 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

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 23. 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 23). However, it should be noted that a number of stocks of marine mammals are incidentally killed in commercial fisheries activities (Table 23). 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 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 groundfish 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). For northern fur seals, adult walleye pollock and salmon consumption (Kajimura 1984, Perez and Bigg 1986, Lowry 1982, Sinclair et al. 1994, 1996) is in direct conflict with commercial harvests.

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 the rookery (Robson 2001), placing them within range of commercial groundfish vessels displaced by Steller sea lion conservation zone restrictions.

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.

Whereas the overall abundance of prey across the entire Bering Sea or GOA may not be affected by fishing activity, reduction in local abundance, or dispersion of schools could be more energetically costly to foraging marine mammals. Thus, the timing and location of fisheries, relative to foraging patterns of marine mammals may prove to be a more relevant management concern than total removals.

Environmental and climatic change - The relative significance and combined impact of fisheries perturbations with broad, regional events such as climatic shifts is uncertain, but given the potential importance of localized prey availability for foraging marine mammals, warrants close consideration.

Most scientists agree that the 1976/77 regime shift dramatically changed environmental conditions in the BSAI and GOA (Benson and Trites 2000). However, there is considerable disagreement on how and to what degree these environmental factors 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). Some suggest the overall biomass of fish was reduced by about 50 percent (Merrick et al. 1995, Piatt and Anderson 1996). Others suggest that the regime shift favored some species over others, in part because of a few years of very large recruitment and overall increased biomass (Beamish 1993, Hollowed and Wooster 1995, Wyllie-Echeverria and Wooster 1998).

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) along with the capacity of fish populations, (and arguably, apex predator populations) to withstand commercial fishing pressures.

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 23. This summary table of Alaska marine mammal stocks includes estimates of fishery mortality and native subsistence harvest levels up through 2004. Fishery mortality is expressed as an annual average for the time period 1998-2003.

Species	Stock	N (est)	CV	C.F.	CV C.F.	Comb. CV	N(min)	0.5 Rmax	F(r)	PBR	Fishery mort.	Subsist mort.	Status
Baird's beaked whale	Alaska	n/a					n/a	0.02	0.5	n/a	0		NS
Bearded seal	Alaska	n/a					n/a	0.06	0.5	n/a	2	6,788	NS
Beluga whale	Beaufort Sea	39,258	0.229	2	n/a	0.229	32,453	0.02	0.5	324	0	162	NS
Beluga whale	E. Chukchi Sea	3,710	n/a	3.09	n/a	n/a	3,710	0.02	1.0	74	0	65	NS
Beluga whale	E. Bering Sea	18,142	0.24	3.09	n/a	0.24	14,898	0.02	1.0	298	0	209	NS
Beluga whale	Bristol Bay	1,888	n/a	3.09	n/a	0.2	1,619	0.02	1.0	32	0.5	19	NS
Beluga whale	Cook Inlet	357	0.107			0.107	326	0.02	0.3	2	0	1	S
Bowhead whale	W. Arctic	10,545	0.128			0.128	9,472	0.02	0.5	95	0.2	41	S
Cuvier's beaked whale	Alaska	n/a					n/a	0.02	0.5	n/a	0	0	NS
Dall's porpoise	Alaska	83,400	0.097			0.097	76,874	0.02	1.0	1,537	37.5	0	NS
Fin whale	NE Pacific	5703	0.2				5,703	0.02	0.1	11.4	0.6	0	S
Gray whale	E. N. Pacific	18,813	0.069			0.069	17,752	0.0235	1.0	442	7.4	122	NS
Harbor porpoise	SE Alaska	10,947	0.242	1.56*	0.108[+]	0.274	8,954	0.02	0.5	90	3*	0	NS
Harbor porpoise	Gulf of Alaska	30,506	0.214	1.37[+]	0.066[+]	0.304	25,536	0.02	0.5	255	40.3	0	NS
Harbor porpoise	Bering Sea	47,356	0.223	1.337[+]	0.062[+]	0.3	39,328	0.02	0.5	393	2	0	NS
Harbor seal	SE Alaska	37,450	0.026	1.74	0.068	0.073	35,226	0.06	1.0	2,114	36	1,749	NS
Harbor seal	Gulf of Alaska	29,175	0.023	1.5	0.047	0.052	28,917	0.06	0.5	868	36	791	NS
Harbor seal	Bering Sea	13,312	0.062	1.5	0.047		12,648	0.06	0.5	379	31	161	NS
Humpback whale	W. N. Pacific	394	0.084			0.084	367	0.035	0.1	1.3	0.69	0	S
Humpback whale	Cent.N. Pacific	4,005	0.095			0.095	3,698	0.035	0.1	12.9	4.2	0	S
Humpback whale	CNP-SEAK feeding area	961	0.12			0.12	868	0.035	0.1	3	2.7	0	S
Killer whale	AK resident	1123	n/a				1,123	0.02	0.5	11.2	2.5	0	NS
Killer whale	N resident (BC)	216	n/a				216	0.02	0.5	0	0	0	NS
Killer whale	S resident (BC)	83	n/a				83	0.02	0.5	0.8	0	0	S
Killer whale	AT1 transient	8	n/a				8	0.02	0.5	0	0	0	S
Killer whale	GOA, AI, BS transient	314	n/a				314	0.02	0.5	2.5	0	0	NS
Killer whale	West Coast transient	314	n/a				314	0.02	0.5	0	0	0	NS
Minke whale	Alaska	n/a					n/a	0.02	0.5	n/a	0	0	NS
North Pacific right whale	E. N. Pacific	n/a					n/a	0.02	0.1	n/a	0	0	S
Northern fur seal	E. North Pacific	688,028		4.475	n/a	0.2	676,540	0.043	0.5	14,546	15	869	S
Pacific white-sided dolphin	Cent.N. Pacific	26,880					26,880	0.02	0.5	n/a	4	0	NS
Ribbon seal	Alaska	n/a					n/a	0.06	0.5	n/a	1	193	NS
Ringed seal	Alaska	n/a					n/a	0.06	0.5	n/a	0.71	9,567	NS
Sperm whale	N. Pacific	n/a					n/a	0.02	0.1	n/a	0.45	0	S
Spotted seal	Alaska	n/a					n/a	0.06	0.5	n/a	2	5,265	NS
Stejneger's beaked whale	Alaska	n/a					n/a	0.02	0.5	n/a	0	0	NS
Steller sea lion	E. U. S.	44,996					43,728	0.06	0.8	1,967	5.12	4	S
Steller sea lion	W.U. S.	38,513					38,513	0.06	0.1	231	30.7	188	S

C.F. = correction factor; CV C.F. = CV of correction factor; Comb. CV = combined CV; Status: S=Strategic, NS=Not Strategic, n/a = not available.

* = No or minimal reported take by fishery observers; however, observer coverage was minimal or nonexistent.

+ = There are two correction factors involved in the estimation of harbor porpoise abundance. One factor is 2.96 (CV = 0.18), which corrects for availability bias, and is used for all three estimates for Alaska harbor porpoise stocks following Laake et al. (1997). The correction factor included in this table corrects for animals missed on the trackline. Because this number differed for different stocks, the factor is included in the summary table.

Seabirds
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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 2000 Ecosystem chapter (NPFMC 2000). 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

Pelagic

The pelagic distribution of seabirds in Alaskan waters has not been examined comprehensively in recent years. Comparisons to historical information, especially that of the OCSEAP surveys completed in the 1970's, and to current fishing effort cannot be made given current data gaps. Recent efforts to address this information gap have included the implementation of 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,

Figure 94. Seabird Colonies of Alaska. Beringian Seabird Colony Catalog (USFWS 2003).

and NMFS to complete "bird-feeder" type surveys on charter vessels conducting halibut and sablefish

surveys. Counts of seabird abundance were performed after each set was brought aboard and within a standardized area astern. Data collected in 2002 were reported (Melvin et al. 2004), as will the 2003 information. In 2004 the program was expanded from longline charter vessels to groundfish charters operated by the Alaska Fisheries Science Center. The opportunity to develop a line-transect seabird survey program on platforms of opportunity is currently being explored.

Colonies

(Not updated). The sizes of seabird colonies and their species composition differ among geographic regions of Alaska (Figure 94), 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.

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. (2004) (see also, NPFMC 2002). Discussion of factors that influence seabird populations was presented in the 2002 Ecosystems chapter (NPFMC 2002). For detailed summaries of seabird chronology, breeding success and population trends for species at specific sites refer to Dragoo et al. (2004), which includes data up to 2002. Below, we summarize data presented in Dragoo et al. (2004), with a focus on broad regional trends, using each species x site as a population sample (Figures 95-97). In addition, we examined the regional trends relative to three feeding guilds of seabirds: planktivores (birds that eat primarily macro-zooplankton and invertebrates), surface piscivores (birds that forage primarily from the surface to catch fish), and diving piscivores (birds that forage by diving into the water column to catch fish). 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 (Figure 95) was early or typical in 2002 for most regions and species within feeding guilds, and in fact there were no cases of later than normal chronology. Among the planktivores, surface feeders (storm petrels) were earlier than normal while the diving feeders (auklets) tended to be average (Dragoo et al. 2004), which reflects the trends in piscivores. Surface-feeding piscivores in particular tended to be early in chronology throughout the Bering Sea as well as the GOA. Diving piscivores, while also showing early breeding for many colonies, tended to have average breeding

initiation among other colonies, particularly in the SE Bering. A trend of earlier breeding in seabirds has been noted throughout the North Pacific, and may be linked to climate changes affecting spring plankton blooms, which may affect forage fish availability (Root et al. 2003).

Seabird productivity in 2002 (Figure 96) was variable throughout regions and among species. Planktivores, concentrated in the SW Bering, tended to have average productivity, although the auklets in the N. Bering (St. Lawerence Island) were above average. Surface feeding piscivores (most cases being black-legged kittiwakes) were mostly above average, particularly in the SE Bering and GOA, while those in the Chukchi and N. Bering had some below average samples (site x species). Productivity of diving piscivores was more mixed, with 16 of 39 cases (41%) showing below average success, concentrated in the SE and SW Bering. The above average samples were also concentrated in the SE Bering and the GOA. The remaining 10 samples of average productivity occurred from the SE Bering to Southeast.

Although there is limited long-term productivity data for the GOA and SEAK, there is some suggestion that between ~ 1994-97, GOA seabirds did poor or average while more SEAK seabirds did well (Table 24). In contrast, during 1999-2002, seabirds did better in GOA than in SEAK, and seabirds in both regions had low or average productivity in 1998. Productivity data suggests that in 1989-97, most SEBS populations did poorly, whereas, most SWBS populations did well (except surface piscivores, which generally did poorly 1993-1996). This switched after 1998, when SEBS seabirds had higher productivity and most SWBS seabirds had low productivity (Table 25). 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 or often not among feeding guilds within the same region. Even where predominate patterns may indicate generally poor or good years regionally, there are usually species or colonies that are exceptions (see Dragoo et al. 2004), indicative of local environmental effects. Although general large-scale patterns are weakened by such species and colony effects, there is some suggestion 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 97) 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. (2004) describe population trends by exponential regression models, with inclusion of 2002 data. Through 2002, declining seabird populations were the minority (18 of 88 cases), and most prevalent in the SE Bering (which includes the Pribilof Islands) and GOA (Figure 97). The highest proportion of increasing trends occurred in the SW Bering (7 of 21 cases). However, in all regions, the majority of species showed no discernable trend. Planktivores were stable or increasing at all monitored sites. Among surface piscivores most populations were stable, with decreasing trends apparent mainly in the SE Bering and to lesser extent in the GOA. The only positive trends occurred in the SW Bering and GOA. Diving piscivores showed more variability, with cases of negative trends strongest in the SE Bering and GOA, positive trends occurring in all regions, but the majority of populations stable.
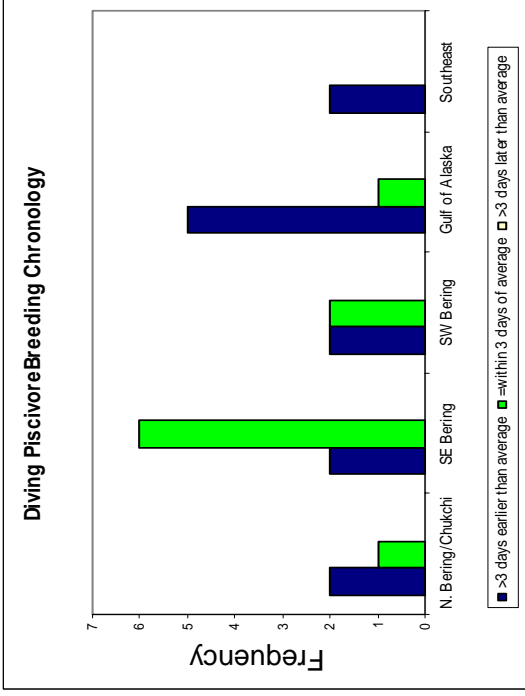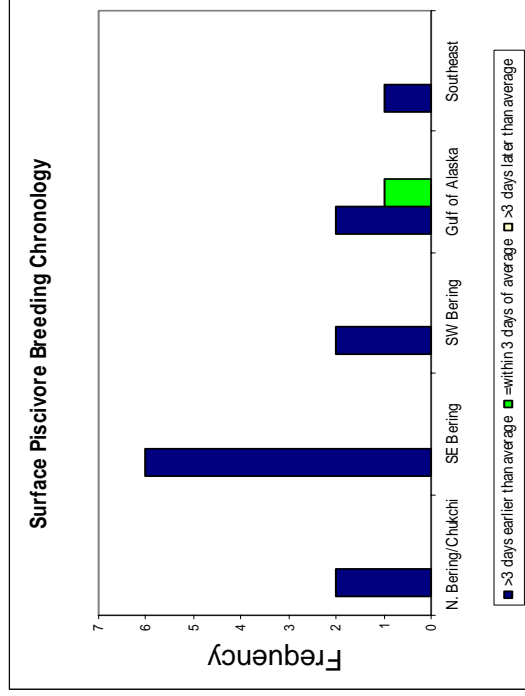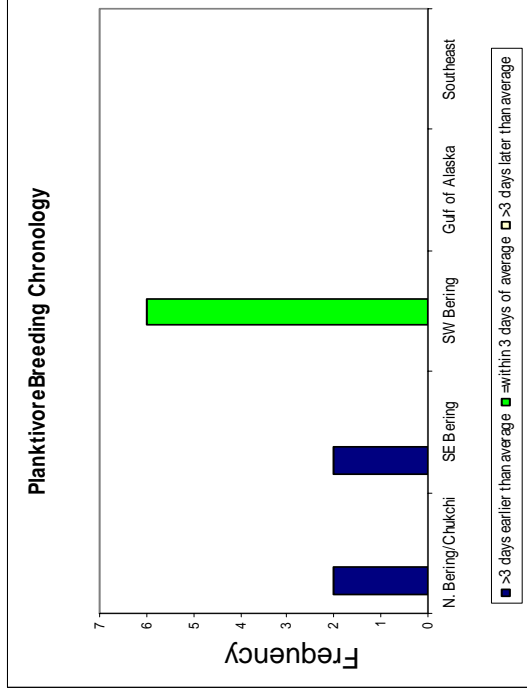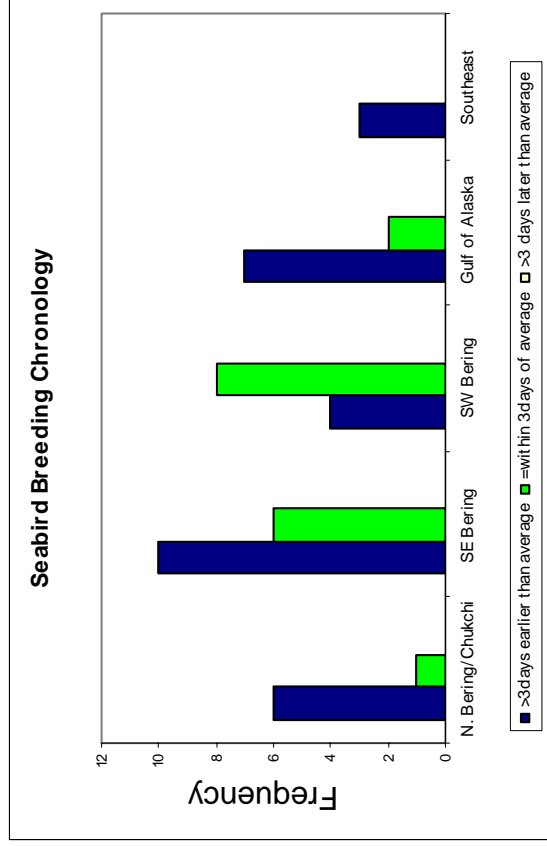
Figure 95. Seabird breeding chronology (by region and for three feeding guilds) for species monitored at selected colonies in Alaska in summer 2002. Frequency is the number of samples (species x site) for each region, showing earlier than average, average, or later than average dates for breeding. Chronology usually used hatch dates. Data are from Table 37 in Dragoo et al. 2004.

Table 24. Average productivity anomalies for seabird species averaged across species in three feeding guilds (surface piscivores (SP), diving piscivores (DP), and surface planktivores (PL)) of the north Bering Sea/Chukchi Sea, southeast Bering Sea (SEBS) and southwest Bering Sea (SWBS). 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. Anomalies were divided into 7 categories for display purposes (see legend).

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

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
NBS/Chukchi	SP	BLKI	.	.	.	.	++	+	+	+	+	-	-	-	.	.	-	.	.	-	.	.	+	-	.	+	.	+	+	-	.
NBS/Chukchi	DP	COMU															+	+	.	.	.	.	.	.	+	.	.	.	+	.	-
NBS/Chukchi	DP	TBMU																				.	+	.	-	.	+	.	.	-	-
NBS/Chukchi	PL	CRAU																								.	.	.	.	.	+
NBS/Chukchi	PL	LEAU																								.	.	.	.	-	+
SEBS	SP	RLKI	.	+	.	.	.	+	-	-	.	-	-	+	+	.	+	+	-	.	.	-	.	-	-	-	-	-	+	-	+
SEBS	SP	BLKI	+	+	+	-	++	.	-	.	-	-	+	+	+	+	-	.	+	.	-	-	.	-	.	.	.	.	+	+	++
SEBS	SP	GWGU						+						.	-				.	.	.	-		+				-	.	.	.
SEBS	DP	COMU	.	.		+			-	.				+	+	+	-	.	.	+	-	+	+	.	+	-	-	.	+	.	.
SEBS	DP	TBMU	++	-		+			---			+	+	.	-	.	-	.	+	+	-	-	-	-	-	-	+	-	-	+	+
SEBS	DP	TUPU					.							-	.	+	+	.	.	-	-	.	.	+	+	.	-	+	+	+	+
SEBS	DP	RFCO	.	.			.							.	.	.	.	.	+	.	+	.	.	.	-	.	+	+	+	.	+
SEBS	DP	PECO												.	+	+	+	+	++	+	.	.	-	.	-	+	+	.	-	+	+
SEBS	PL	LHSP	--												.	-	+	.	+	+	+	+	.	-	-	-	.	+	+	+	--
SEBS	PL	FTSP	--												.	+	.	.	.	.	.	.	+	+	+	+	+	-	.	+	+
SWBS	SP	BLKI								.	.	.	-	-	+	.	+	++	+	-	++	-	-	-	+	.	.	.	.	.	.
SWBS	SP	RLKI												-	+	+	++	+	++	.	+	-	-	-	+	.	.	.	.	-	.
SWBS	SP	GWGU													.	.	.	+	.	.	-	-	+	.	++	+	.	+	.	-	+
SWBS	DP	HOPU							-	-	-	--	-	.	+	--	.	+	.	+	+	+	+	+	+	+	+	.	.	.	-
SWBS	DP	TUPU							+	.	.	.	.	.	+	-	.	.	.	+	+	.	+	+	++	.	.	.	.	.	-
SWBS	DP	COMU																		-	+	+	++	.	+	.	+	.	.	.	.
SWBS	DP	TBMU															+	.	+	.	+	+	+	+	+	+	.	-	.	+	.
SWBS	DP	PECO	+																++	+	-	-	.	+	-	+	+	+	-	+	+
SWBS	DP	RFCO																				.	+	.	.	.	.	+	+	+	+
SWBS	PL	PAAU																		.	+	.	.	.	+	+	-	+	+	+	.
SWBS	PL	WHAU																	.	-	.	+	.	+	+	.	-	+	.	.	+
SWBS	PL	CRAU															-	.	-	.	+	.	+	+	.	-	-	.	-	.	.
SWBS	PL	LEAU																	--	+	.	.	++	++	.	.	-	+	-	.	.
SWBS	PL	LHSP	--	--	--													.	+	+	+	+	+	+	+	.	-	.	.	.	+
SWBS	PL	FTSP	--	--													.	+	+	+	+	.	+	+	+	-	.	+	.	.	+

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Table 25. Average productivity anomalies for seabird species averaged across colonies in three feeding guilds (surface piscivores (SP), diving piscivores (DP), and surface planktivores (PL)) of the GOA and 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. Anomalies were divided into 7 categories for display purposes (see legend).

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
GOA	SP	BLKI				+	·	-		++	+	·	+	·	·	-	+	·	-	-	·		·	·	·	·	-	-	·	+	+
GOA	SP	GWGU					·																·	·	·	-	+	·	·	+	+
GOA	DP	HOPU																							+	·	-	+			
GOA	DP	TUPU																				+	·	·		-	-	+	+	+	
GOA	DP	COMU						-	+	+								·	·		+	·	·	-	·	·	-		+	+	+
GOA	DP	TBMU						·	·	‡								·	·			·	·	·	·	·	‡			+	·
GOA	DP	PECO				·				++	++	++	+	+	-	-	-	-	·	·	-	+	+	-	·		·		+	+	+
GOA	DP	RFCO						·					+	+				-	·	·		+	+	-	+	-	-	-	+	+	+
GOA	DP	RHAU			+	-																·				-	·	+		+	-
SEAK	SP	GWGU																					-	-	-		·	-	-	+	+
SEAK	DP	TUPU																					+	⁓	+	·	·	·	·	·	·
SEAK	DP	COMU																					+	·	-	+	·	-	·	+	-
SEAK	DP	TBMU																					·	·	-	‡	·	-	+	+	·
SEAK	DP	PECO																					-	·	‡		·	·	+	·	·
SEAK	DP	RHAU																							+		-	+	+	+	
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 96. Seabird breeding success (by region and for three feeding guilds) for species monitored at selected colonies in Alaska in summer 2002. 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. 2004 for variants). Data are from Table 38 in Dragoo et al. 2004.

