APPENDIX C

Ecosystem Considerations for 2008

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

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

December 2006 SSC Comments

1. ….it would be useful to include condition indices (weight-at-length) in the ecosystem considerations chapter, which should be readily available for most exploited species and would provide an indication of poor prey availability.

Response:
This is something that we are working on and will try to include in a future draft.

2. The SSC notes that the assessment is quite extensive (66 pages). In future iterations, a separate abstract or summary of the ecosystem assessment would be useful and/or the assessment itself could be streamlined to highlight changes from previous years (more extensive discussions could be included by reference).

Response:
We are currently working on the Ecosystem Assessment to make it more concise. We are attempting to rate and vet indicators that we use in the assessment, and blend data analyses and modeling to come up with fewer indicators that clearly communicate the state and possible future directions of the ecosystems.

3. …we encourage the authors to add a single table summarizing recent changes in the biomass and year-class strength for all assessed fish populations, as well as a brief overview of status or trend indicators for other marine mammal populations, in particular whales and ice-associated seals.

Response:
We will attempt to add a table that summarizes recent changes in assessed fish populations as well as marine mammal populations. Currently, there is a table in the Ecosystem Assessment that shows several time series (including some groundfish and mammals) in terms of anomalies.

4. Bering Sea jellyfish: it should be noted in the contribution that in early part of time series, jellyfish were often thrown out and not quantified and probably weren't quantified until later in the time series.

Response:
This statement was added to the Bering Sea jellyfish contribution.

5. Will the GOA zooplankton time series be continued past 2003?

Response:
Russ Hopkroft and Ken Coyle were funded by NPRB to continue the zooplankton sampling along the Seward transect in the Gulf of Alaska.

6. Mammals: were there any updates? Need to get counters on surveys. Need regular update on mammals

Response:
Contributions summarizing trends in Bowhead whale, harbor seal, and ice seal populations were added to the report.

RESPONSES TO THE ALEUTIAN ISLANDS FISHERY ECOSYSTEM PLAN (AI FEP)

The North Pacific Fishery Management Council appointed a Team to produce an Aleutian Islands (AI) Fishery Ecosystem Plan (FEP). The goal of the FEP is to provide enhanced scientific information and measurable indicators to evaluate and promote ecosystem health, sustainable fisheries, and vibrant communities in the Aleutian Islands region. The FEP is intended to be an educational tool and resource that can provide the Council with both an 'early warning system', and an ecosystem context to decisions affecting the Aleutian Islands area. The AI FEP Team utilized information and indicators presented in this report (Ecosystem Considerations report) and also suggested improvements or new indicators that could be used to improve the assessment of important interactions in the AI (http://www.fakr.noaa.gov/npfmc/current_issues/ecosystem/AIFEP507.pdf). In collaboration with AI FEP Team scientists, efforts to produce and improve AI indicators in the Ecosystem Considerations report have begun. Part of these efforts include requesting that contributing authors break out the AI from the Bering Sea as well as include some new AI-specific indicators in this report. Most recommended indices have been requested from existing or potential contributing authors. In the current draft, two indicators have been added: 1. Pot fishing effort in the AI, and 2. Eddies in the AI. There has also been an AI-specific climate summary added to the North Pacific Climate contribution. Some improvements recommended by the AI FEP Team that have been included in this and past reports include: 1. Forage -AI (relative mean CPUE and frequency of occurrence of forage species), 2. Miscellaneous species -AI (relative mean CPUE and frequency of occurrence of miscellaneous species), 3. HAPC Biota -AI (relative mean CPUE and frequency of occurrence of HAPC species), 4. Trophic level of the catch in the AI, and 5. Pelagic trawl fishing effort in the AI. Additionally, a contribution examining the distribution of rockfish species along environmental gradients in the Gulf of Alaska and Aleutian Islands bottom trawl surveys has been added to the report this year. It is expected that in future drafts we will be incorporating more of the AI FEP- recommended indices.

EXECUTIVE SUMMARY OF RECENT TRENDS

Fishing Effects on Ecosystems

- No significant adverse impacts of fishing on the ecosystem relating to predator/prey interactions, energy flow/removal, or diversity were noted, either in observed trends or ecosystem-level modeling results
- 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. 2 crab stocks are overfished.
- The overall human population of GOA fishing communities in 2000 was over 21 times larger than its 1920 population, with the majority of that growth occurring in Anchorage.
- Chinook salmon bycatch increased in recent years and for all of Alaska was essentially unchanged in 2006 compared to 2005, but it increased by about 18% in the BSAI where, in 2006 for the first time ever, the Chinook SSA was closed to fishing during the pollock 'A' season. The closure resulted in a large economic impact on the pollock fishery during the winter roe season.
- The "other salmon" bycatch (primarily chum) has also increased dramatically in 2003-2005 and decreased by about 54% in 2006. The increases in 2003 and 2005 and the decrease in 2006 are in line with changes in salmon abundance.
- Nontarget catch of HAPC and non-specified biota has decreased and non-target forage fish catch has increased in the BSAI. Nontarget catch of HAPC has been variable, non-specified catch has been relatively low, and forage catch has decreased from a peak in 2005 in the GOA.
- Community size spectrum analysis of the eastern Bering Sea fish community indicates there has not been a systematic decline in the amount of large fish from 1982 to 2006.
- Bottom trawl fishing effort continued to decrease in the BS, AI, and GOA in 2006. Hook and line effort decreased in the BS and increased in the GOA and AI. Pot fishing effort increased in all three ecosystems.