220
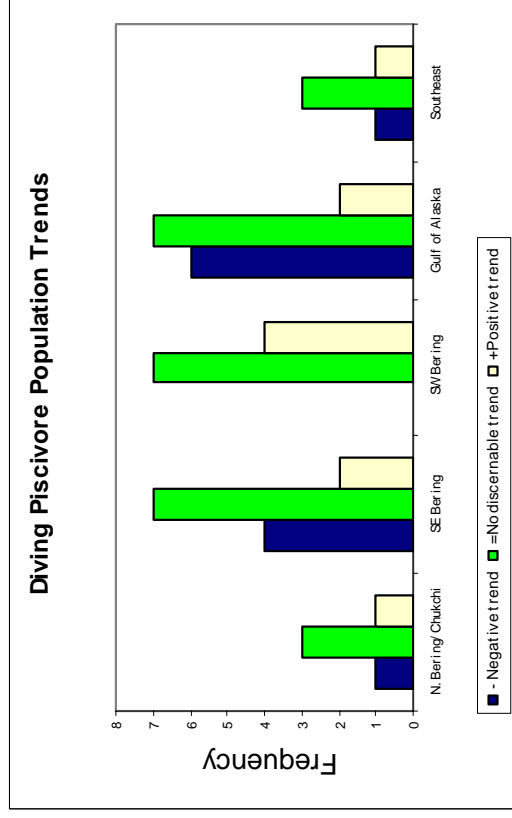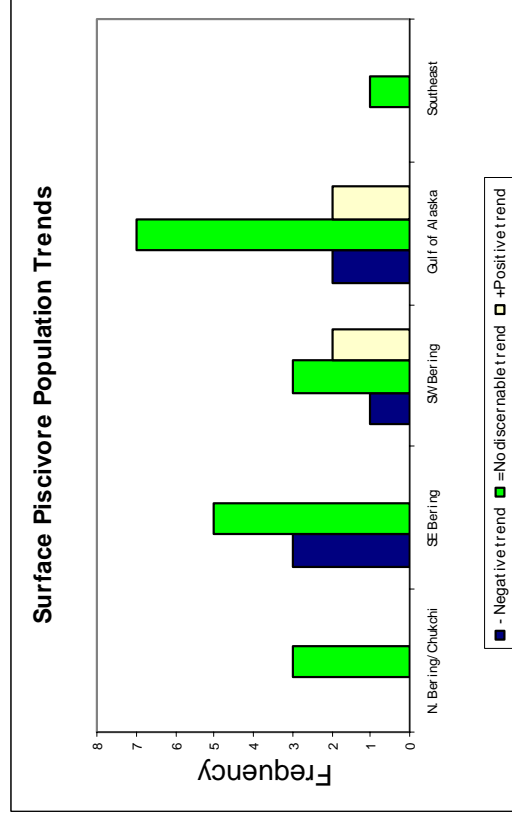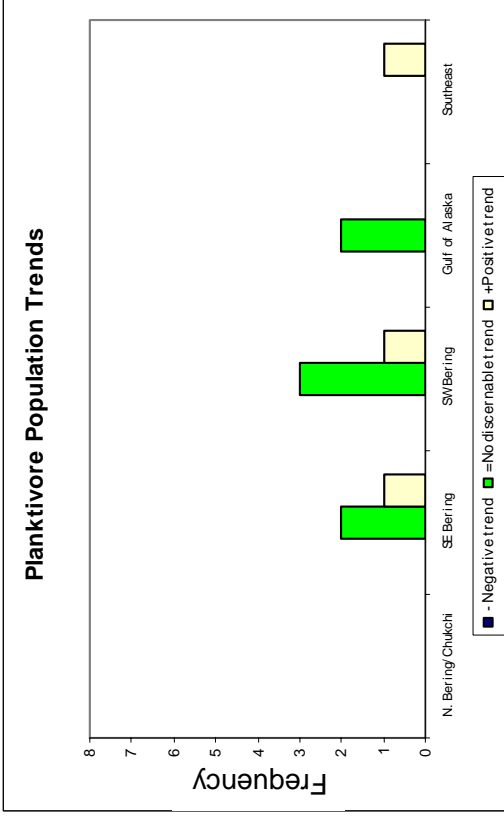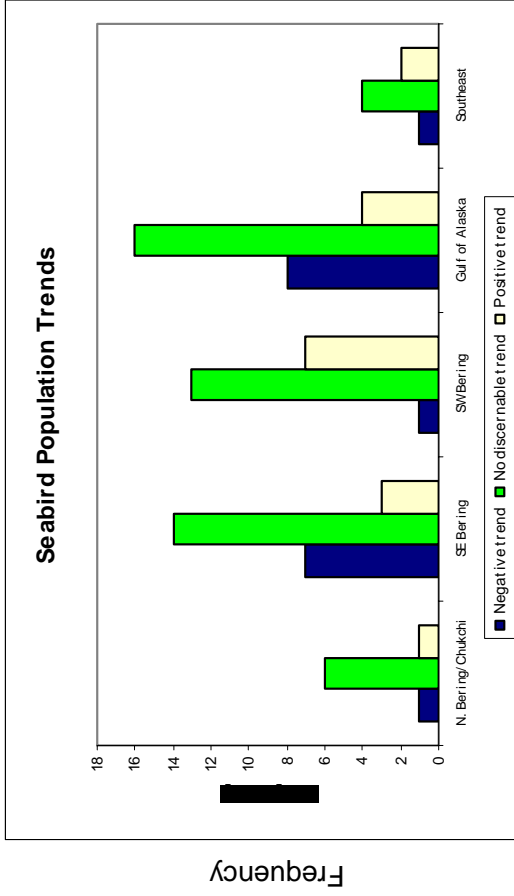
Figure 97. Seabird population trends (by region and for three feeding guilds) for species monitored at selected colonies in Alaska in summer 2002. Frequency is the number of samples (species x site) for each region, showing negative trends, no statistically significant trend, or positive trends in population, derived from exponential regression models for samples with multiple years of data. Data are from Table 39 in Dragoo et al. 2004.

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Ecosystem Factors Affecting Seabirds

Food Availability

Seabird foraging and effects of food limitations on seabird populations were addressed in the 2000 Ecosystem chapter (NPFMC 2000). A comprehensive review has not been completed since then. 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 discard 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, and bycatch information is available through observer data. 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 2003. The data from 2004 will be included at a later date, after data are compiled and prepared for distribution. Those data will also be available at the AFSC seabird/fishery interaction website during fall of 2005 at http://www.afsc.noaa.gov/refm/reem/Seabirds/Default.htm

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). The definitions for species or group codes used in the detailed seabird bycatch tables at the end of this section are:

STAL - Short-tailed albatross
LAAL - Laysan's albatross
BFAL - Black-footed albatross
NOFU - Northern fulmar
Gull - Unidentified gulls (herring gulls, glaucous gulls, glaucous-winged gulls)
SHWR - Unidentified shearwaters (unidentified dark shearwaters, sooty shearwaters, short-tailed
        shearwaters)
Unidentified Tubenose - Unidentified procellariiformes (albatrosses, shearwaters, petrels)
Alcid - Unidentified alcids (guillemots, murres, puffins, murrelets, auklets)
Other - Miscellaneous birds (could include loons, grebes, storm-petrels, cormorants, waterfowl, eiders,
        shorebirds, phalaropes, jaeger/skuas, red-legged kittiwakes, black-legged kittiwakes, terns)
Unidentified ALB - Unidentified albatrosses (could include short-tailed albatrosses, Layson's albatrosses,
black-footed albatrosses)

Bycatch in 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; Table 26). 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 98). 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 (Figure 98). While seabird bycatch increased in 2003 over 2002, the rate remained constant while effort continued an upward trend (Figure 98 and Figure 99). Note that a total of 3,835 seabirds were taken in BSAI longline fisheries in 2002 (Table 27). 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 26).

In the GOA seabird bycatch was also higher in 2003 (632 birds) than in 2002 (259 birds) (Table 28). 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 98-100).

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.   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.
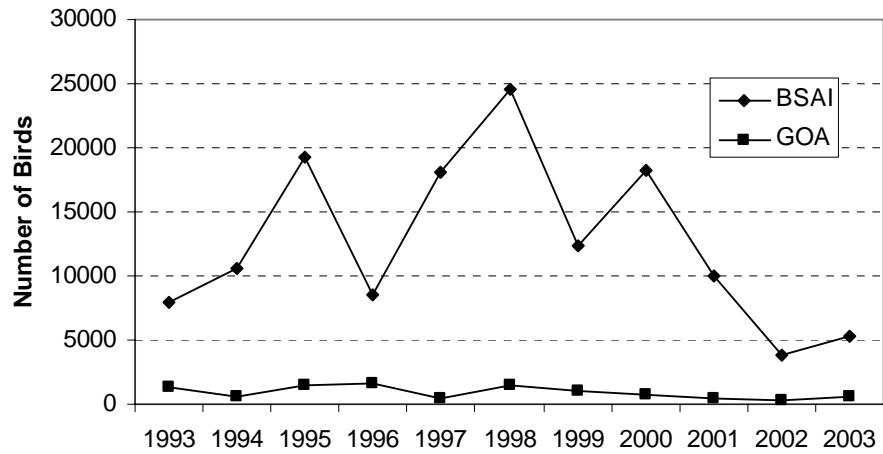
Figure 98. Estimated seabird bycatch in the BSAI and GOA groundfish longline fisheries of the Alaskan EEZ, 1993 to 2003.
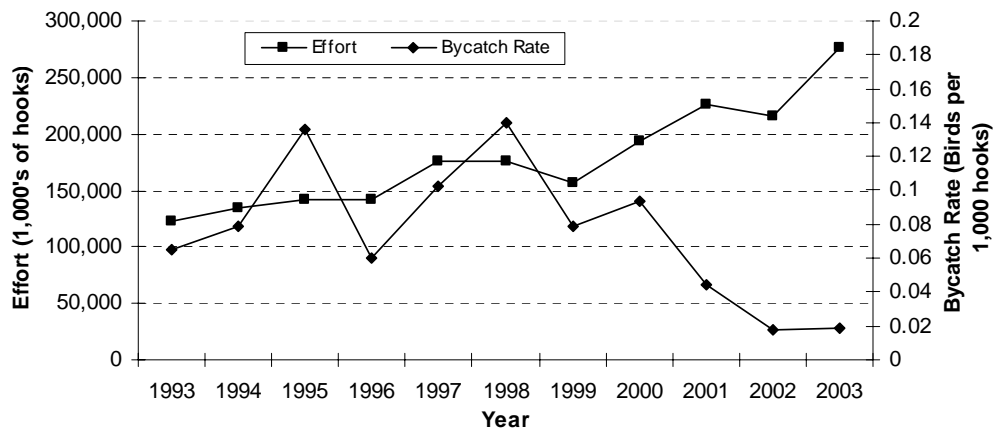
Figure 99. BSAI groundfish longline effort and seabird bycatch rate, 1993 through 2003.

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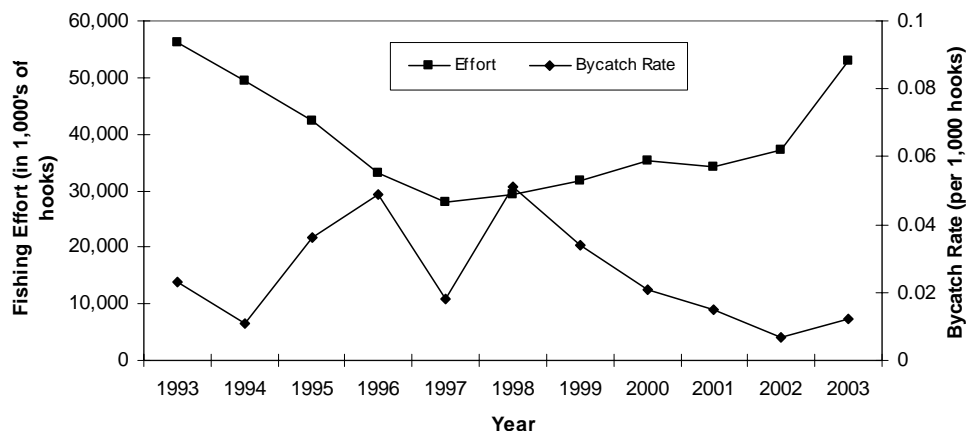
Figure 100. GOA groundfish longline effort and seabird bycatch rate, 1993 through 2003.

Pot: Seabird bycatch from groundfish pot fishing has traditionally been very limited. The overall average bycatch in this fishery, 1993 through 2003, is 55 seabirds. That trend continues, with only 10 birds observed taken in 2003, extrapolating up to an estimated 153 total mortalities (Table 29).

Trawl: On trawl vessels only, observers use either whole haul, partial haul, or basket sampling to record prohibited species bycatch and determine the species composition of the haul. Observers are often required to use 2 sample types in a single haul, in order to best sample for either of these goals. Observers have been instructed to use the largest sample available when monitoring for seabird bycatch. Unfortunately, that has not always occurred. This would not be a problem for estimation purpose, as observers record their sample size for each species in their sample, except that the great majority of hauls do not have any seabird bycatch. NMFS did not require observers to record the sample size when no birds were observed, so it is unknown which sample size was used to monitor for seabird bycatch in these hauls. Thus, it has been necessary to calculate two alternative sets of estimates of seabird bycatch for trawlers based on the largest (alternative1) and smallest (alternative2) sizes of sampling effort recorded for fish species (Figure 101 and Table 30). 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. It is not known which of the 2 estimates is more accurate. Seabird bycatch on trawl vessels probably lies somewhere between them. If the majority of observers had been able to use their largest sample size to monitor for seabird bycatch, as instructed, then the lower of the two estimates more closely represents seabird bycatch on the trawl fleet (Table 30). This issue has been resolved for data collections beginning in the 2004 season, where the sample size used to monitor for seabirds will be noted whether a bird was taken or not. Estimates are provided for 1998 through 2003 only due to the way the commercial catch data were organized prior to that. Northern fulmars are again the most common species taken, constituting more than 53% of the seabird bycatch.

Another source of mortality for seabirds on trawl vessels are the cables that run between net monitoring devices and the vessel, or the trawl door cables themselves. To date, only anecdotal information is available, so the extent of the mortality from this cause is uncertain. Special projects were also designed and implemented for observers during 2004 and will be expanded for the 2005 fishing season. We are currently developing estimates on total effort and will use the 2004 and 2005 observer data to better characterize interaction rates and mortalities. A collaborative project has been started between industry,

the Alaska Fisheries Science Center, the University of Washington, and the USFWS to determine and test mitigation measures to reduce seabird interactions with trawl sonar transducer cables.
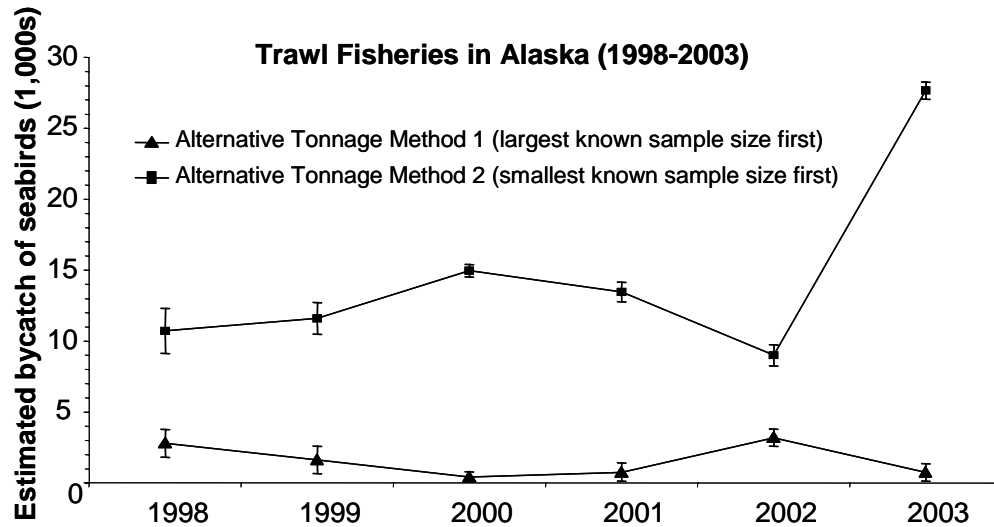
Figure 101. Seabird bycatch in Alaskan groundfish trawl fisheries (combined) using two alternate estimation methods incorporating potential sample sizes used while monitoring for seabirds in observer samples.

Pot: Seabird bycatch from groundfish pot fishing has traditionally been very limited. The overall average bycatch in this fishery, 1993 through 2003, is 55 seabirds. That trend continues, with only 10 birds observed taken in 2003, extrapolating up to an estimated 153 total mortalities.

Species Composition: Depending on which trawl estimate is used (see above), longline gear accounted for 94 or 65 percent of the total average annual seabird bycatch while trawl gear accounted for either 6 or 35 percent. Pot gear was less than 1 percent in all cases. The higher percentage of trawl bycatch coincides with the alternate trawl estimation methods as described above (Figure 101). Based on the average annual estimates of seabirds observed taken in groundfish longline fisheries from 1993 to 2003, 93 percent of the longline seabird bycatch was caught in the BSAI and 7 percent in the GOA. Also of note, the bycatch rates in the BSAI are higher than in the GOA (Figure 99 and Figure 100).

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 101 and Table 30). 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 102). 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 (Table 30). 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 103). 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.
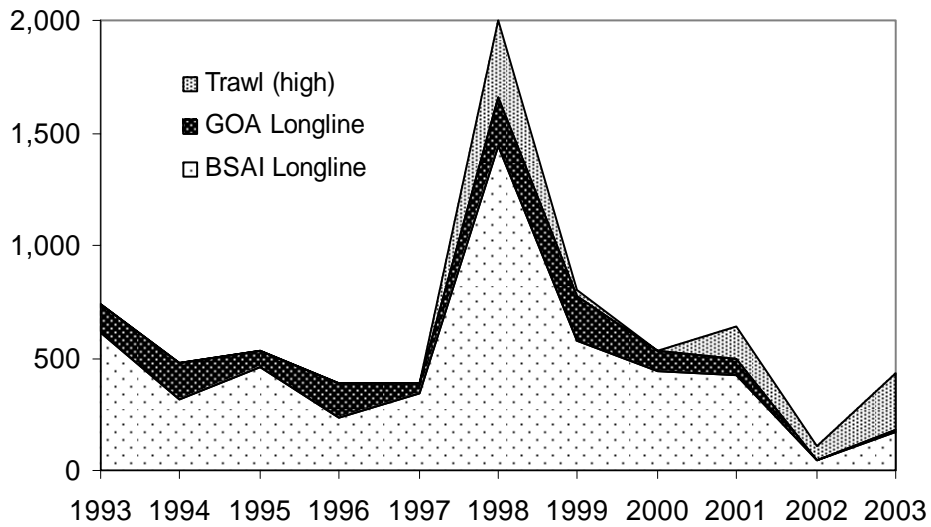
Figure 102. Combined bycatch in Alaskan groundfish fisheries for Laysan albatross, 1993 through 2003. Data for trawl fisheries begins in 1998.
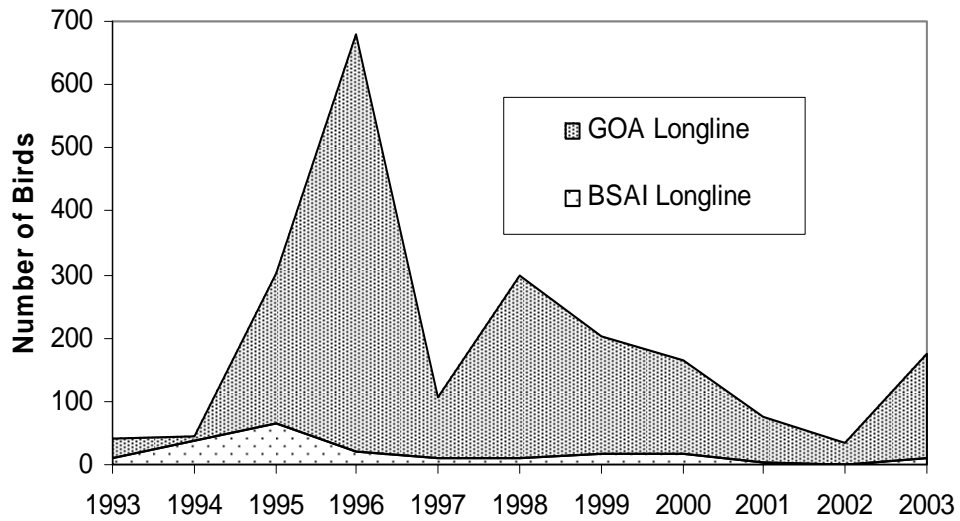
Figure 103. Combined bycatch in Alaskan groundfish fisheries for black-footed albatross, 1993 through 2003.

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 104 a and b represents 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 104a) and a high estimate (Figure 104b). 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.
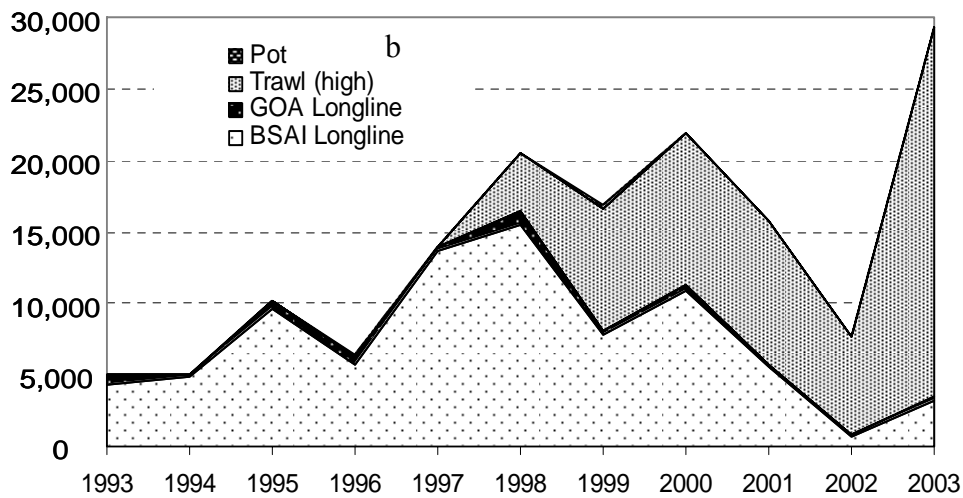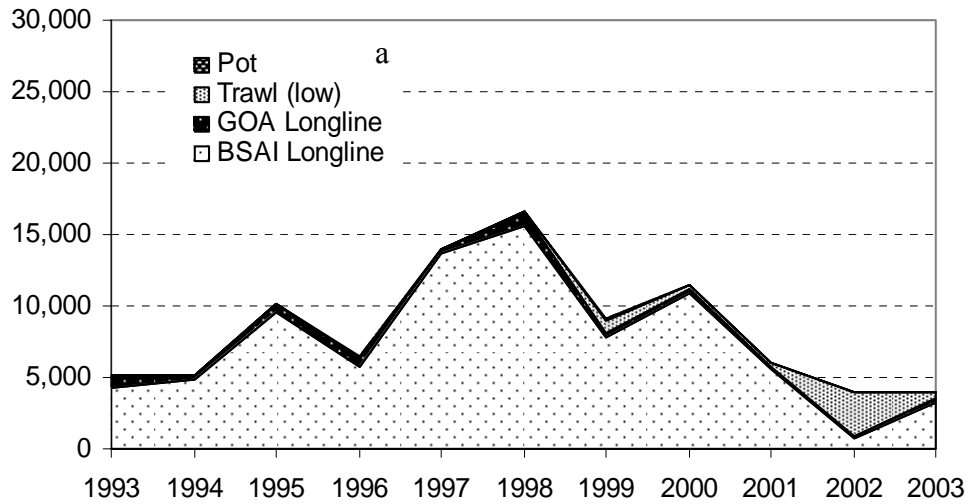
Figure 104. Estimated northern fulmar bycatch in North Pacific groundfish fisheries, using low (a) and high (b) estimation procedures for the trawl fishery. Data from the trawl fishery prior to 1997 are not included.

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 26. Annual estimates, by area, of total fishery effort, total numbers and bycatch rates of seabirds taken in Alaskan groundfish demersal longline fisheries.

Year	Effort (No. of Hooks in 1,000s)	Number of Birds	95% Confidence Bounds	Bycatch Rate (Birds per 1,000 Hooks)	Percent of Hooks Observed
Bering Sea and Aleutian Islands					
1993	123,232	7,975	6,981-8,968	0.065	24.5
1994	134,954	10,637	9,608-11,666	0.079	24.5
1995	141,779	19,214	17,853-20,576	0.136	24.2
1996	141,810	8,526	7,641-9,412	0.060	23.8
1997	176,594	18,063	16,491-19,634	0.102	22.6
1998	175,530	24,602	22,779-26,425	0.140	23.5
1999	157,319	12,418	10,950-13,887	0.079	25.0
2000	192,994	18,191	16,599-19,783	0.094	22.8
2001	226,185	9,992	9,027-10,958	0.044	21.0
2002	216,197	3,835	3,328-4,342	0.018	22.5
2003	276,327	5,351	4,705-5,997	0.019	22.6
BSAI Average Annual Estimates					
1999-2003	213,804	9,958	9,455-10,460	0.047	22.6
1993-2003	178,447	12,619	12,246-12,991	0.071	23.2
Gulf of Alaska					
1993	56,300	1,309	1,056-1,563	0.023	10.2
1994	49,452	532	397-668	0.011	4.9
1995	42,357	1,519	1,302-1,736	0.036	12.7
1996	33,195	1,634	1,206-2,062	0.049	10.8
1997	28,047	514	338-689	0.018	10.0
1998	29,399	1,498	795-2,200	0.051	8.1
1999	31,895	1,093	812-1,375	0.034	8.6
2000	35,345	751	402-1,101	0.021	6.5
2001	34,216	512	311-713	0.015	7.8
2002	37,166	259	114-404	0.007	9.3
2003	53,066	632	268-995	0.012	6.5
GOA Average Annual Estimates					
1999-2003	38,338	649	523-775	0.017	7.6
1993-2003	39,131	932	831-1,033	0.024	8.6

Table 27. Estimated total incidental catch of seabirds by species or species groups in Bering sea and Aleutian islands demersal groundfish longline fisheries, 1993-2003. Values in parentheses are 95% confidence bounds.

Year	Actual No. Taken[a]	STAL	BFAL	LAAL	NOFU	Gull	SHWR	Unid. Tube-noses	Alcid	Other	Unid. ALB	Unid. Seabird	Total
1993	1,942	0	11 (4-21)	617 (458-777)	4,259 (3,416-5,103)	853 (576-1,130)	64 (22-107)	0	15 (4-30)	4 (1-10)	352 (188-517)	1,799 (1,399-2,200)	7,975 (6,981-8,968)
1994	2,700	0	37 (7-66)	311 (218-404)	4,829 (4,188-5,470)	1,734 (1,297-2,172)	675 (487-864)	350 (226-475)	4 (1-13)	4 (1-11)	76 (43-109)	2,615 (1,956-3,274)	10,637 (9,608-11,666)
1995	4,832	0	66 (26-107)	463 (267-660)	9,628 (8,613-10,643)	3,954 (3,274-4,634)	330 (225-434)	475 (253-697)	4 (1-11)	45 (16-74)	38 (19-57)	4,211 (3,489-4,933)	19,214 (17,853-20,576)
1996	2,002	4 (1-13)	20 (5-48)	234 (156-313)	5,677 (4,858-6,496)	1,493 (1,238-1,747)	487 (246-728)	14 (4-26)	46 (9-103)	49 (13-86)	60 (31-90)	442 (326-558)	8,526 (7,641-9,412)
1997	4,123	0	9 (2-22)	343 (252-433)	13,611 (12,109-15,122)	2,755 (2,276-3,234)	300 (154-445)	173 (103-243)	0	7 (2-16)	14 (3-28)	852 (519-1,185)	18,063 (16,491-19,634)
1998	5,850	8 (2-18)	9 (2-21)	1,441 (1,078-1,804)	15,533 (13,873-17,192)	4,413 (3,732-5,093)	1,131 (936-1,326)	21 (5-38)	53 (24-82)	48 (15-81)	4 (1-11)	1,941 (1,584-2,297)	24,602 (22,779-26,425)
1999	3,293	0	18 (4-34)	576 (478-674)	7,843 (6,477-9,209)	2,209 (1,817-2,601)	449 (358-540)	414 (150-679)	4 (1-10)	47 (12-85)	0	859 (551-1,167)	12,418 (10,950-13,887)
2000	3,868	0	16 (5-33)	441 (320-562)	10,941 (9,503-12,378)	4,541 (3,894-5,188)	556 (414-697)	85 (44-125)	5 (1-14)	16 (4-30)	15 (3-30)	1,576 (1,166-1,985)	18,191 (16,599-19,783)
2001	1,987	0	4 (1-12)	425 (304-547)	5,517 (4,701-6,332)	2,459 (2,044-2,873)	457 (337-578)	94 (49-139)	2 (1-6)	33 (6-61)	5 (1-14)	997 (698-1,295)	9,992 (9,027-10,958)

Table 27 continued.

Year	Actual No. Taken[a]	STAL	BFAL	LAAL	NOFU	Gull	SHWR	Unid. Tube-noses	Alcid	Other	Unid. ALB	Unid. Seabird	Total
2002	877	0	0	48 (19-77)	701 (582-819)	2,523 (2,040-3,006)	154 (95-213)	17 (5-34)	10 (2-23)	16 (4-32)	5 (1-14)	361 (259-462)	3,835 (3,328-4,342)
2003	1,123	0	10 (2-23)	167 (77-257)	3,204 (2,655-3,754)	1,346 (1,029-1,662)	287 (209-366)	14 (3-38)	11 (3-22)	62 (24-99)	0	250 (177-324)	5,351 (4,705-5,997)
Average Annual Estimate													
1999-2003	na	0	10 (4-16)	331 (287-376)	5,641 (5,197-6,085)	2,616 (2,408-2,823)	381 (335-427)	125 (70-180)	6 (2-11)	35 (22-48)	5 (1-9)	808 (687-930)	9,958 (9,455-10,460)
1993-2003	na	1 (0-3)	18 (12-25)	461 (413-508)	7,431 (7,106-7,756)	2,571 (2,425-2,717)	445 (402-487)	151 (116-186)	14 (7-21)	30 (22-38)	52 (36-68)	1,446 (1,326-1,566)	12,619 (12,246-12,991)

a Actual number taken is the total number of seabirds recorded dead in the observed hauls.

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Table 28. Estimated total incidental catch of seabirds by species or species groups in Gulf of Alaska demersal groundfish longline fisheries, 1993-2003. Values in parentheses are 95% confidence bounds.

Year	Actual No. Taken	STAL	BFAL	LAAL	NOFU	Gull	SHWR	Unid. Tube-noses	Alcid	Other	Unid. ALB	Unid. Seabird	Total
1993	318	0	29 (9-50)	125 (62-187)	833 (615-1,052)	45 (12-77)	59 (18-99)	0	0	3 (1-7)	3 (1-9)	213 (107-318)	1,309 (1,056-1,563)
1994	126	0	7 (2-16)	169 (89-250)	258 (165-351)	30 (2-81)	26 (5-54)	0	0	0	8 (2-18)	33 (8-66)	532 (397-668)
1995	374	0	236 (169-304)	67 (35-99)	520 (348-692)	99 (53-145)	39 (9-69)	6 (1-16)	0	3 (2-6)	376 (275-476)	173 (105-240)	1,519 (1,302-1,736)
1996	250	0	658 (455-860)	154 (90-218)	668 (352-985)	121 (6-317)	14 (2-35)	0	0	0	0	19 (3-42)	1,634 (1,206-2,062)
1997	74	0	99 (32-167)	40 (5-109)	307 (164-451)	46 (14-79)	9 (2-21)	0	0	0	0	12 (2-30)	514 (338-689)
1998	184	0	289 (25-596)	217 (56-378)	922 (310-1,533)	53 (14-92)	13 (3-30)	0	0	0	4 (1-12)	0	1,498 (795-2,200)
1999	159	0	183 (70-297)	202 (123-280)	277 (156-399)	358 (136-581)	50 (8-93)	0	0	7 (1-21)	0	16 (4-37)	1,093 (812-1,375)
2000	72	0	148 (62-235)	93 (25-160)	297 (70-524)	179 (15-415)	0	0	0	0	0	34 (2-102)	751 (402-1,101)
2001	45	0	72 (20-124)	67 (6-128)	230 (115-344)	98 (4-244)	20 (1-58)	0	6 (1-18)	0	15 (1-44)	3 (1-9)	512 (311-713)
2002	51	0	33 (10-57)	0	129 (24-238)	83 (17-177)	0	0	0	0	0	14 (3-30)	259 (114-404)
2003	37	0	166 (11-350)	12 (3-23)	260 (81-439)	58 (4-140)	0	0	118 (1-369)	0	0	18 (1-53)	632 (268-995)
Average Annual Estimate													
1999-2003	na	0	121 (72-169)	75 (50-99)	239 (168-309)	155 (80-231)	14 (2-26)	0	25 (0-76)	1 (0-5)	3 (0-9)	17 (2-34)	650 (523-1,033)
1993-2003	na	0	175 (133-216)	104 (81-127)	427 (351-504)	106 (66-146)	21 (13-29)	1 (0-2)	11 (0-35)	1 (0-3)	40 (27-47)	49 (34-63)	932 (831-1,033)

Table 29. Estimated total incidental catch of seabirds by species or species groups in the combined Bering Sea and Aleutian Islands and Gulf of Alaska groundfish pot fisheries, 1993–2002. Values in parentheses are 95% confidence bounds.

Year	Actual Number Taken[a]	STAL	BFAL	LAAL	NOFU	Gull	SHWR	Unid. Tubenoses	Alcid	Other	Unid. ALB	Unid. Seabird	Total
1993	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	6	0	0	0	9 (2-23)	3 (1-10)	7 (1-20)	0	19 (2-55)	0	0	0	39 (6-79)
1996	9	0	0	0	80 (7-174)	0	0	2 (1-6)	0	0	0	7 (1-19)	89 (9-183)
1997	4	0	0	0	14 (3-29)	0	0	0	9 (1-26)	0	0	0	23 (4-46)
1998	2	0	0	0	19 (1-54)	15 (1-44)	0	0	0	0	0	0	33 (2-79)
1999	47	0	0	0	166 (71-261)	0	9 (1-26)	14 (5-28)	0	0	0	0	189 (91-286)
2000	1	0	0	0	0	0	0	0	0	0	0	42 (1-122)	42 (1-122)
2001	3	0	0	0	13 (2-33)	3 (1-8)	0	0	0	0	0	0	16 (3-36)
2002	6	0	0	0	18 (5-34)	0	0	0	0	0	0	3 (0-26)	21 (6-38)
2003	10	0	0	0	92 (8-182)	0	2 (1-4)	0	59 (1-171)	0	0	0	153 (10-296)
Average Annual Estimate													
1999-2003	na	0	0	0	58 (31-85)	1 (0-2)	2 (0-6)	3 (1-6)	12 (0-35)	0	0	9 (0-26)	84 (45-123)
1993-2003	Na	0	0	0	37 (22-53)	2 (0-5)	2 (0-4)	1 (0-30)	8 (0-19)	0	0	5 (0-13)	55 (34-76)

a Actual number taken is the total number of seabirds recorded dead in the observed hauls.

Table 30. Range of estimates of the total incidental catch of seabirds by species or species groups in the combined Bering Sea and Aleutian Islands and Gulf of Alaska groundfish trawl fisheries, 1998–2003.

Year	Actual Number Taken [a]	Estimate Range	STAL	BFAL	LAAL	NOFU	Gull	SHWR	Unid. Tubenoses	Alcid	Other d	Unid. ALB	Unid. Seabird	Total
1998	45	low	0	0	135	96	1,590	856	1	110	3	0	8	2,798
		high	0	0	343	4,012	708	1,353	163	543	2,494	0	1,110	10,725
1999	154	low	0	0	8	858	0	82	0	664	2	0	17	1,630
		high	0	0	27	8,528	0	1,149	0	791	85	0	1,025	11,604
2000	101	low	0	0	0	298	37	10	2	1	0	0	60	407
		high	0	0	0	10,678	114	3,086	155	333	0	0	603	14,969
2001	141	low	0	0	8	323	4	329	9	1	3	0	65	741
		high	0	0	150	10,022	288	887	1,075	68	297	0	681	13,468
2002	69	low	0	0	1	3,111	4	4	0	5	9	0	59	3,193
		high	0	0	56	6,809	71	595	0	878	124	0	475	9,008
2003	78	low	0	0	186	456	52	1	1	49	0	0	1	746
		high	0	0	253	25,792	242	127	172	551	0	0	528	27,665
Average Annual Estimate														
1999-2003	Na	low	0	0	41	1,009	19	85	2	144	3	0	40	1,343
		high	0	0	97	12,366	143	1,169	280	524	101	0	662	15,343

a Actual number taken is the total number of seabirds recorded dead in the observed haul

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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 (Shannon Fitzgerald, Alaska Fisheries Science Center, personal communication). Table 31 summarizes these research needs and notes the status of efforts. Steps toward addressing many of the identified research needs (Table 31) 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 31. 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
	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
Population level effects	Assess bycatch mortality at the colony level.	2001-2003: genetic profiling of fulmar populations	Hatch, USGS-BRD, Anchorage.
		2002-2003: Genetic profiling of albatrosses	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
	Seasonal pattern of offal discharge vs seabird energy needs.	NRC should lay groundwork for this effort in 2005	Fitzgerald & Edwards, NMFS
Distribution	Short-tailed albatross spatial & temporal distribution	2001: Satellite telemetry studies begin on Torishima Island	Balogh, USFWS Anchorage
		2003 and 2005: At-sea capture in Alaska.	Balogh, USFWS Anchorage
& fisheries	Pelagic Distribution of Seabirds	N. Pacific Pelagic Seabird Database begun in 2002;	USGS-BRD & USFWS,
		Stationary seabird surveys began in 2002.	WA Sea Grant
		Line transects: need to use platforms of opportunity	
	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 No work specific to Alaska waters completed	Suryan et al., Oregon State U. various publications
	Identify & quantify seabird food items.	Great deal of work completed	Various authors
	Define seabird feeding areas (horizontally & vertically)	Telemetry for STAL only	Suryan et al., Oregon State U.
Food & foraging	Define relationship between feeding and fishing areas.	No comprehensive study.	
	Describe seabird diet during fall through spring months	No comprehensive study.	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.	Dragoo et al. 2004, 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.	
	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
Gear & mitigation methods	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, <u>Heather.Lazrus@noaa.gov</u>
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
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 105). 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 105). 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.
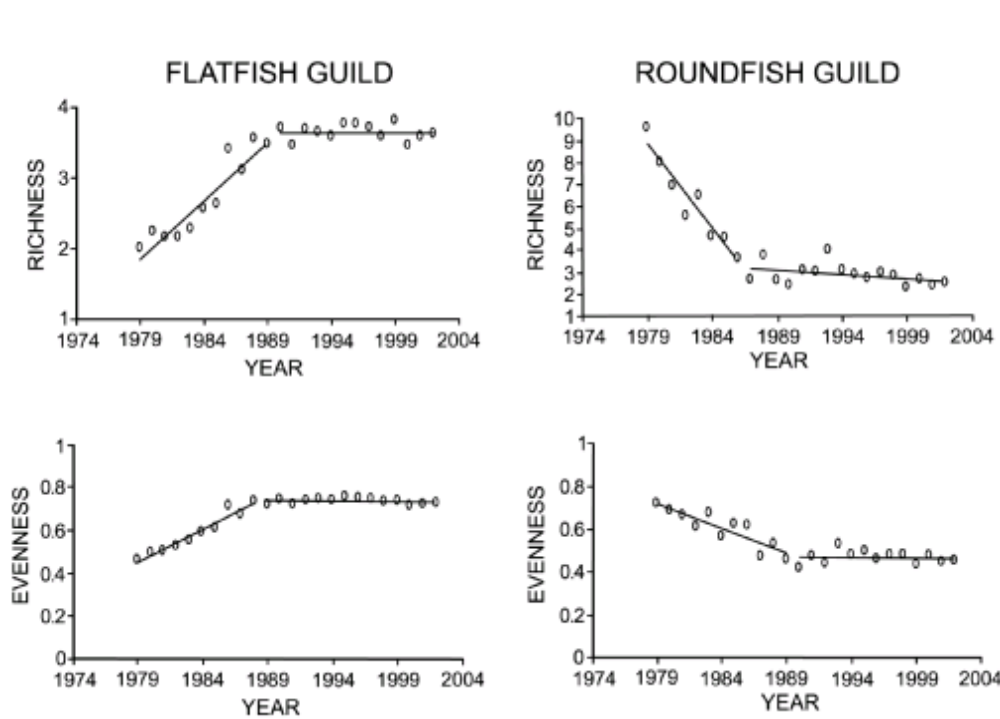
Figure 105. Plots of biodiversity (richness and evenness) indices for two fish guilds (flatfish and roundfish) from the eastern Bering Sea. Biodiversity showed a distinct shift in trends in the late 1980s which corresponds to reported regime shift events.

Combined Standardized Indices of recruitment and survival rate
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Last updated: September 2005

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, 11 stocks, dusky rockfish was added this year). Time series of recruitment and spawning biomass for demersal fish stocks were obtained from the 2004 SAFE reports (NPFMC 2004a 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 recruitment 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). Recruitment or SR series were lined up by year-class, resulting in matrices of recruitment / 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 in each series were estimated by imputation using additive regression, bootstrapping, and predictive mean matching as implemented in the "hmisc" package for S-Plus (Frank Harrell, Univ. of Virginia, pers. comm.). 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 R and SR was not accounted for.

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 106). Estimates at the beginning and end of the series were based on only a few stocks and are highly uncertain, but recruitment in the BSAI remained mostly below average through 2003, the last year for which data for at least 3 stocks was available. Recruitment indices for the GoA indicated variable recruitment through the 1990s and below average recruitment in 2001 and 2002. The CSI_{SR} were more variable but showed very similar patterns. Both regions had unusually high survival and recruitment indices in 1984, when recruitment of all stocks except flathead sole in the GoA and yellowfin sole in the BSAI were estimated to be above average.

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 = 0.52). These variations in productivity are correlated with and may in part be driven by variations in large-scale climate patterns such as the PDO, which changed sign in 1976/77, and the Victoria pattern, which changed sign in 1989/90. Recruitment and survival indices for the Gulf of Alaska (but not for the Bering Sea) were significantly positively correlated with the Nov-Mar PDO index for the preceding winter (r = 0.56, p < 0.001 for CSI_R; r=0.36, p = 0.045 for CSI_{SR}).
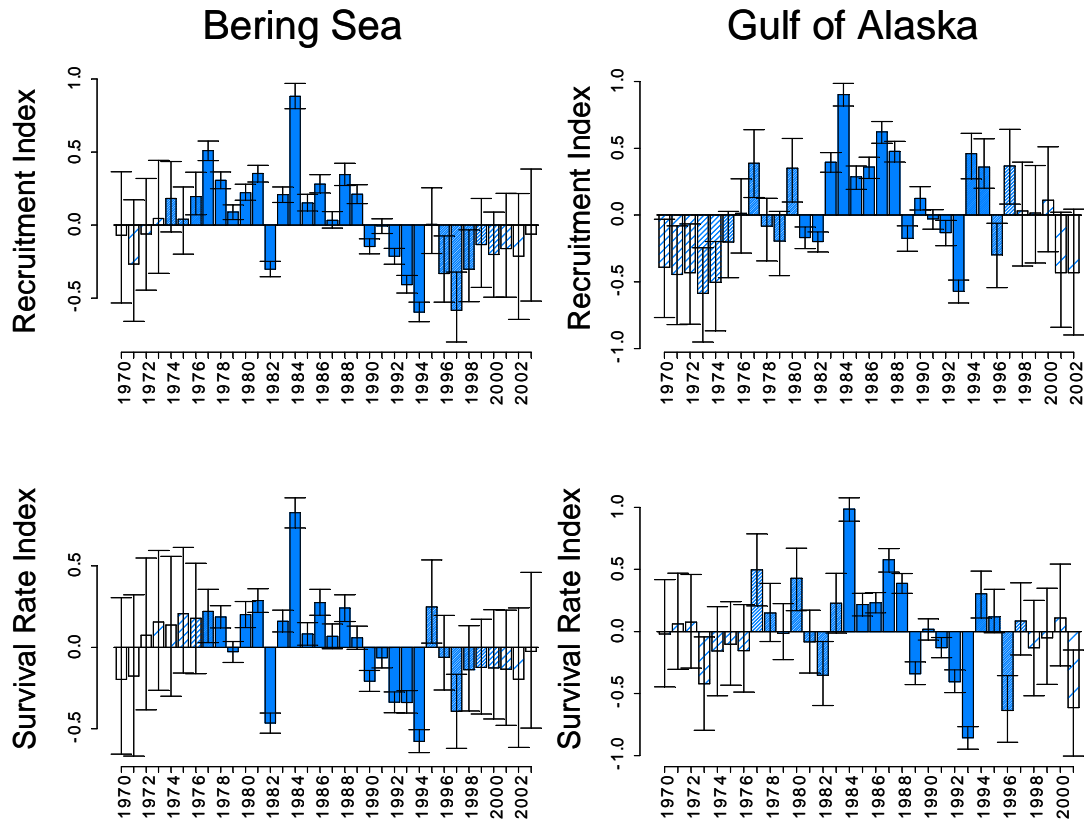
Figure 106. Combined Standardized Indices of recruitment (top) and survival rate (Ricker residuals, bottom) by year class across demersal stocks in the Bering Sea / Aleutian Island region (11 stocks) and in the Gulf of Alaska (11 stocks). Solid blue bars represent years with data for all stocks or stock groups. Lighter shading corresponds to years with more missing stocks. Series were truncated in 1970 and only years with data for at least 3 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 107). Species richness and diversity on the Eastern Bering Sea shelf have undergone significant variations from 1982 to 2004 (Figure 108). 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 100m 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.
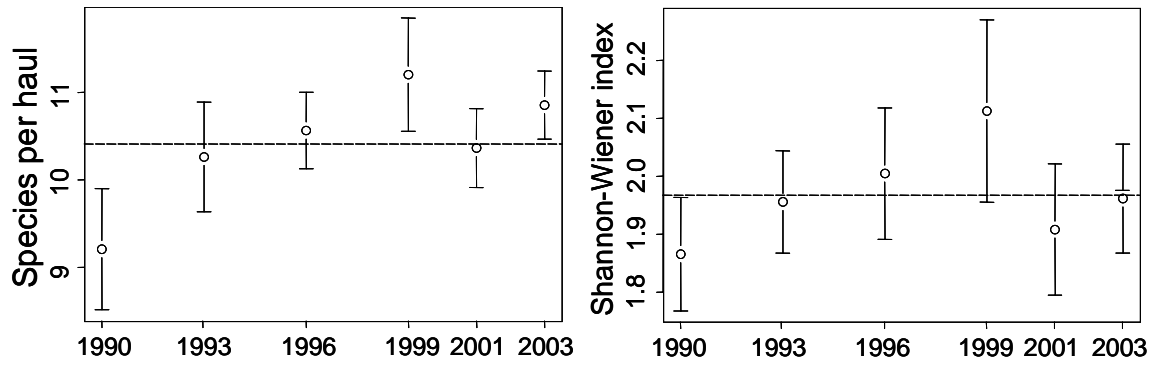
Figure 107. Model-based annual averages of species richness (average number of species per haul), and species diversity (Shannon-Wiener index) in the western Gulf of Alaska, 1990-2003, based on 55 fish taxa collected by standard bottom trawl surveys with 95% confidence intervals. Model means were adjusted for differences in area swept, depth, date and time of sampling, and geographic location among years.
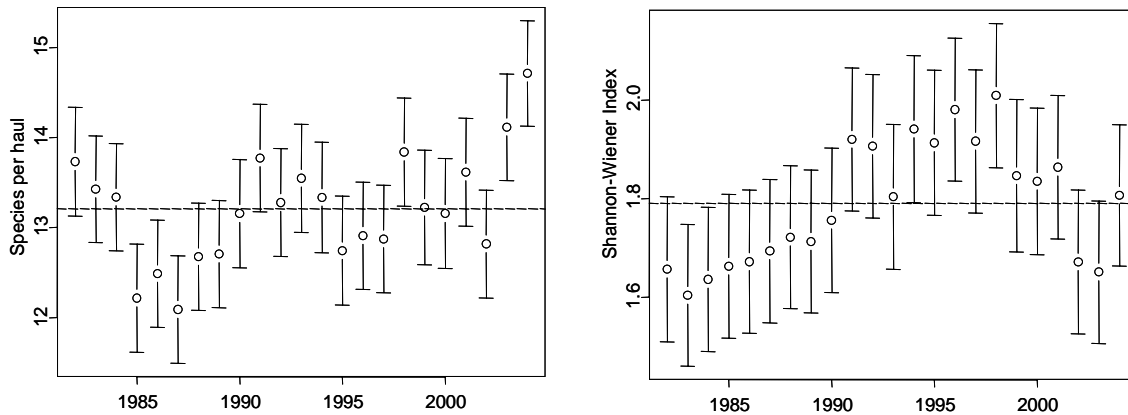
Figure 108. Model-based annual averages of species richness (average number of species per haul), and species diversity (Shannon-Wiener index) in the Eastern Bering Sea, 1982-2004, based on 47 fish taxa collected by standard bottom trawl surveys with 95% confidence intervals. Model means were adjusted 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

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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, pers. comm.) 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 109). 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 110), 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.
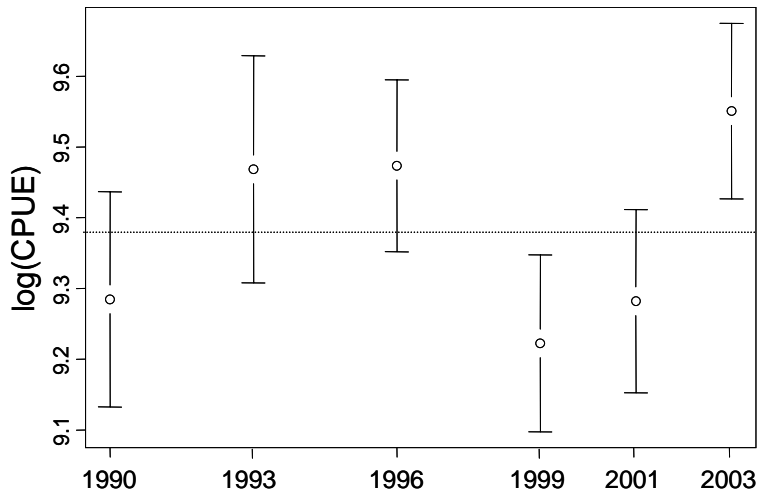
Figure 109. Model-based estimates of log(CPUE) for all fish and invertebrate taxa captured in bottom trawl surveys from in the western Gulf of Alaska (west of 147˚ W) by survey year with approximate 95% confidence intervals. Estimated means were adjusted for differences in depth, day of sampling, area swept and sampling locations among years.
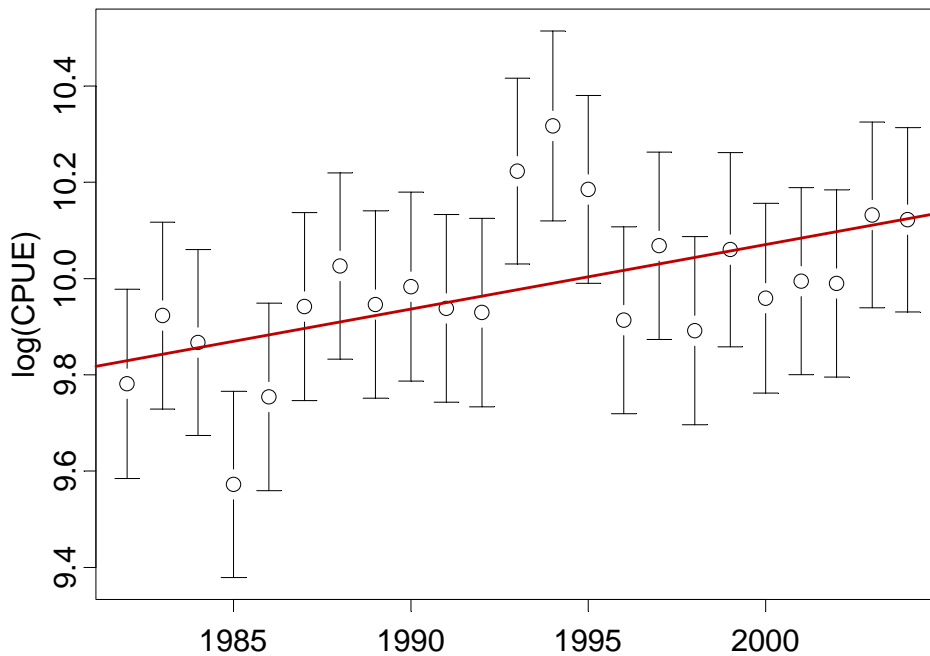
Figure 110. Model-based estimates of total log(CPUE) of all fish and invertebrate taxa captured in bottom trawl surveys from 1982 to 2004 in the Bering Sea with approximate pointwise 95% confidence intervals and long-term linear trend. Estimates were adjusted for differences in depth, bottom temperature, 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 Terry Hiatt and Joe Terry, Alaska Fisheries Science Center
Last updated: November 2005

The retention and sale of crab, halibut, herring, and salmon generally is prohibited in the groundfish fishery; therefore, these are referred to as prohibited species. The prohibition was imposed to reduce the catch or bycatch of these species in the groundfish fishery. A variety of other management measures have been used to control the bycatch of these species, and data from the groundfish observer program have been used to estimate the bycatch of these species and the bycatch mortality of halibut. Most of the groundfish catch and prohibited species bycatch is taken with trawl gear. The implementation of the halibut and sablefish IFQ programs in 1995 allowed for the retention of halibut in the hook and line groundfish fishery and effectively addressed an important part of the halibut bycatch problem in that fishery, but it also made it very difficult to differentiate between halibut catch and bycatch for part of the hook and line groundfish fishery. Therefore, the estimates of halibut bycatch mortality either for the hook and line fishery or for the groundfish fishery as a whole are not comparable before and after 1995.

Estimates of the bycatch of prohibited species other than halibut and estimates of halibut bycatch mortality are presented in Figure 111. Halibut bycatch is managed and monitored in terms of bycatch mortality instead of simply in terms of bycatch. This is done to provide an incentive for fishermen to increase the survival rate of halibut that are discarded. The survival rates for discarded salmon and herring are thought to approach zero and there is substantial uncertainty concerning the survival rates for discarded crab. Currently, the limited ability to control or measure survival rates for the other prohibited species makes it impracticable to manage and monitor their bycatch in terms of bycatch mortality.
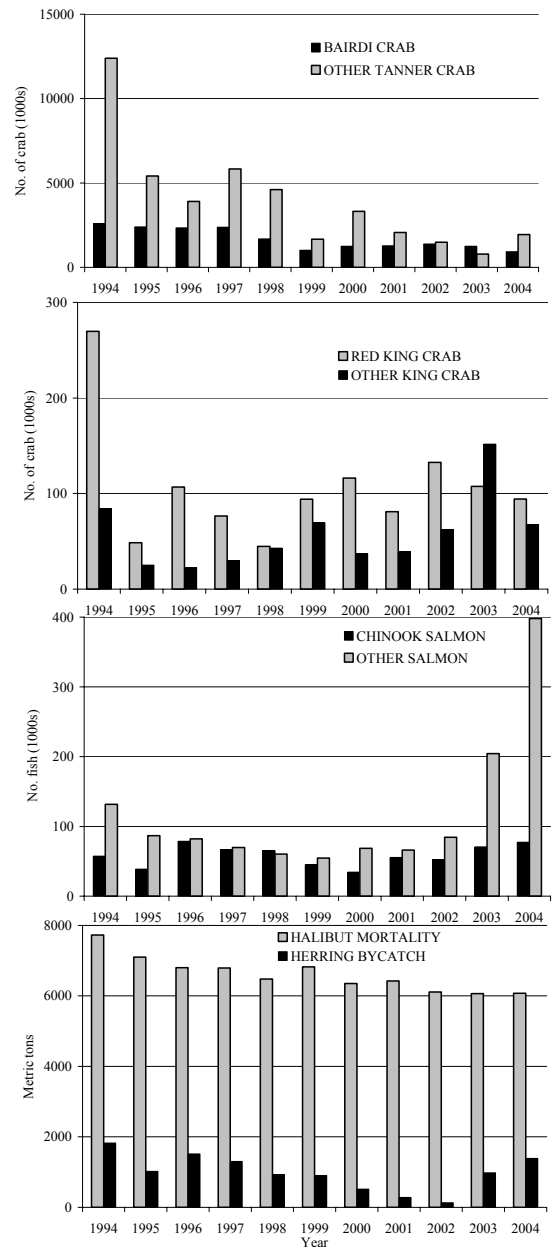
Figure 111. Bycatch of tanner and king crab, salmon, halibut, and herring in groundfish fisheries off Alaska, 1994-2004.

Between 2002 and 2003, there were large increases in the bycatch of herring, "other king crab" (OKC) and "other salmon" (OS), with herring bycatch increasing by over 600% and the bycatch of both OKC and OS more than doubling.

Most of the herring bycatch in all years occurs in the BSAI trawl fisheries (98% in 2002, 99% in 2003 and 80% in 2004), primarily during the months of July, August and September with smaller amounts in January through March and October. After the dramatic increase in 2003, the herring bycatch increased again by about 42% in 2004. The recent rise in bycatch can be partly explained by increases of herring biomass; the biomass of Kuskokwim herring, for example, is estimated to have increased by about 34% in 2003 and again by about 32% in 2004. GIS maps of haul-by-haul observer data (which cannot be published because of confidentiality constraints) reveal differences in the distribution of both effort (all pelagic-trawl hauls) and bycatch (hauls with herring in the species composition) over the years 2002-04. In February, March, September and October of 2003 and in February, September and October of 2004, pelagic trawl activity and the resulting herring bycatch extended further to the northwest along the edge of the Bering Sea shelf than in the corresponding months of 2002; bycatch events occurred between 200 and 250 kilometers further to the northwest in all months cited except for October of 2003 (about 130 kilometers further northwest than in 2002), and October, 2004 (almost 700 kilometers further). Also, in July and August of 2003 and in August of 2004, the amount of both effort and bycatch, as shown by the density of hauls on the maps, increased noticeably in the northwesternmost portions of the fleet's range compared to the same periods in 2002.

The OKC bycatch decreased in 2004, but it remained almost 50% higher than the average bycatch over the years 1994-2002. In 2002, most of the OKC bycatch occurred in the BSAI sablefish pot and BSAI longline Pacific cod fisheries, with about 27% of the total OKC bycatch in each of the two fisheries. In 2003 and 2004, however, 94% and 89%, respectively, of the OKC bycatch occurred in the BSAI sablefish pot fishery.

As for the OS bycatch, part of the 2003 increase could be explained by the 28% increase in the overall catch of OS in 2003 compared to 2002 (as reported by the Alaska Department of Fish & Game), which suggests that there simply may have been more salmon available to be caught in 2003. The OS bycatch nearly doubled again in 2004, however, even though the overall catch was essentially unchanged from 2003. The source of the problem is that the regulatory measures implemented to control chum salmon bycatch in the BSAI trawl fisheries (which account for about 95% of salmon bycatch) have not been working. In 1994, the North Pacific Fisheries Management Council and NMFS established the Chum Salmon Savings Area (CSSA) in parts of the Bering Sea and at times when salmon bycatch had been highest based on historical observer data. Unfortunately, in both 2003 and 2004 the highest chum salmon bycatch rates were outside of the CSSA and after its closure. Similar problems occurred in 2003 and 2004 with Chinook salmon bycatch outside of the Chinook Salmon Savings Area—the highest bycatch rates were encountered by the pollock trawl fleet outside of the Savings Area after regulations had forced its closure. The resulting Chinook salmon bycatch was about 28% higher in 2003 and 41% higher in 2004 than the long-term average for the years 1994-2002. To address these problems, the Council is considering other means to control salmon bycatch.

Annual estimates for the years 1994-2002 come from NMFS Alaska Region's blend estimates; 2003-04 estimates are from the Alaska Region's new Catch Accounting System.

Time trends in groundfish discards
Contributed by Terry Hiatt and Joe Terry, Alaska Fisheries Science Center
Last updated: November 2005

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 112). 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 have increased somewhat since 1998 but are still lower than amounts observed in 1997, prior to the implementation of the improved retention regulations. Estimates of discards for 1994-2002 come from NMFS Alaska Region's blend data; estimates for 2003-04 come from the Alaska Region's new Catch Aaccounting 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.
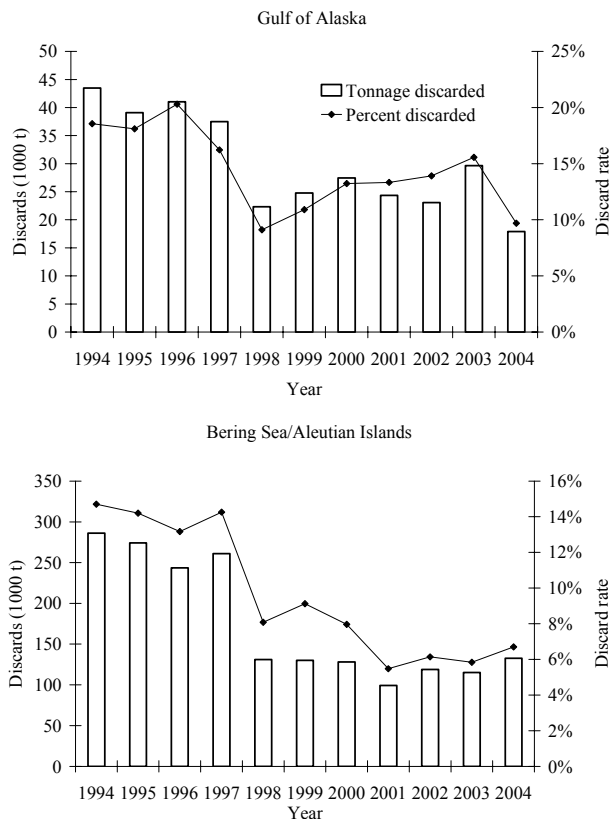
Figure 112. Total biomass and percent of total catch biomass of managed groundfish discarded in the GOA and BSAI areas 1994-2004. (Includes only catch counted against federal TACs).

Time Trends in Non-Target Species Catch
Contributed by Sarah Gaichas and Jennifer Boldt, Alaska Fisheries Science Center
Last updated: November 2004

In addition to prohibited and target species catches, groundfish fisheries also catch non-target species (Figure 113). There are four categories of non-target species: 1.) forage species (gunnels, sticheids, sandfish, smelts, lanternfish, sandlance), 2.) non-specified species (grenadiers, crabs, starfish, jellyfish, unidentified invertebrates, benthic invertebrates, echinoderms, other fish, birds, shrimp), 3.) other species (sculpins, unidentified sharks, salmon sharks, dogfish, sleeper sharks, skates, octopus, squid), and 4.) HAPC (seapens/whips, sponges, anemones, corals, tunicates).

In the BSAI, non-target catch was primarily comprised of non-specified and other species categories (Figure 113). Jellyfish, starfish, grenadiers, and other fish dominated the non-
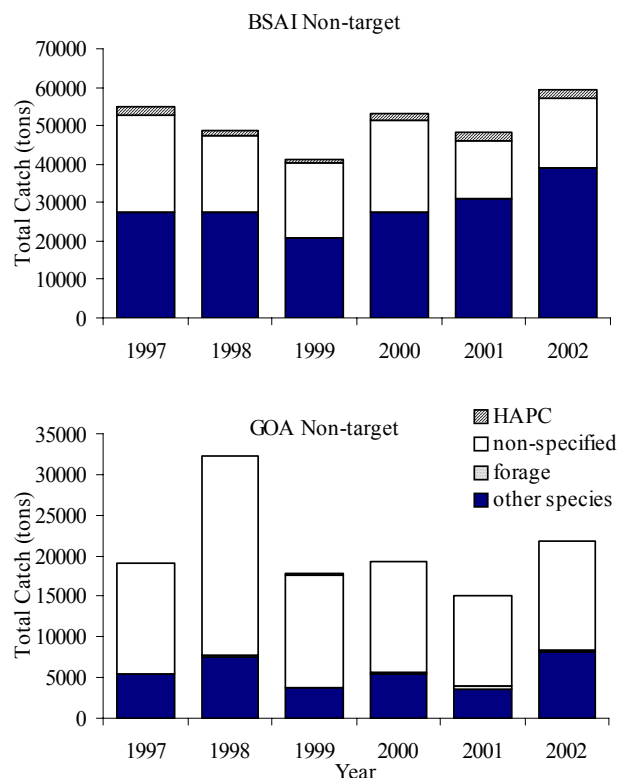
Figure 113. Total catch of non-target species (tons) in the BSAI and GOA areas by groundfish fisheries.

specified group and skates, sculpins and squid dominated the other species category. The non-target catch in the GOA also consisted primarily of non-specified and other species categories. Grenadiers were the dominant fish caught in the non-specified category in all years; other fish were also important in 1998. The other species category in the GOA consisted primarily of skates, but also included sculpins, dogfish, and unidentified sharks.

HAPC biota and forage species are also presented in Figure 113, but are small relative to the other categories of non-target catch. HAPC biota catch estimates range from 922 to 2548 t (primarily tunicates) in the BSAI, and from 27 to 46 t, (primarily anemones) in the GOA. Non-target forage catches consist primarily of smelts and range from 24 to 83 t in the BSAI and from 27 to 541 t in the GOA.

Most non-target catch is discarded as well as some target catch. Non-target and target discard estimates are comparable in the GOA. BSAI discards of non-target species are more than double the GOA discards of non-target species. In the BSAI, however, non-target discard estimates are less than one-third of the target discard estimates. 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.

Ecosystem Goal: Maintain and Restore Fish Habitats

Areas closed to bottom trawling in the EBS/ AI and GOA
Contributed by Cathy Coon, NPFMC
Last updated: November 2005

Many trawl closures have been implemented to protect benthic habitat or reduce bycatch of prohibited species (i.e., salmon, crab, herring, and halibut) (Table 32 and Figure 114). 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 32. 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 2005 as part of protection for Essential Fish Habitat encompasses a large portion of the Aleutian Islands (Figure 115). 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.
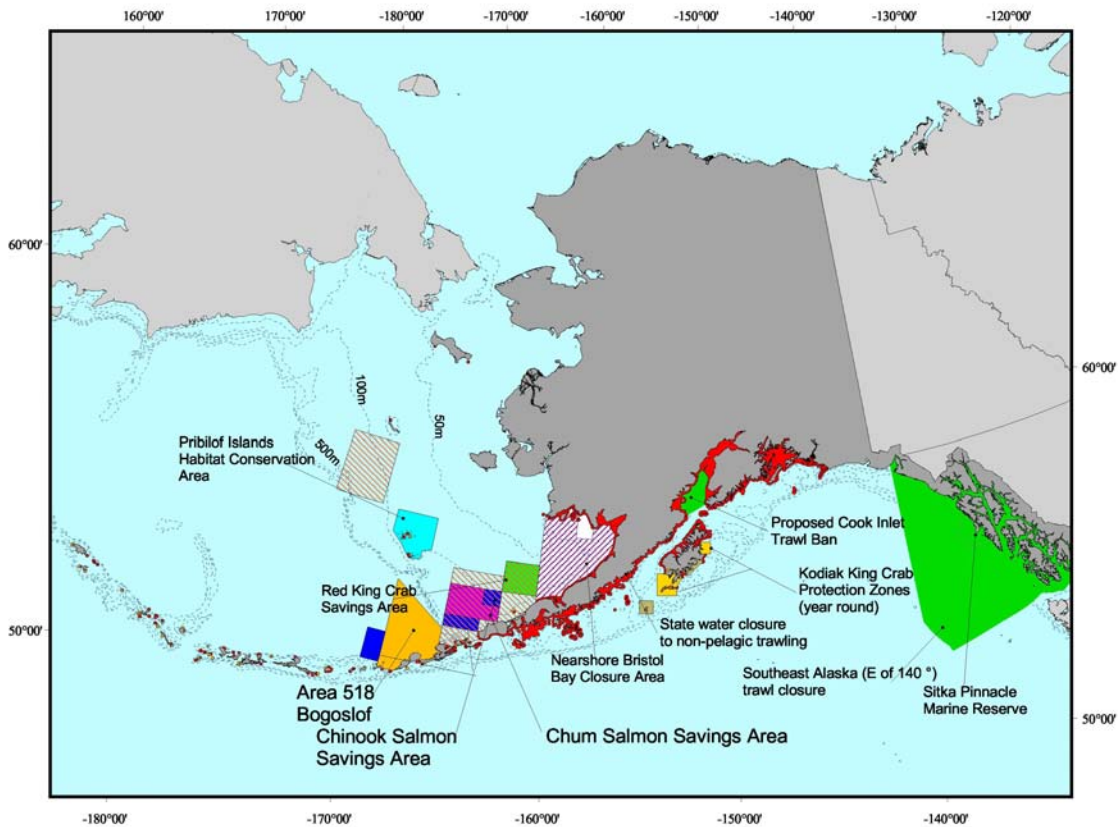
Figure 114. Groundfish closures in Alaska's Exclusive Economic Zone
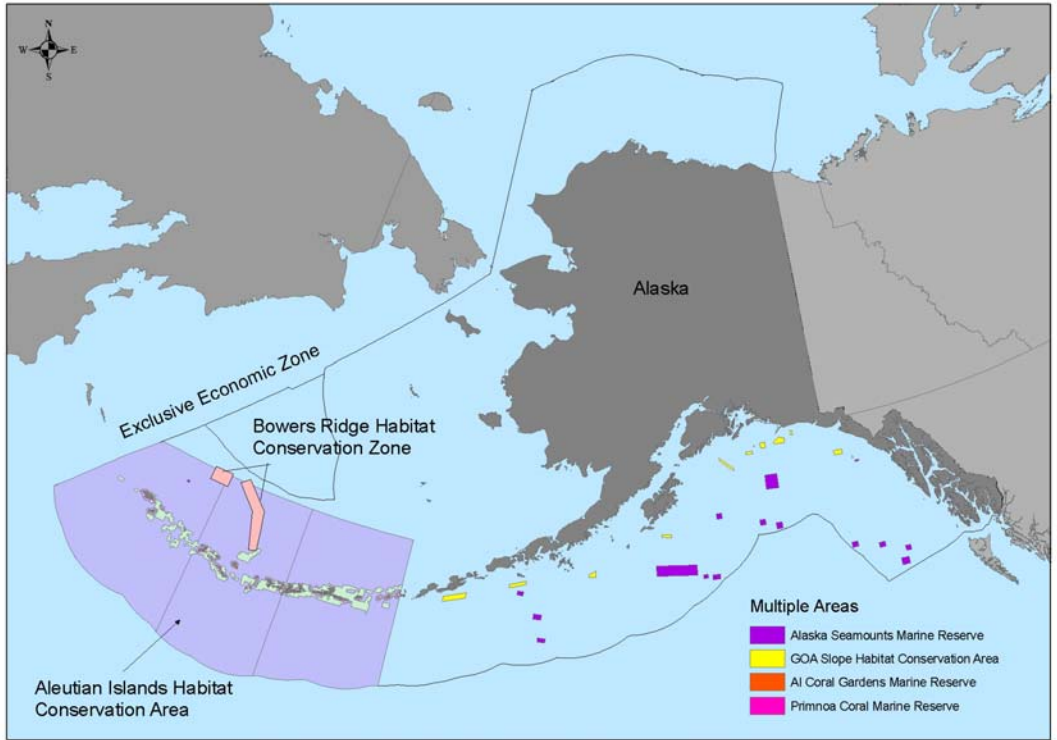
Figure 115. Additional Closures within the Aleutian Islands for bottom trawling implemented in 2005 as part of Essential Fish Habitat rule making. Other areas pending regulations in 2006 will protect seamounts and Gulf of Alaska Slope areas.

Table 32. 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	29,000 nm^2	
	Mackerel Restrictions			
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	29,000 nm^2	
	Mackerel Restrictions			
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	29,000 nm^2	
	Mackerel Restrictions			
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 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 nm2	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			

2000 Pollock haulout trawl exclusion zones for GOA* *areas include EBS, AI*
                No trawl all year 11,900 nm2*
                No trawl (Jan-June)14,800 nm2*

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 nm2*
                No trawl (Jan-June)14,800 nm2*

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 nm2*
                No trawl (Jan-June)14,800 nm2*
      Cook Inlet trawl closure: non-pelagic trawl exclusion to address crab bycatch avoidance
            Year round   nm2

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 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
Last updated: November 2005

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 116. 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 118-122 show the spatial patterns and intensity of longline effort, based on observed data as well as anomalies based on year 2004. 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.
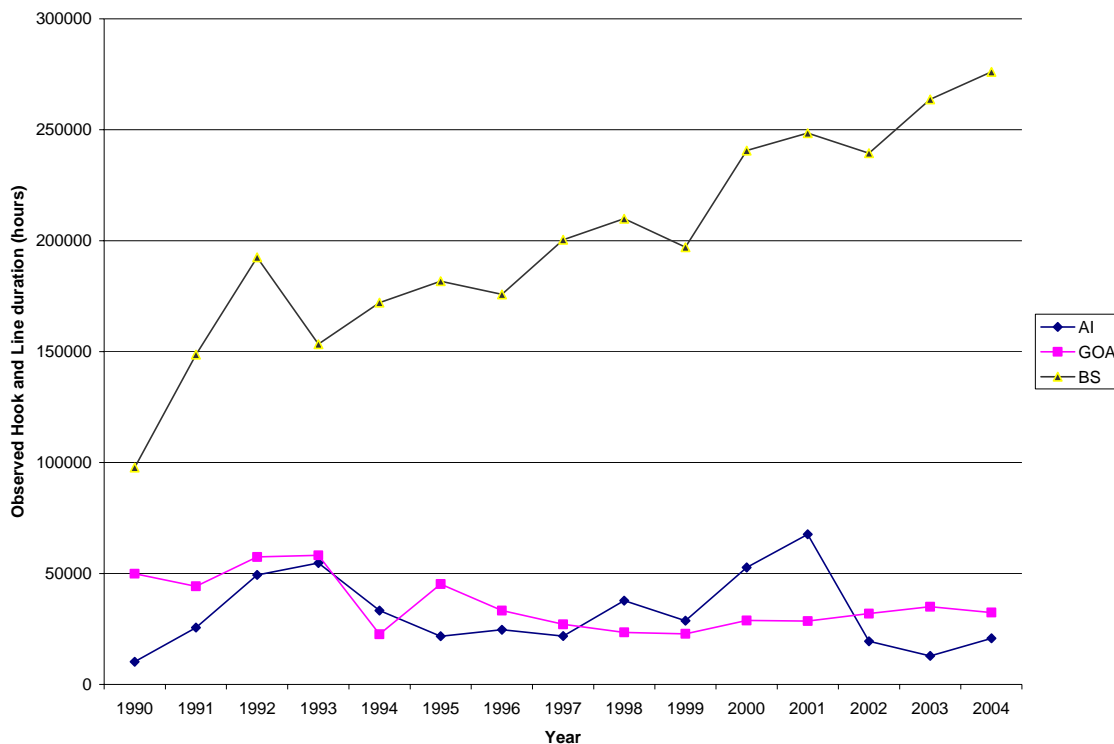
Figure 116. Estimated hook and line duration in the Gulf of Alaska, Bering Sea, and Aleutian Islands during 1990-2004.

Bering Sea

For the period 1990-2004, there were a total of 171,043 observed longline sets in the Bering Sea fisheries. Spatial patterns of fishing effort were summarized on a 5km2 grid (Figure 117). 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 2004, fishing effort was anomalously high throughout the main fishery footprint, and is not readily attributable to seasonal allocations (Figure 118).
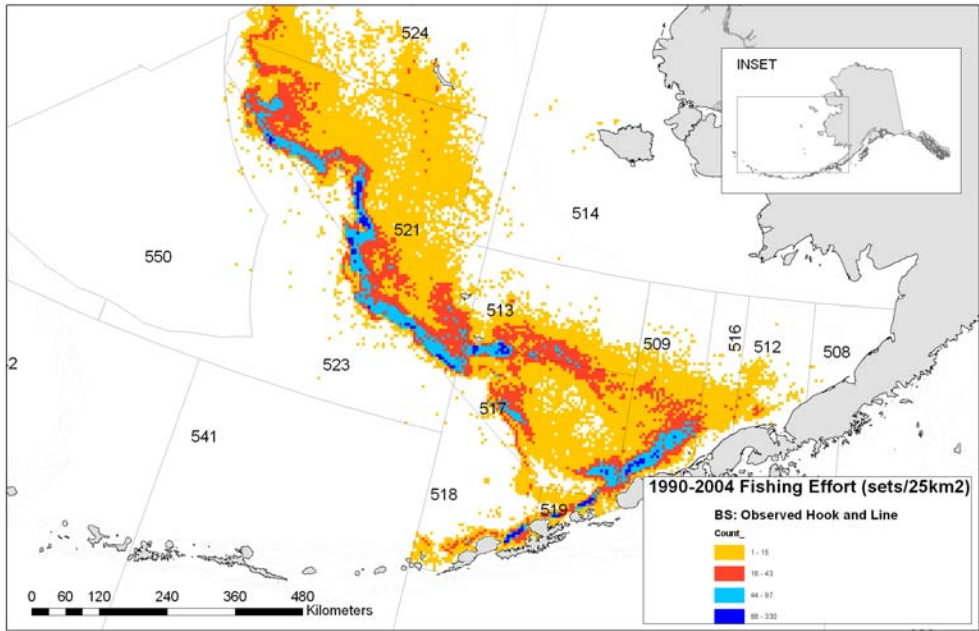
Figure 117. Spatial location and density of hook & line (longline) effort in the Bering Sea 1990-2004.
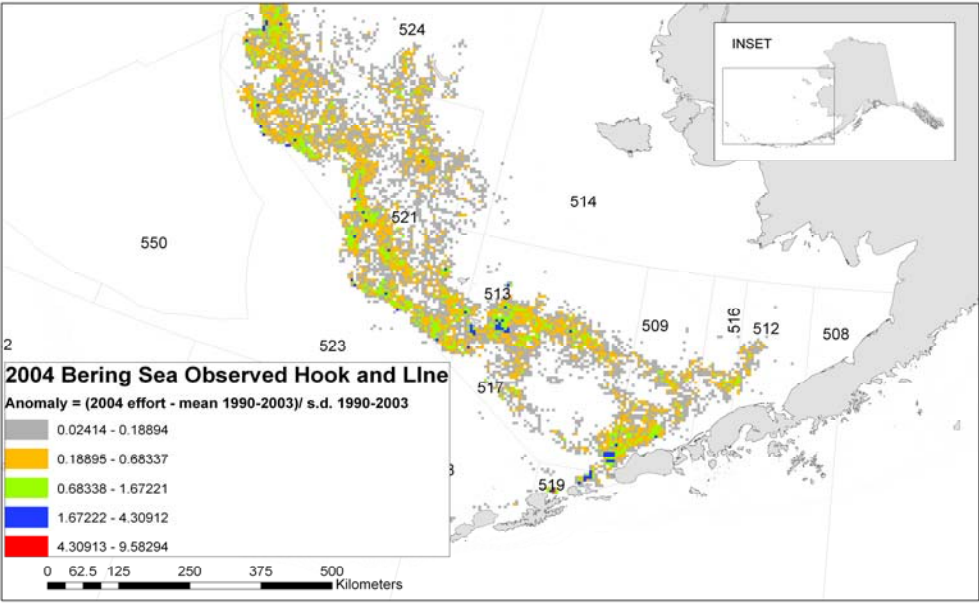
Figure 118. Anomaly plot for Bering Sea observed hook and line (longline) effort in 2004 relative to the average effort during 1990-2003 ((estimated effort for 2004 - average effort from 1990-2003)/stdev(effort from 1990-2003)).

Aleutian Islands

For the period 1990-2004 there were 36,104 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 (Figure 119). 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. In 2004, fishing effort was anomalously high in areas 541 and 542 and was based primarily within the Pacific cod and sablefish fisheries (Figure 120).
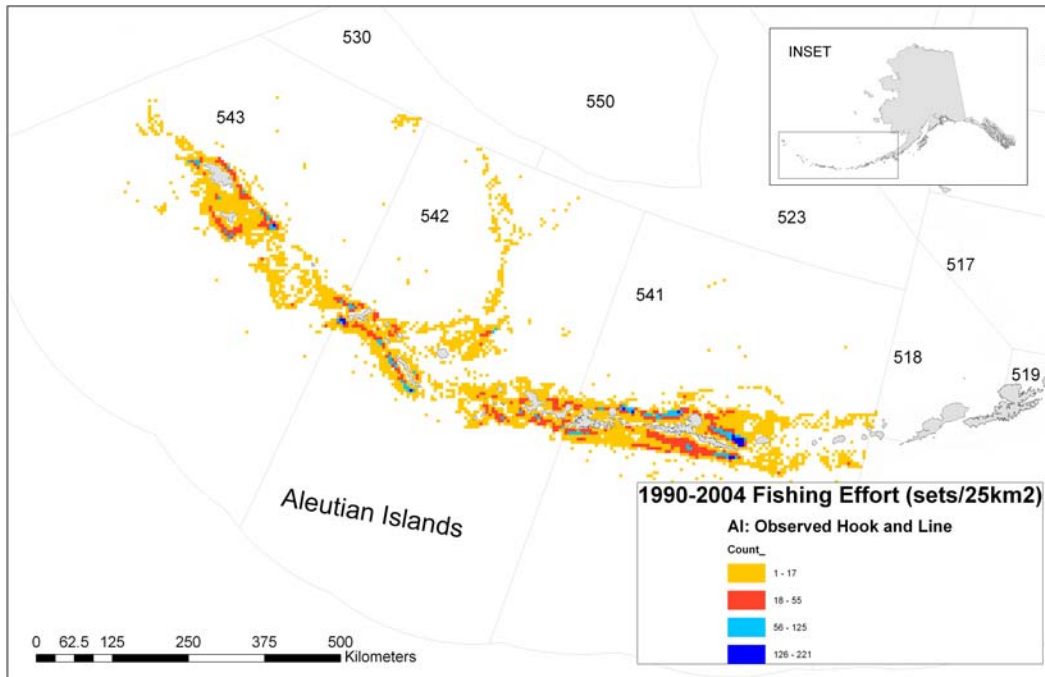
Figure 119. Spatial location and density of hook & line effort in the Aleutian Islands, 1990-2004.
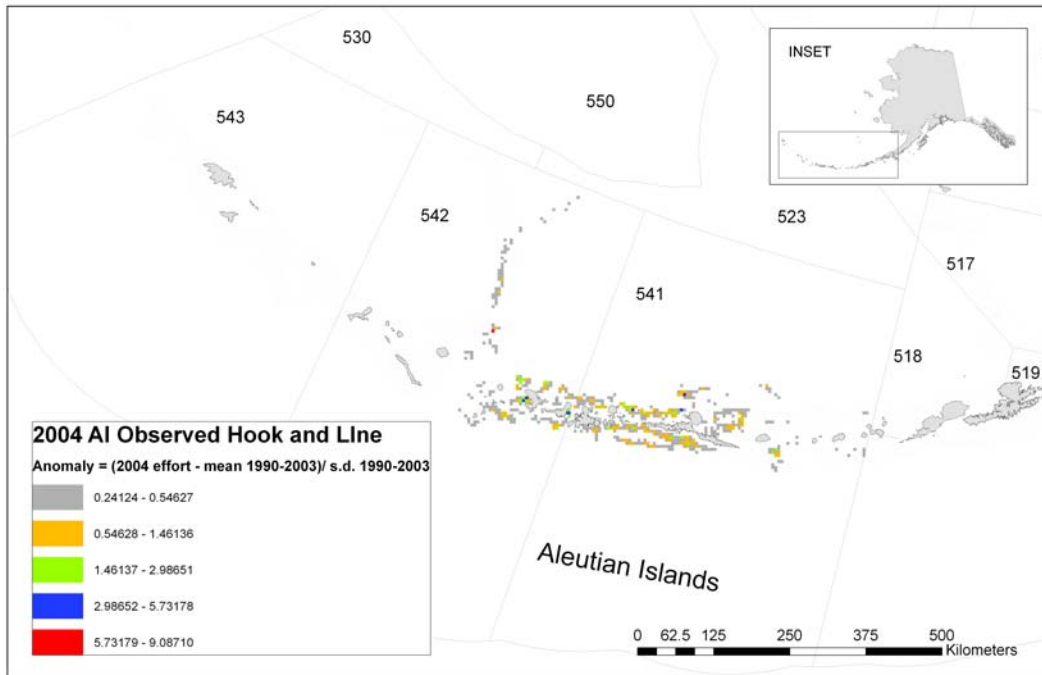
Figure 120.   Anomaly plot for Aleutian Islands observed hook and line (longline) effort in 2004, relative to the average effort during 1990-2003 ((estimated effort for 2004 - average effort from 1990-2003)/stdev(effort from 1990-2003)).

Gulf of Alaska

For the period 1990-2004 there were 34,625 observed hook and line sets in the Gulf of Alaska. Patterns of high fishing effort were dispersed along the shelf (Figure 121). 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. In 2004, fishing effort was anomalously high throughout the main fishery footprint, and is not readily attributable to seasonal allocations (Figure 122).

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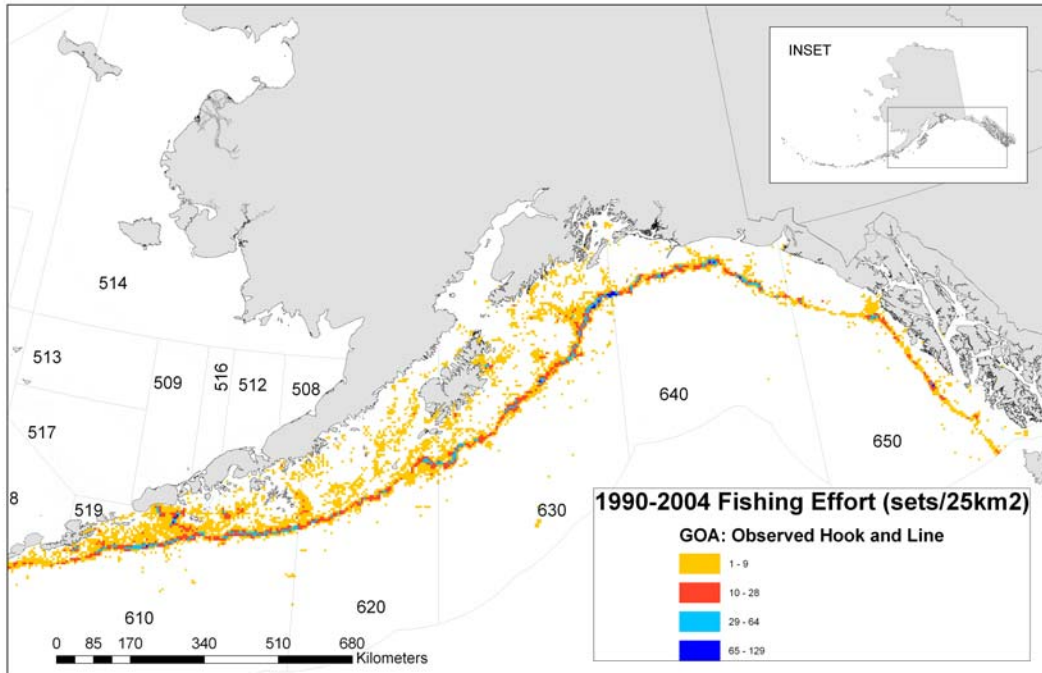
Figure 121. Spatial location and density of hook & line effort in the Gulf of Alaska, 1998-2003.
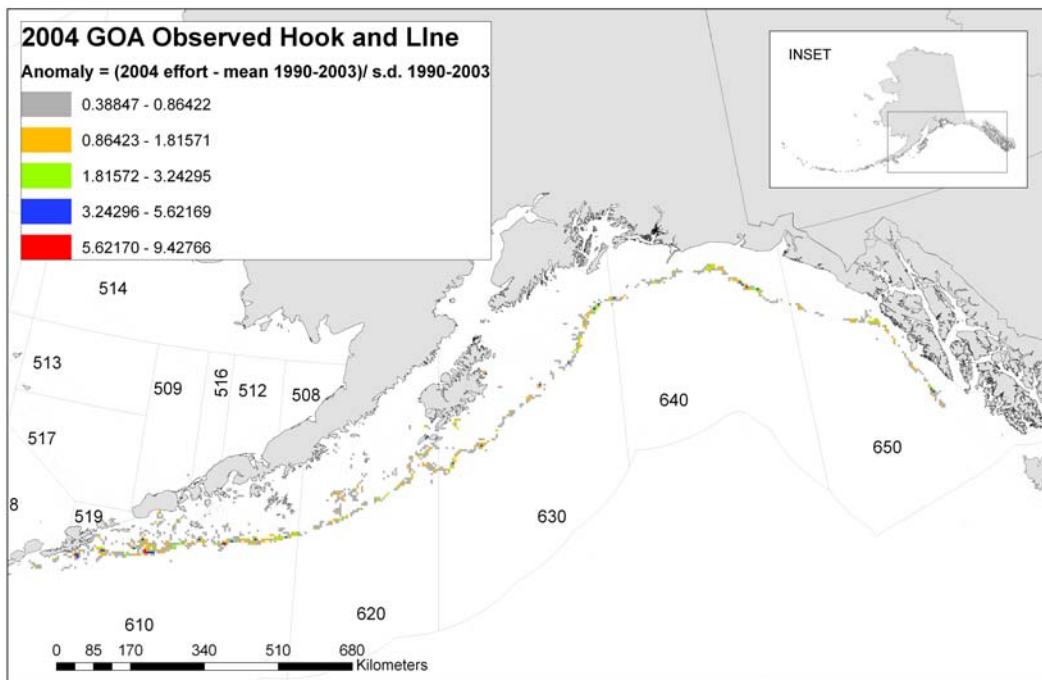
Figure 122.   Anomaly plot for the Gulf of Alaska observed hook and line (longline) effort in 2004, relative to the average effort during 1990-2003 ((estimated effort for 2004 - average effort from 1990-2003)/stdev(effort from 1990-2003)).

Groundfish bottom trawl fishing effort in the Gulf of Alaska, Bering Sea and Aleutian Islands
Contributed by Cathy Coon, NPFMC
Last updated: November 2005

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 123). Effort in the Bering Sea remained relatively stable from 1991 through 1997, peaked in 1997, then declined (Figure 123). 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).

Bering Sea
For the period 1990-2004, there were a total of 271,057 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 124). 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 2004, fishing effort was anomalously high in areas 509 and 516 (Figure 125) where there were catches of Pacific cod, pollock and rockfish.
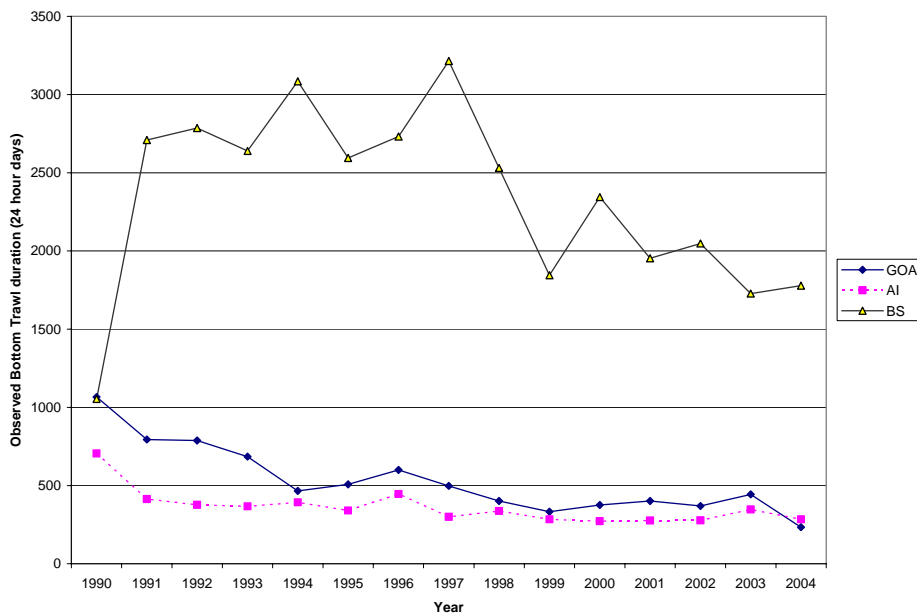

Figure 123. Estimated bottom trawl time in the Gulf of Alaska, Bering Sea, and Aleutian Islands during 1990-2004.
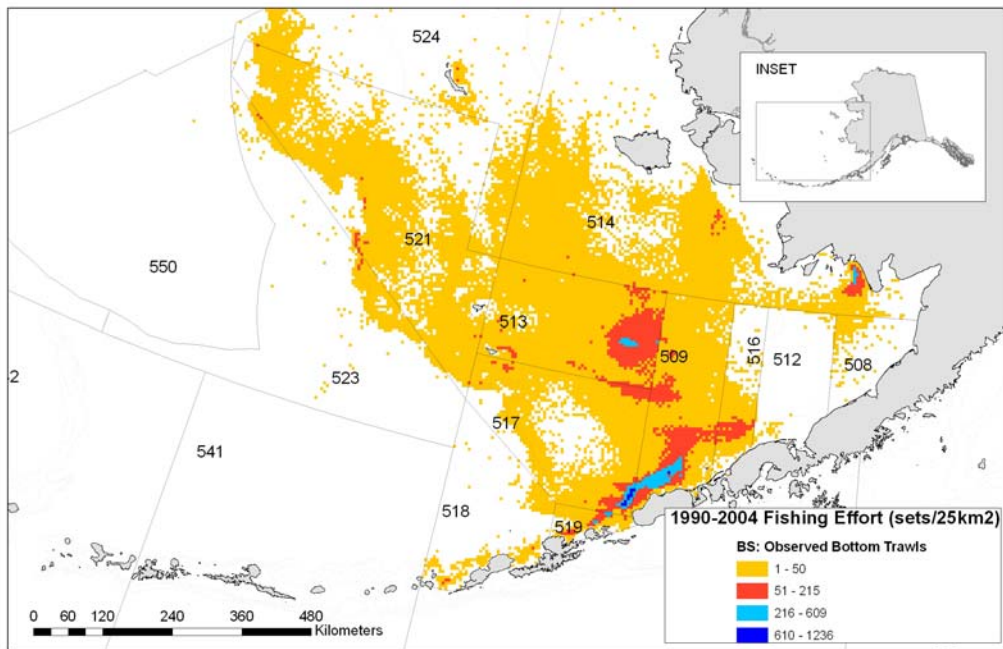
Figure 124. Spatial location and density of bottom trawling in the Bering Sea, 1990-2004.
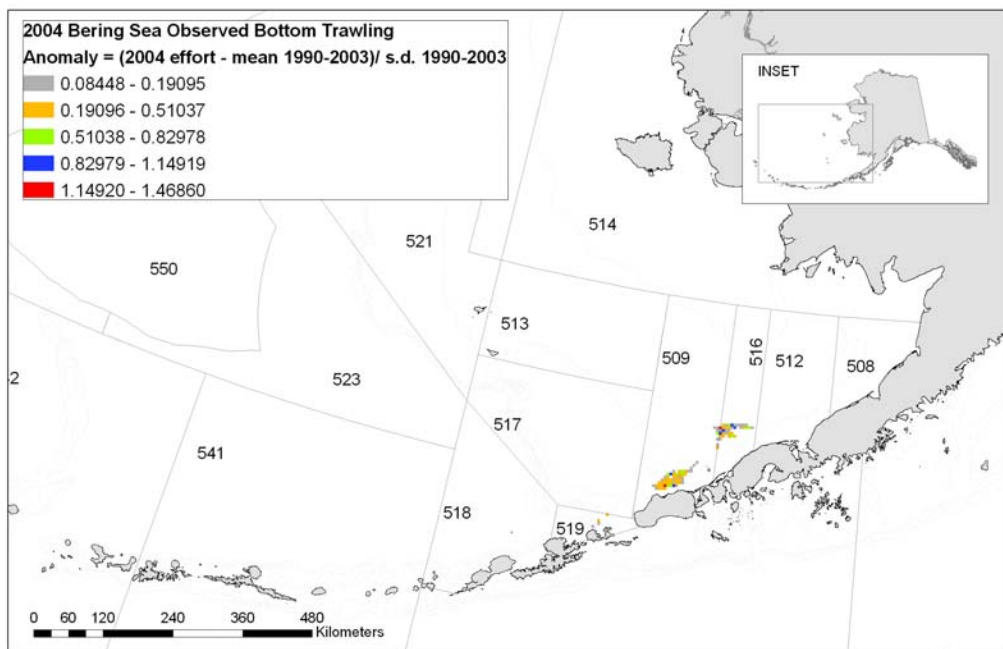
Figure 125. Fishing effort in 2004 shown as an anomaly relative to previous years of fishing effort (1990-2003) for Bering Sea observed bottom trawls ((estimated effort for 2004 minus average effort from 1990-2003)/stdev(effort from 1990-2003)).

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Aleutian Islands

For the period 1990-2004 there were 43, 465 observed bottom trawl sets in the Aleutian Islands. The spatial pattern of this effort was dispersed over a wide area. During 2004, the amount of trawl effort was 2,347 sets, which was the low for the 10 year period. Patterns of high fishing effort were dispersed along the shelf edge (Figure 126). 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 2004, fishing effort was anomalously high in areas 541 and 543 and fisheries in these areas targeted Atka mackerel, Pacific cod and rockfish (Figure 127).
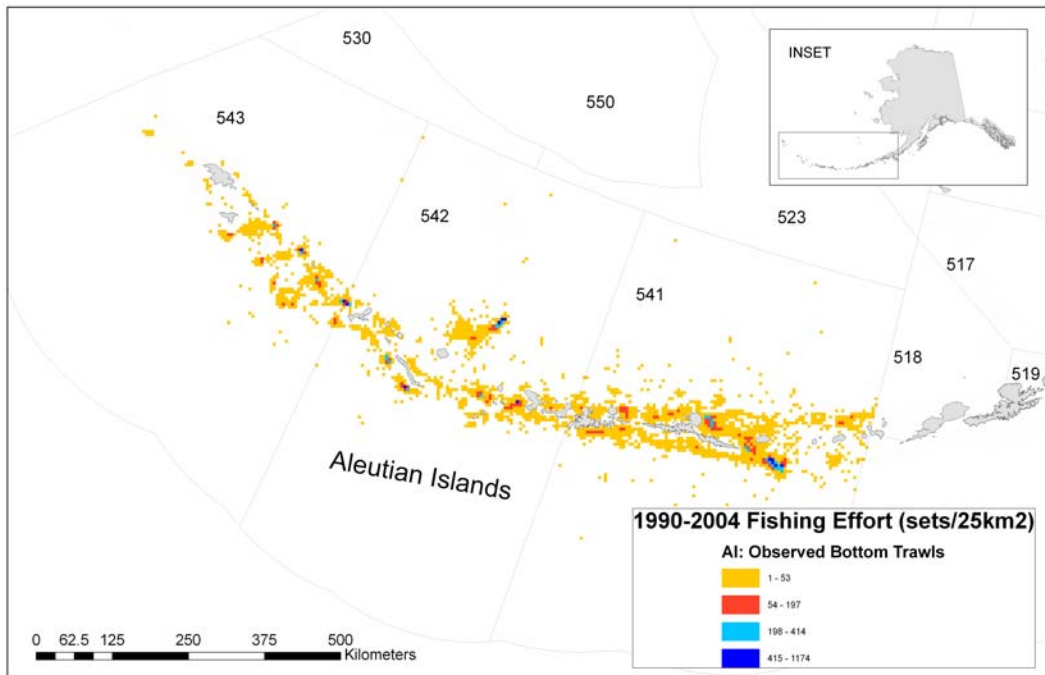
Figure 126. Spatial location and density of bottom trawl effort in the Aleutian Islands, 1990-2004.
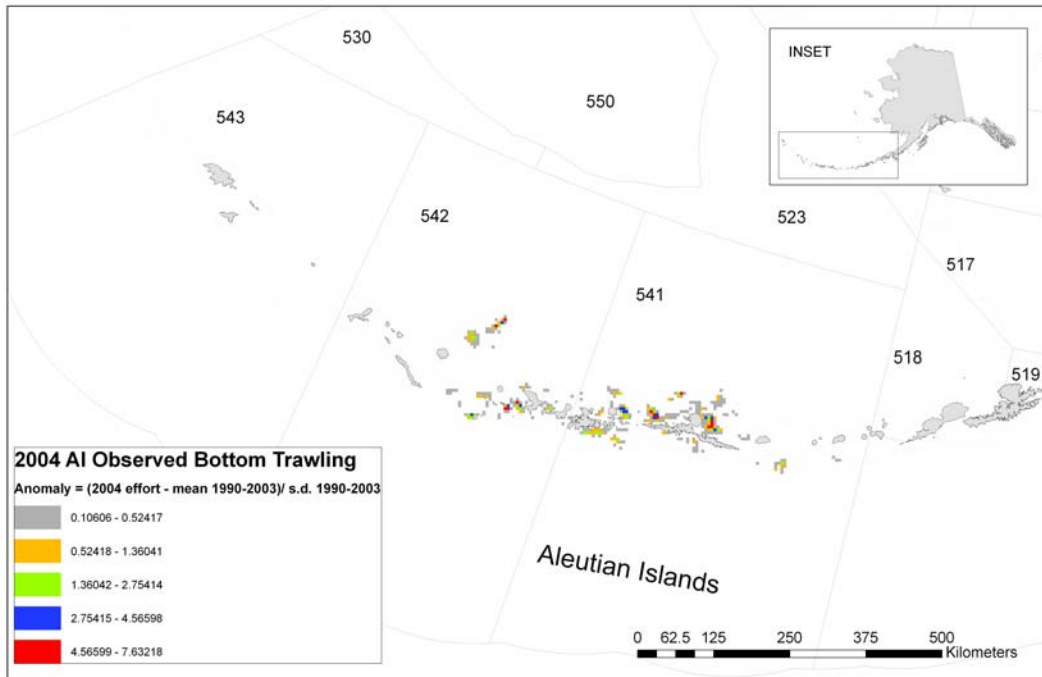
Figure 127. Fishing effort in 2004 shown as an anomaly relative to previous years of fishing effort (1990-2003) for Aleutian Islands observed bottom trawls ((estimated effort for 2004 minus average effort from 1990-2003)/stdev(effort from 1990-2003)).

Gulf of Alaska

For the period 1990-2004 there were 76,752 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 2000, the amount of trawl effort was 3,443 sets. 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 128). 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. In 2004, fishing effort was anomalously high along the shelf break and northeast of Kodiak Island (Figure 129). Fish caught in these areas were arrowtooth flounder, Pacific cod, rockfish, and shallow-water flatfishes.
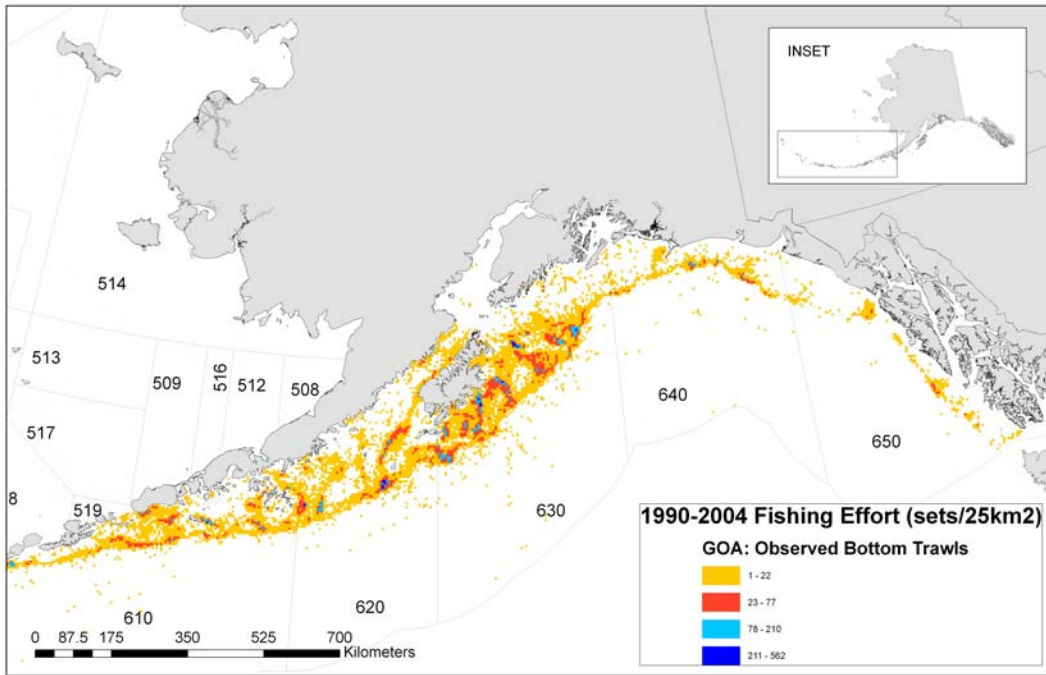
Figure 128. Spatial location and density of bottom trawl effort in the Gulf of Alaska, 1990-2004.
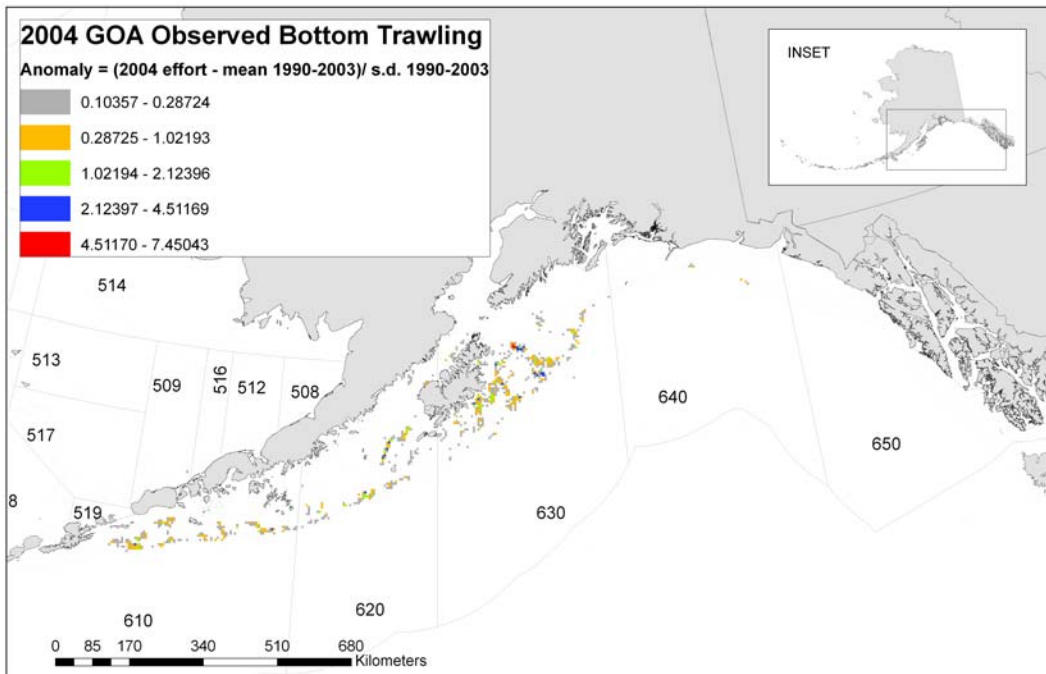
Figure 129. Fishing effort in 2004 shown as an anomaly relative to previous years of fishing effort (1990-2003) for Gulf of Alaska observed bottom trawls ((estimated effort for 2004 minus average effort from 1990-2003)/stdev(effort from 1990-2003)).

Groundfish pelagic trawl fishing effort in the Eastern Bering Sea
Contributed by Cathy Coon, NPFMC
Last updated: November 2005

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 130. The spatial pattern of fishing effort was summarized on a 5km^2 grid (Figure 131). 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.

In 2004, fishing effort was anomalously high throughout the main footprint of the fishery (Figure 132) these were based almost entirely on catches of pollock. 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.
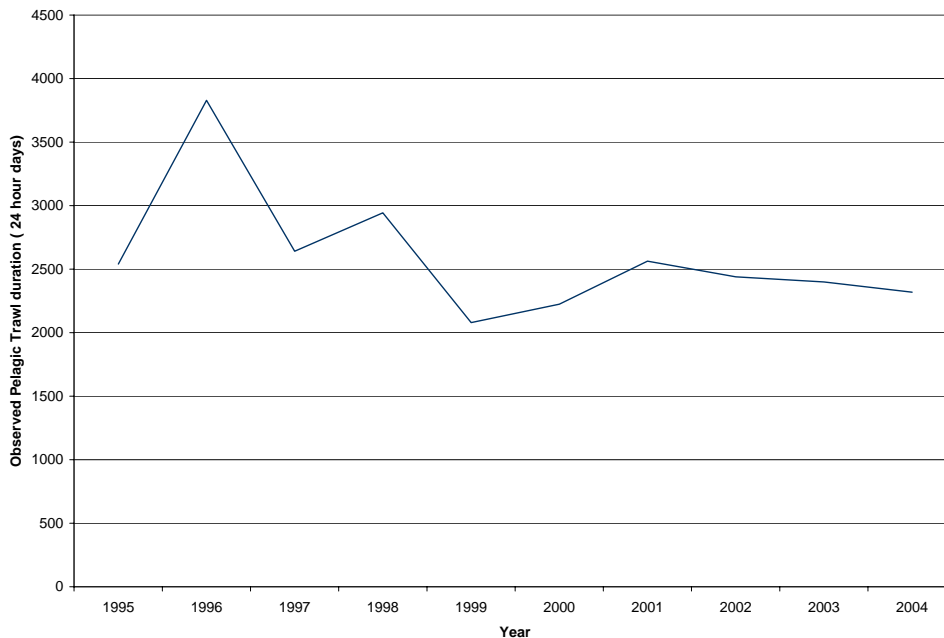
Figure 130. Observed pelagic trawl time in the eastern Bering Sea during 1990-2004.

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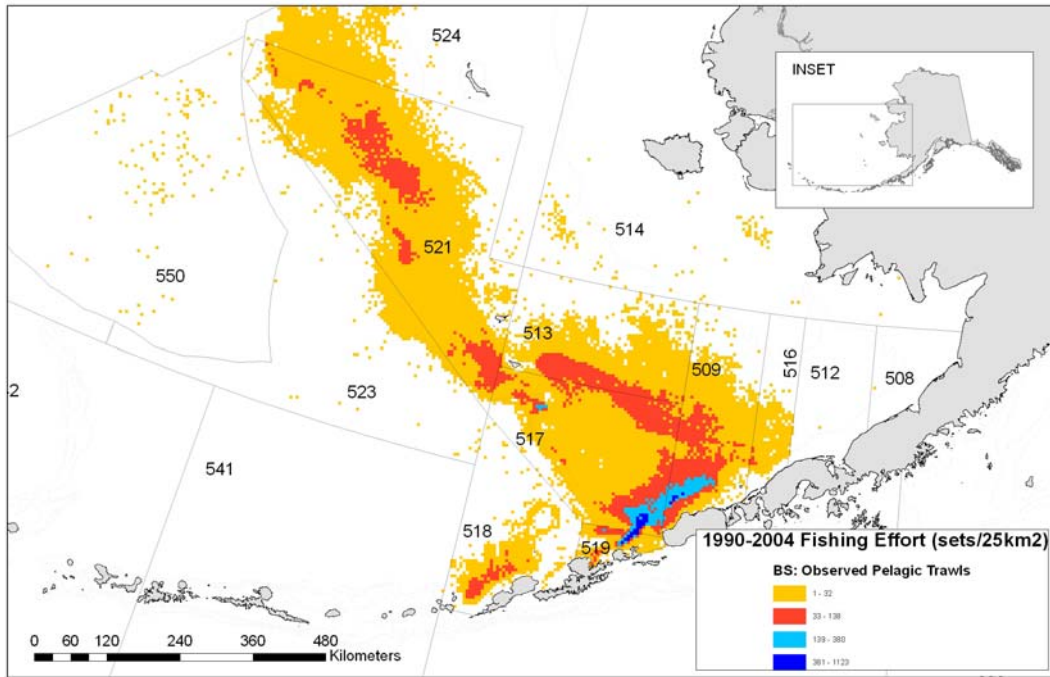
Figure 131. Spatial location and density of pelagic trawl effort in the eastern Bering Sea 1990-2004.
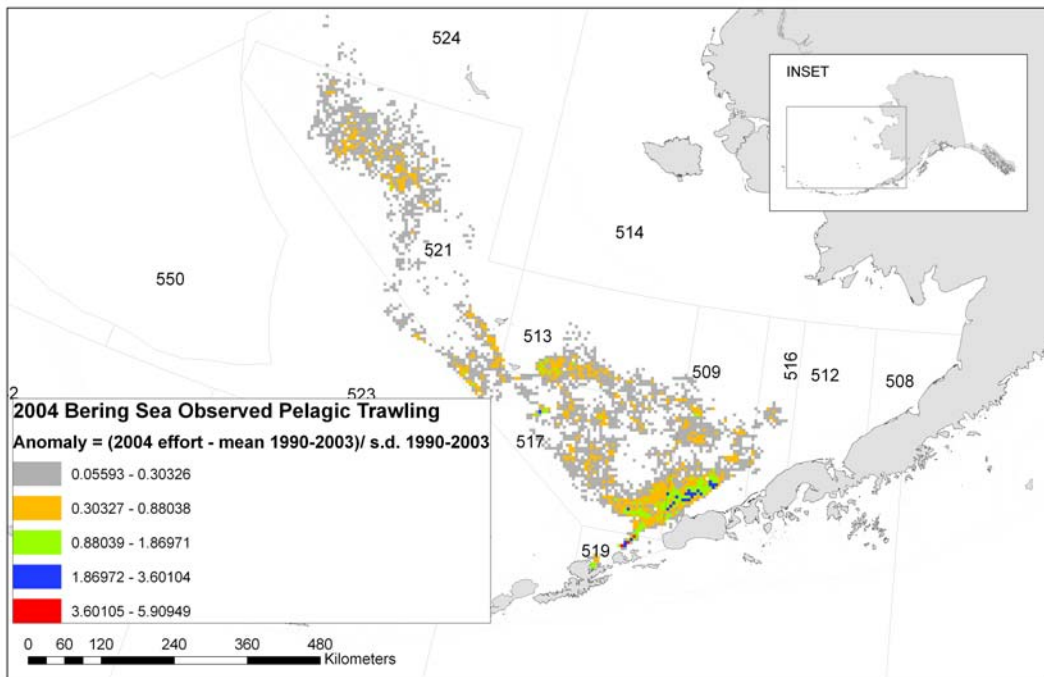
Figure 132. Anomaly plot for Bering Sea observed pelagic trawling effort in 2004 relative to the average effort during 1990-2003 ((estimated effort for 2004 - average effort from 1990-2003)/stdev(effort from 1990-2003)).

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

Trophic level of the catch

Contributed by Pat Livingston, Alaska Fisheries Science Center

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 Is Balanced (FIB) Index in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska areas were determined. Total catch levels and composition for the three regions show the dominance of walleye pollock in the catch from around the 1970's to at least the early 1990's (Figure 133). Other dominant species groups in the catch were rockfish prior to the 1970's in the Aleutian Islands and the Gulf of Alaska, and Atka mackerel in the 1990's 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 134) 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 1960's in all areas, the trophic level of the catch has been high and stable over the last 25 years.
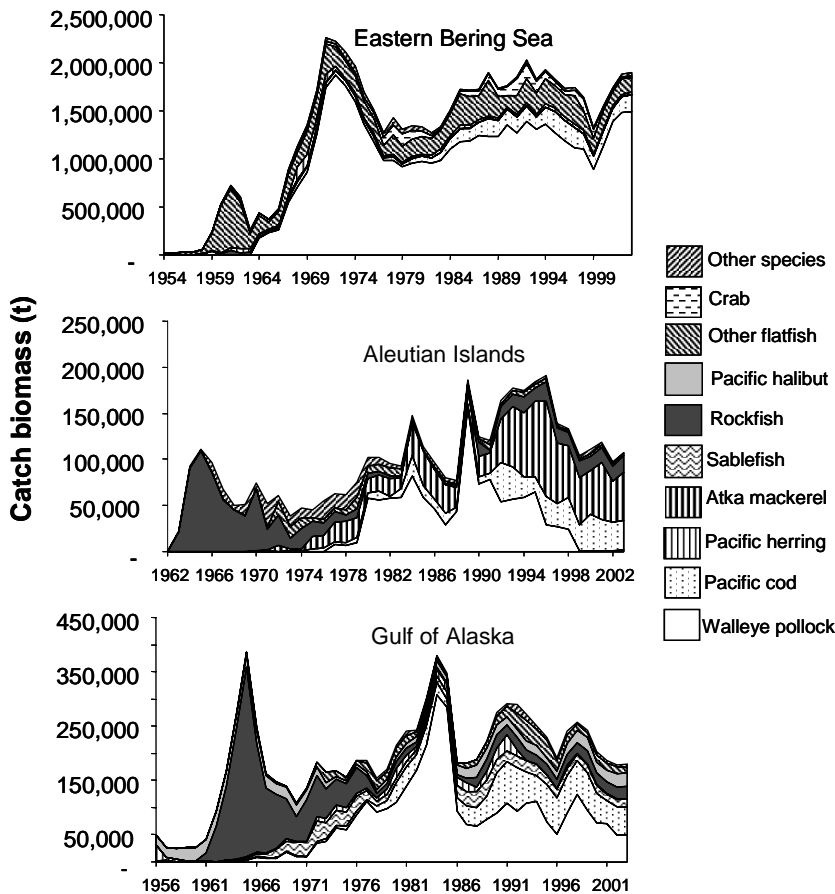
Figure 133. Total catch biomass (except salmon) in the EBS, GOA, and AI through 2003.

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 134) 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.
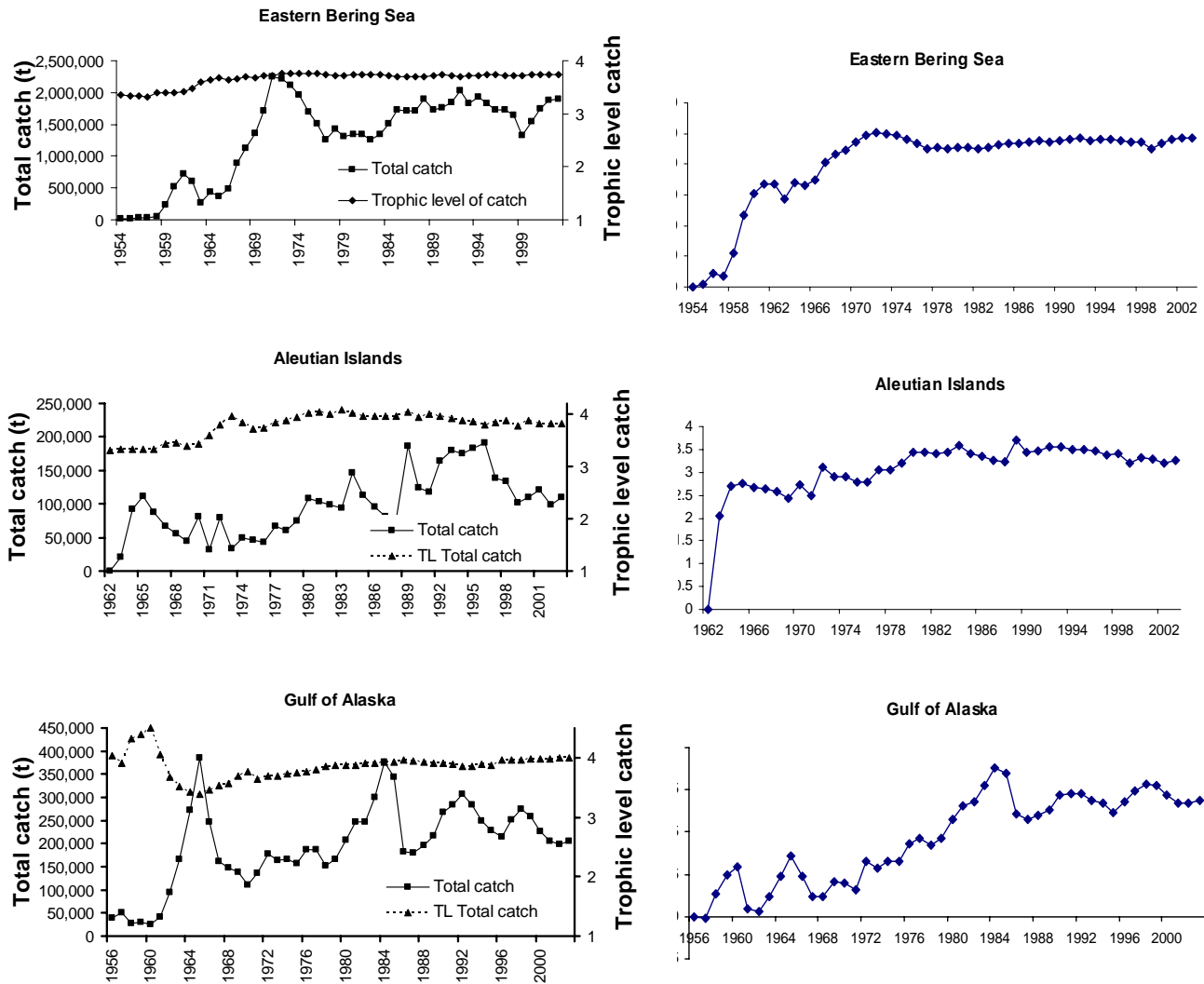
Figure 134. Total catch (groundfish, herring shellfish, and halibut) and trophic level of total catch in the EBS/AI and GOA through 2003 (left column). Right column shows FIB index values for the EBS, AI and GOA through 2003.

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Status of groundfish, crab, salmon and scallop stocks
Updated by Pat Livingston, Alaska Fisheries Science Center

Table 33 summarizes the status of Alaskan groundfish, crab, salmon and scallop stocks or stock complexes managed under federal fishery plans in 2004 from the Annual Report on Status of Stocks available on the web at: http://www.nmfs.noaa.gov/sfa/reports.htm

Table 33. Description of major and minor stocks managed under federal fishery management plans off Alaska, 2004. (Major stocks have landings of 200 thousand pounds or greater.)

| Stock Group | Number of Stocks and Stock Complexes | Overfishing? | | | | | Overfished? | | | | | Approaching Overfished Condition |
		Yes	No	Not Known	Not Defined	NA	Yes	No	Not Known	Not Defined	NA	
Major	53	0	49	3	1	0	1	31	0	21	0	0
Minor	17	0	9	8	0	0	3	1	0	13	0	0
Total	70	0	58	11	1	0	4	32	0	1	0	0

Four stocks are considered in the overfished category (Bering Sea Tanner crab and Pribilof Island Blue king crab, St. Matthew Island Blue king crab, and BS snow crab). 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 33, since it is jointly managed with the West Coast) that is not considered subject to overfishing. Since 2003, changes to the status of stocks include: BSAI Northern rockfish, three species of the GOA deep water flatfish complex, and GOA flathead sole, were all previously listed as unknown and are now considered not overfished. 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.

Total annual surplus production and overall exploitation rate of groundfish
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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 (excluding flathead sole and Dover sole in the GoA). 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 2004 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:

$$u_t = C_t / B_t$$

Status and trends: The resulting indices suggest high variability in groundfish production in the EBS (Figure 135) and a decrease in production between 1978 and 2004 (slope = - 76,500 mt / year, t = -1.70, p = 0.101). Production in the GoA was much lower on average, less variable, and decreased slightly from 1978 to 2004 (slope = - 15,900 mt/ year, t = -0.80, p = 0.429).

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 136). 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 are largely driven by variability in walleye pollock in the EBS and variability in walleye pollock and arrowtooth flounder in the GoA we computed ASP_t without these stocks included (Figure 137). The results suggest a strong, significant decrease in aggregate surplus production of all non-pollock species from 1978 – 2004 in the Bering Sea (slope = -30,000 mt / year, t = -8.64, p < 0.0001) and a similar decrease in surplus production aggregated across stocks (excluding pollock and arrowtooth) in the GoA over this period (slope = -3,300 mt / year, t = -3.27, p = 0.0032). 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 1978-2004. In the Gulf of Alaska, long-term trends in ASP were less pronounced but declines were evident for 5 out of the remaining 9 species, while three species showed no obvious long-term trends and (besides arrowtooth flounder) only thornyhead production increased notably from the late 1970s to the 1990s.

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 is highest during periods of increasing total biomass (e.g. 1978-1985 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. Long-term declines in ASP and low production in recent years in the EBS are a result of low recruitment, reduced growth, increased natural mortality or some combination thereof. These declining trends suggest that substantial reductions in total catches may be necessary in the near future. It is unclear whether existing levels of precaution implemented at the single-species level will be sufficient to deal with declines in overall system productivity when trying to meet multi-species or ecosystem objectives.

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.
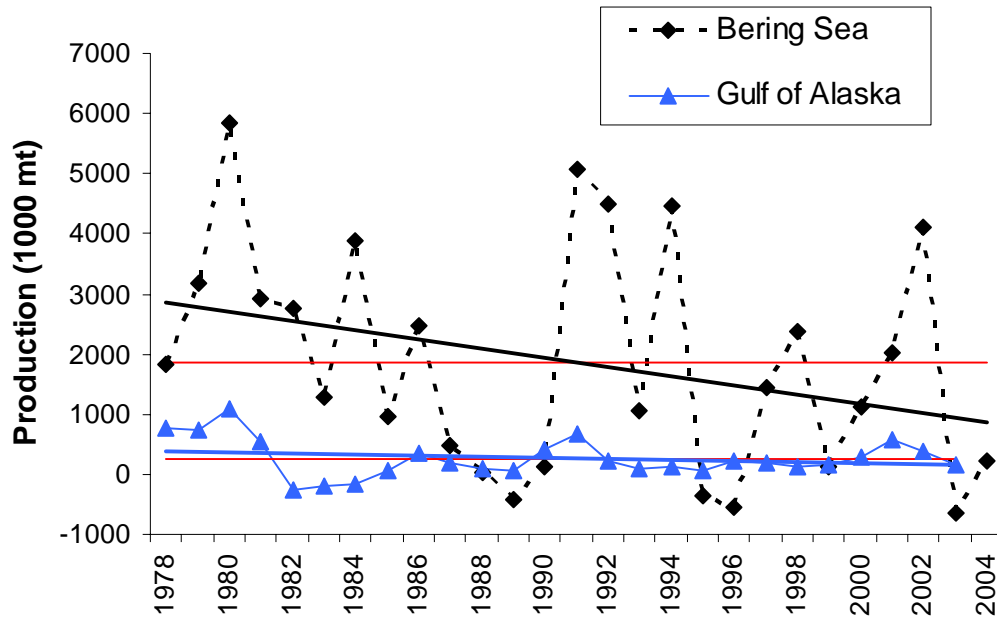
Figure 135. Total annual surplus production (change in biomass plus catch) across all major groundfish species in the Gulf of Alaska and Bering Sea with estimated linear trends (solid lines) and long-term means (red).
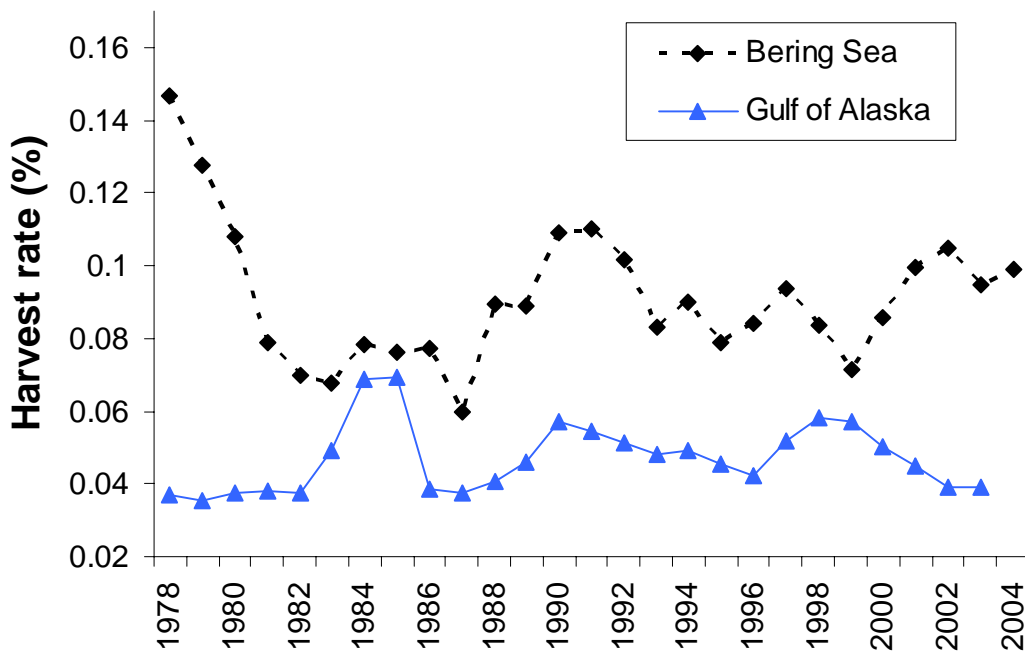
Figure 136. Total exploitation rate (total catch / total biomass) across all major groundfish species in the Gulf of Alaska and Bering Sea.
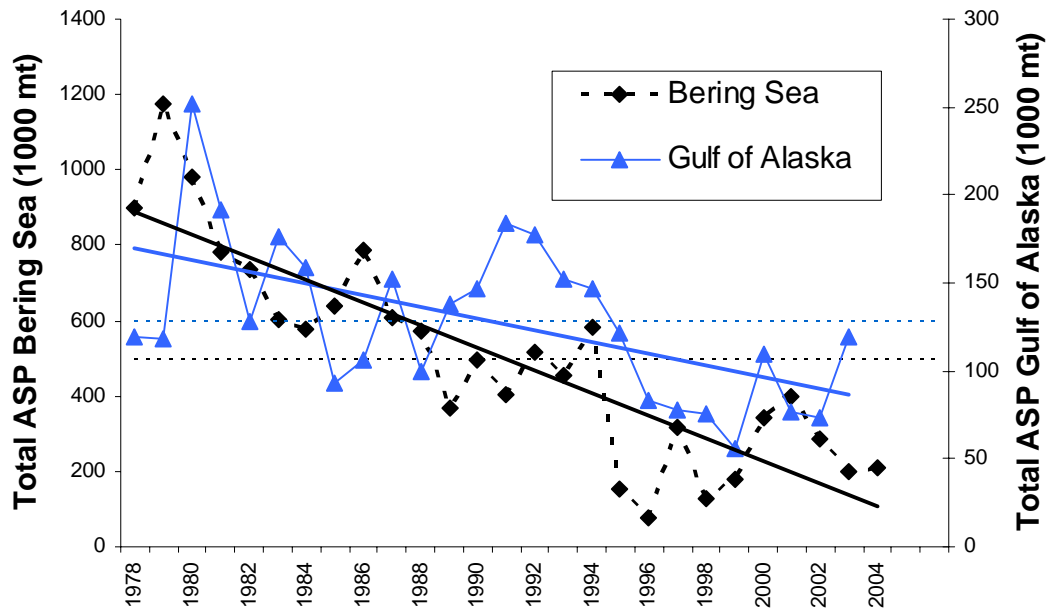
Figure 137. Total annual surplus production (change in biomass plus catch) across all major groundfish species excluding walleye pollock in the Bering Sea and excluding both walleye pollock and arrowtooth flounder in the Gulf of Alaska, with estimated linear trends (solid lines) and long-term means (dotted lines).

Ecosystem indicators for the bottom trawl fish community of the eastern Bering Sea
Shannon Bartkiw, Pat Livingston, and Gary Walters, AFSC

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 138a). 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 138b and c). Factors other than fishing, such as the regime shift in 1988/89, may have had an influence on the community size spectrum.
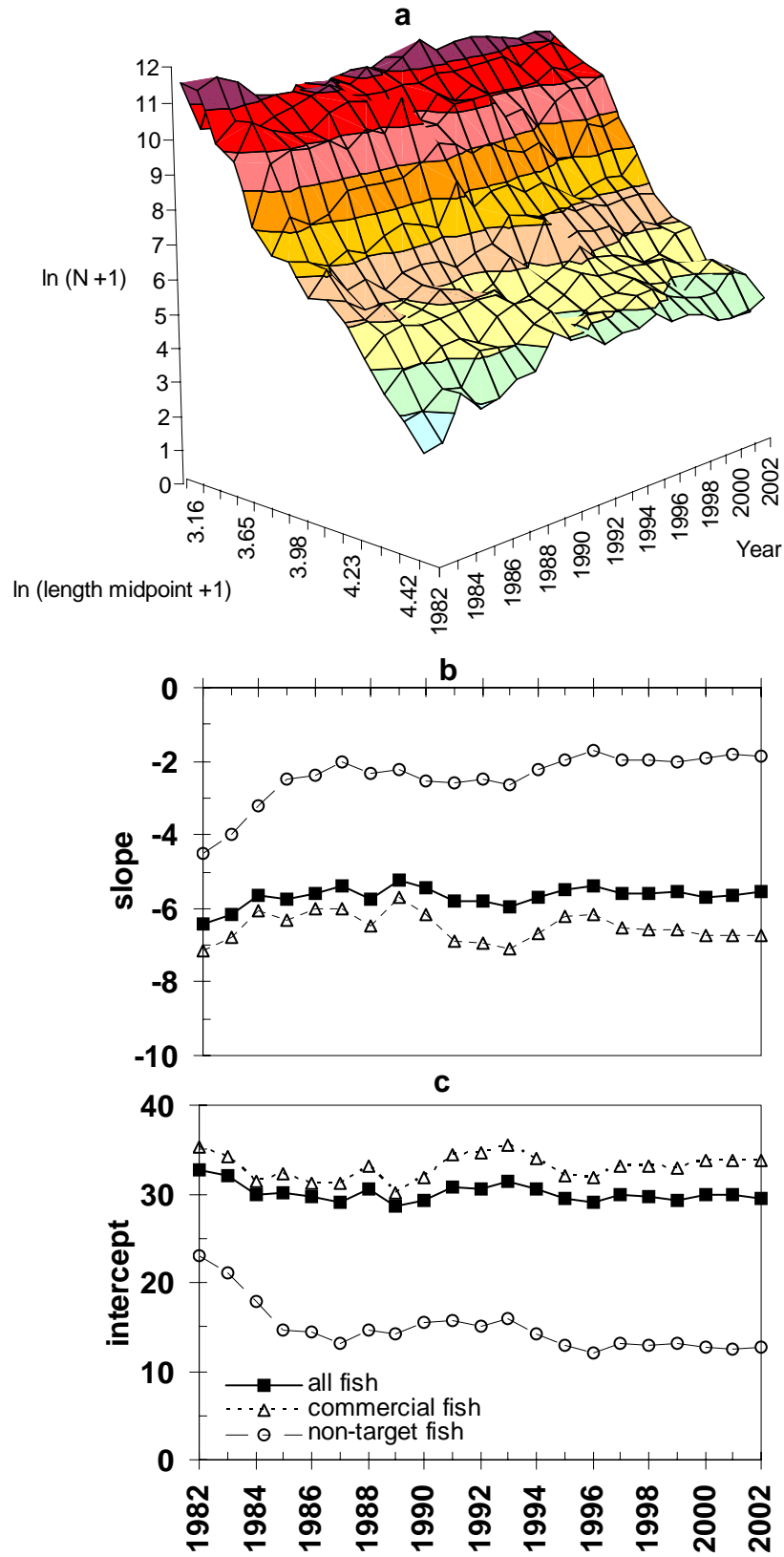
Figure 138. Eastern Bering Sea demersal fish (20-90 cm) community size spectrum (CSS), 1982-2002 (a); changes in slope (b) and intercept (c) of the CSS 1982 to 2002.

Ecosystem Goal: Humans are part of ecosystems

Fishing overcapacity programs
Updated by Ron Felthoven and Terry Hiatt (NMFS, Alaska Fisheries Science Center), and Jessica
Gharrett (NMFS, Alaska Regional Office)

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 will, beginning in 2005, place management of most
crab fisheries of the Bering Sea and Aleutian Islands (BSAI) under a quota system, in which quota shares
are 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, Congress recently directed National Marine
Fisheries Service (NMFS), in consultation with the Council, to develop a two-year demonstration quota
program for 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 350 licenses, of which an estimated 309 are currently being used). The number of current LLP groundfish licenses (1,847) 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 1,461 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 will be modified to incorporate "sideboard" restrictions on GOA groundfish activities and 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 has developed 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 is implementing, 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 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 August 1, 2005, NOAA Fisheries Service has initially issued one or more types of harvesting quota to 504 persons; and processing quota to 25 persons. For harvesters, NOAA Fisheries initially issued quota to 285 applicants who qualified based on holding a transferable LLP crab license; and to 231 individuals who qualified for "Captain" or "crew" shares by virtue of both historic and recent participation in these crab fisheries. Fishing under Crab Rationalization begins 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 4,828 persons were initially issued halibut quota share (QS) and 1,051 were initially issued sablefish QS. At the end of 2004, 3,369 persons held halibut QS and 885 held sablefish QS. The number of vessels landing halibut in the IFQ fishery declined from 3,450 in 1994 to 1,304 at the end of 2004; the number landing sablefish in the IFQ fishery declined from 1,191 in 1994 to 396 in 2004.

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 A/B season and six chose not to fish during the C/D season. This pattern continued in 2000 and 2001 when four and three catcher/processors were idle in the A/B season, respectively. Five of the catcher/processors were idle in both 2000 and 2001 for the C/D season. In 2002, three vessels were idle in the A/B season and four were idle in the C/D season. In 2003, sixteen of nineteen vessels harvested pollock during the year, while in 2004 this number increased to eighteen. These increases in vessel participation relative to earlier post-AFA years can probably be attributed to the increase 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, and increased to 18 in 2004.

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.

Finally, it should be noted that the AFA also restricts eligible vessels from shifting their effort into other fisheries. "Sideboard" measures, as they have become known, prevent AFA eligible vessels from increasing their catch in other fisheries beyond their average 1995-97 levels. Sideboard restrictions reduce the likelihood that the fishing capacity of AFA eligible vessels will spill over and compete in other fisheries.

Groundfish fleet composition
Contributed by Terry Hiatt and Joe Terry,
Alaska Fisheries Science Center
Last updated: November 2005

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 1,404 in 1994, decreased to 1,151 in 1998, and was 996 in 2004, the most recent year for which we have complete data (Figure 139). Hook and line vessels accounted for about 1,114 and 674 of these vessels in 1994 and 2004, respectively. The number of vessels using trawl gear has tended to decrease; during this eleven-year period it decreased from 255 to 191 vessels. During the same period, the number of vessels using pot gear peaked in 2000 at 315, but decreased to 203 in 2004. Vessel counts in these tables were compiled from blend and Catch Accounting System estimates and from fish ticket and observer data.
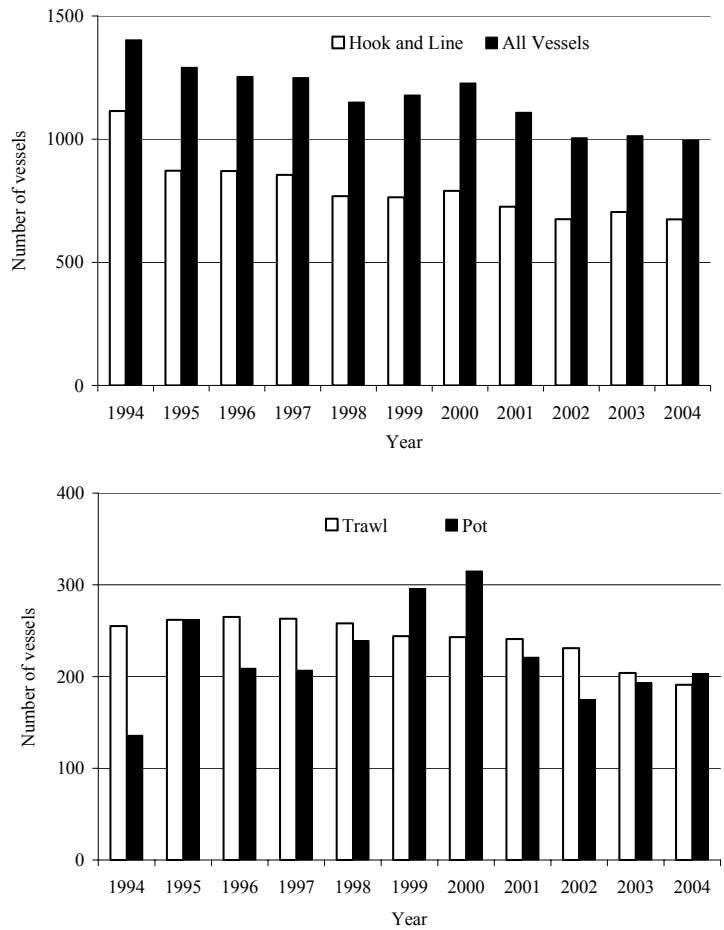
Figure 139. Number of vessels participating in the groundfish fisheries off Alaska by gear type, 1994-2004.

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APPENDIX 1

Essential Fish Habitat Research by AFSC

   Fish Habitat Assessment and Classification of Alaska Estuaries
   Mitch Lorenz, Auke Bay Laboratory, NMFS
   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.
Patricia Harris, Auke Bay Laboratory, NMFS
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, jerry.hoff@noaa.gov
> 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**
> Robert Lauth, Alaska Fisheries Science Center
> Last updated: November 2005

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
Edited by Jonathan Heifetz (Alaska Fisheries Science Center, Auke Bay Laboratory)
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)

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 140). 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.
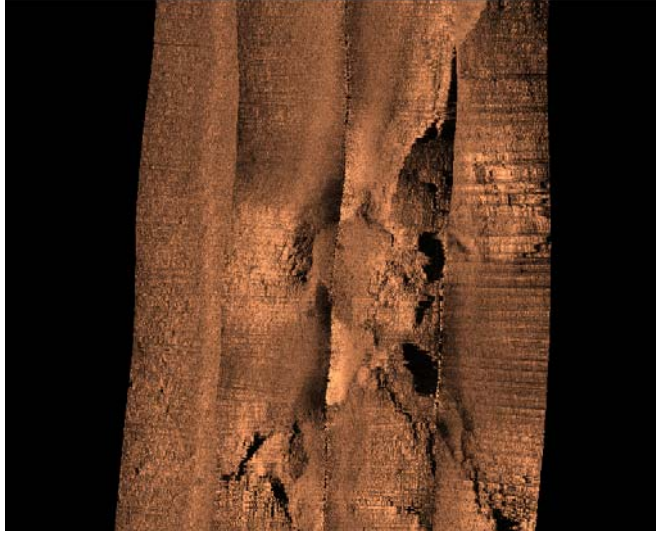
Figure 140. Side scan sonar mosaic from the Islands of Four Mountains west study location, showing interesting geological features on the seafloor.

Distribution of deep-water corals and associated communities in the Aleutian Islands.
Principal Investigators - Robert Stone (AFSC - ABL), Jon Heifetz (AFSC - ABL), Doug Woodby (ADFG), and Jennifer Reynolds (University of Alaska, Fairbanks)

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 (University of Alaska Fairbanks), and Chris Rooper (AFSC - RACE)

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.
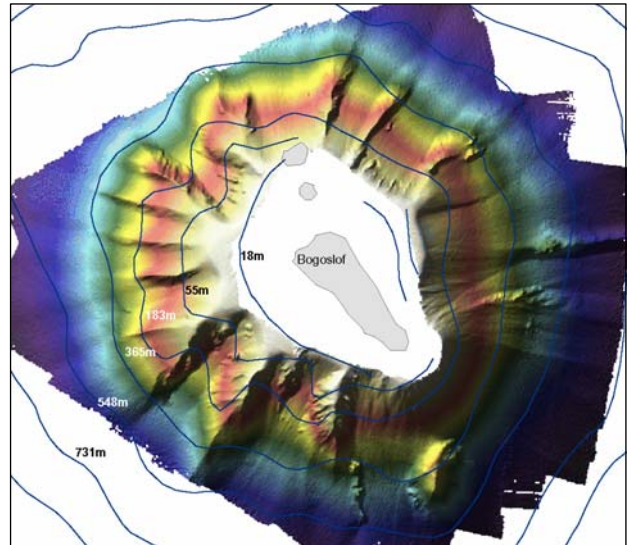

Figure 141. Preliminary multibeam map of the seafloor surrounding Bogoslof Island. Relief is artificially shaded from the northwest.

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 141). 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)

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.
Principal Investigators - Chris Rooper (AFSC - RACE) and Jennifer Boldt (University of Washington)

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 142). Juvenile POP CPUE increased with depth from 76 to 140 m, and decreased with increasing temperature from 3 to 5.5 °C. Juvenile POP CPUE also increased with increasing sponge and coral catch rates (Figure 143). 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 170° 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.
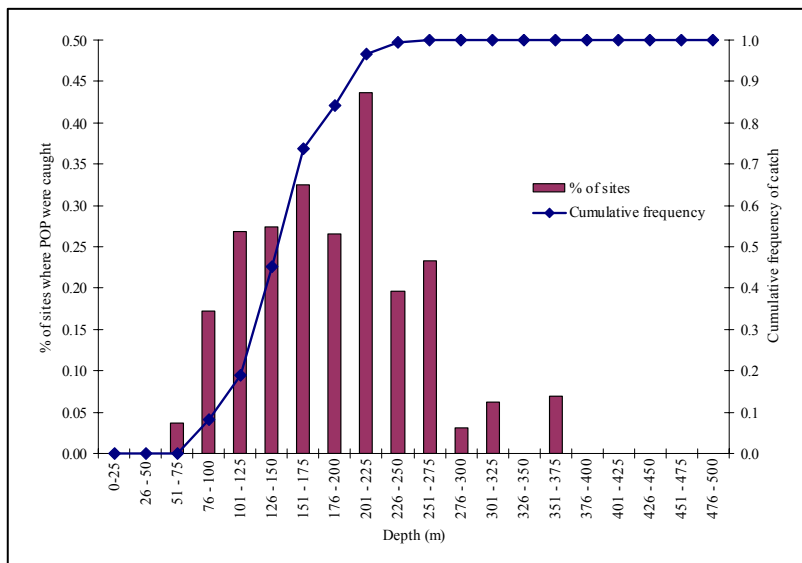

Figure 142. Cumulative frequency distribution of juvenile POP catch and proportion of trawl survey sites with rockfish present. Data are presented in 25-m depth bins.
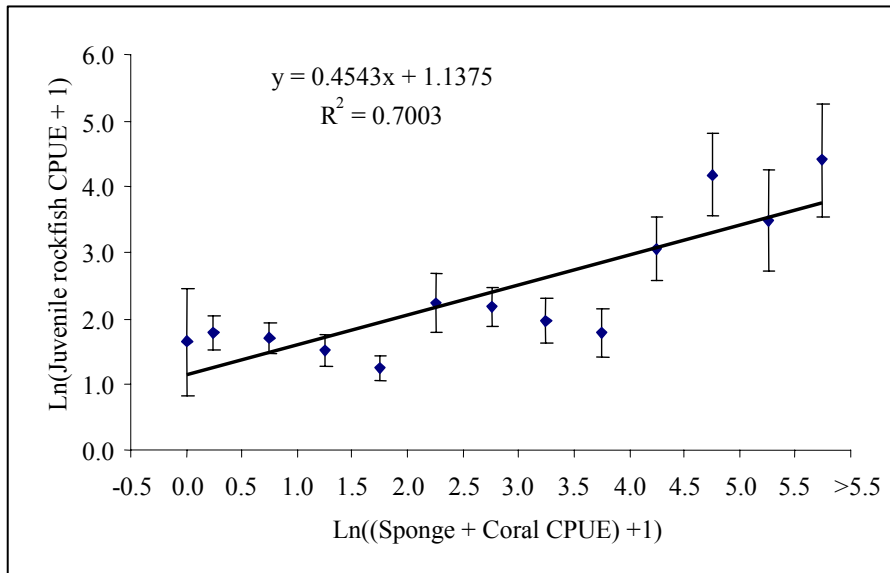
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Figure 143. Relationship between sponge and coral CPUE (kg/ha) and juvenile POP CPUE (no./ha) at sites where juvenile POP were caught. Data are divided into 0.5 CPUE bins and each data point is plotted in the center of its bin.

Effects of experimental bottom trawling on soft-sediment sea whip habitat in the Gulf of Alaska. Principal Investigator - Robert Stone (AFSC - ABL)

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)

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,

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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)

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 detectable 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)

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)

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)

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)

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)

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)

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)

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)

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)

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 144). 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 144). 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.
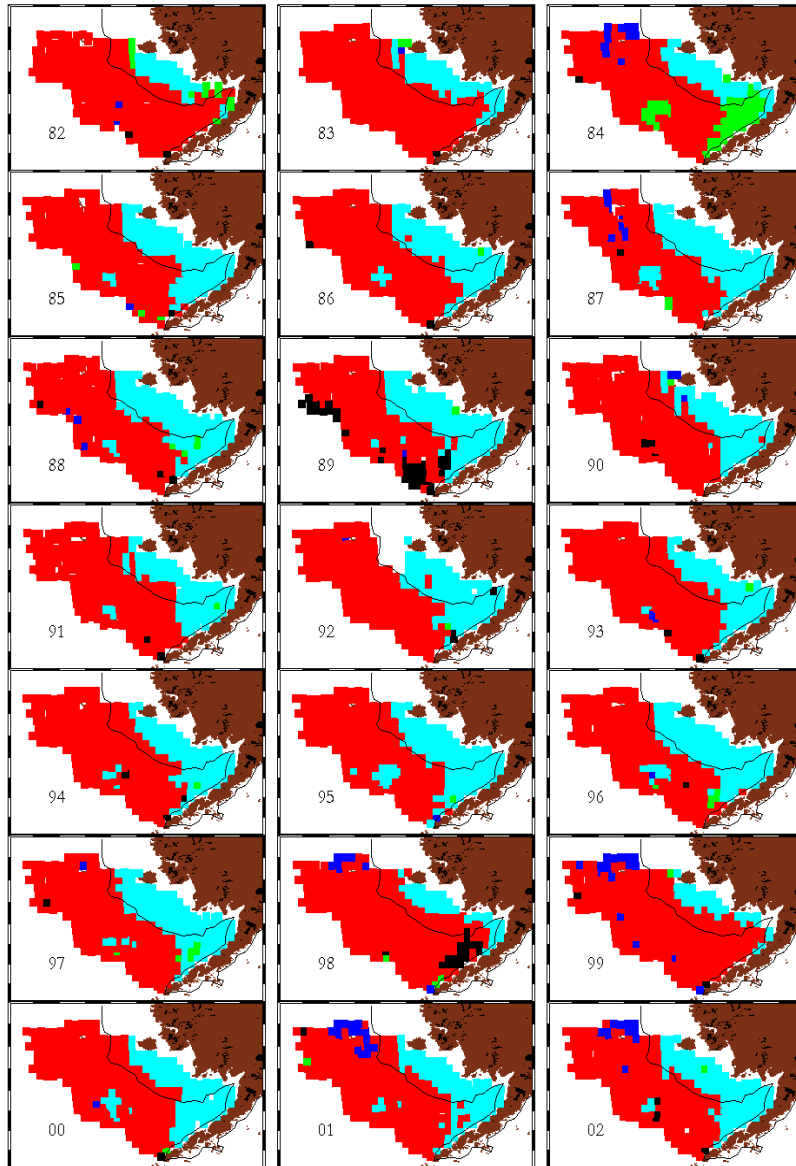
Figure 144. Survey stations clustered by the similarity of their core taxa assemblage. A maximum of 5 clusters are displayed. Stations are color-coded by cluster membership for visual interpretation. Colors are assigned to clusters to facilitate the spatial comparison of station groupings across surveys, 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.