Climate Effects on Ecosystems

- The PDO, the leading mode of North Pacific sea surface temperature variability (SST), transitioned from moderately positive in early 2006 to moderately negative in the summer/early fall of 2006 and has slowly increased to weakly positive values during the summer of 2007. When the PDO is positive SST anomalies tend to be positive along the North American coast, extending to the south-eastern Bering Sea.
- There were weak-moderate El Nino conditions near the end of 2006. Neutral conditions returned by early spring 2007. A cooling trend resumed in summer 2007 and it now appears probable at least a weak La Nina will form by the fall/winter of 2007-08.
- The Bering Sea experienced a relatively cold winter and spring (2007) with pronounced warming in late spring resulting in above normal upper ocean temperatures by mid-summer. This and the presence of a substantial cold pool resulted in strong thermal stratification on the Bering Sea shelf. The amount of ice and the extent of the cold pool can affect production and distribution of marine organisms.
- In spring 2007, BS sea ice lasted for almost two months just to the north of the Pribilof Islands, contrasting with previous years since 2000. The presence of sea ice together with below normal ocean temperatures likely resulted in the first ice edge primary production bloom since 1999.
- Unlike the northern BS and Arctic Ocean hot spots, the rate of warming in the southern Bering Sea is slowing down, suggesting a large natural variability component to recent extremes in addition to a background anthropogenic contribution toward warmer temperatures.
- There was a record low total area of sea ice in the Arctic in the summer of 2007. The implications of this trend for the North Pacific are likely to include a tendency for a shorter season during which intense cold-air outbreaks of arctic origin can occur.

- In the Gulf of Alaska, the winter of 2006-07 featured anomalous southwesterly winds causing relatively shallow mixed layer depths in the central Gulf, and deep mixed layer depths close to the coast. During spring 2007, anomalously low SLP was present in the central Gulf of Alaska, which promotes anomalous downwelling in the coastal zone, and a relatively strong Alaska Coastal Current.
- GOA summer survey temperatures indicate cooling of surface waters and warming of deeper waters, supporting idea that there was anomalous mixing on the GOA shelf.

Ecosystem Trends

- Demersal groundfish species in the BSAI and GOA had above-average recruitments from the mid- or late 1970s to the late 1980s, followed by below-average recruitments during most of the 1990s. There is an indication for above-average recruitment from 1994-2000 (with the exception of 1996). In the Gulf of Alaska, recruitment has been below average across stocks since 2001.
- Annual groundfish surplus production in the EBS and GOA decreased between 1978 and 2005. Declines in production may be a density-dependent response to observed increases in biomass and aging populations of groundfish.
- There was a larger than expected return of age-4 and age-5 Togiak herring in the 2006 fishery, suggesting a strong recruitment event in the future.
- Jellyfish CPUE in the BS survey continues to be low.
- Eulachon CPUE sampled in the NMFS bottom trawl survey was the highest of the last 4 years in the EBS and continues to be relatively high in the central GOA.
- The overall trend for the western stock of Steller sea lions in Alaska (through 2007) is either stable or declining slightly.
- Pribilof Islands northern fur seal pup production continued to decrease in 2006; wheras, Bogoslof Island pup production increased (1995-2007). Neither trend is due solely to immigration/emigration between Islands.
- Trends in harbor seal populations are mixed but, overall populations are lower than they were in the 1970s and 1980s. In southeast Alaska, the trends at different sites are mixed. Decreases were observed in PWS (mid-1980s to 1990s) and Kodiak (mid-1970s to 1990s); however, increases were observed near Kodiak in recent years (1993-2001). Harbor seal populations in the BS and AI have decreased from the late 1970s to the 1990s.
- Reliable estimates for the current minimum population size, abundance and trend of the Alaska stocks of bearded, ribbon, ringed or spotted seals are considered unavailable.
- The Western Arctic stock of Bowhead whales appears to be recovering. The rate of increase of the stock and the record high count of 121 calves in 2001 (last survey) suggest a steady recovery of the stock.

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. We are currently working on a more concise ecosystem assessment utilizing a blend of data analysis and modeling to clearly communicate the current status and possible future directionsof ecosystems.

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 2000-2007 Ecosystem Considerations sections included some new contributions in this regard and will be built upon in future years. Evaluation of the meaning of the observed changes needs to be done separately and in the context of how the indicator relates to a particular ecosystem component. For example, particular oceanographic conditions such as bottom temperature increases might be favorable to some species but not for others. Future evaluations will need to follow an analysis framework, such as that provided in the draft Programmatic groundfish fishery environmental impact statement that links indicators to particular effects on ecosystem components.

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

It was requested that contributors to the ecosystem considerations chapter provide actual time series data or make it available electronically. Most of the time series data for contributions are now available on the web, with permission from the authors. It is particularly important that we spend more time in the development of ecosystem-based management indices. Ecosystem-based management indices should be developed to track performance in meeting the stated ecosystem-based management goals of the NPFMC, which are:

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

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

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

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

ECOSYSTEM ASSESSMENT

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Introduction

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

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

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

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

Methods

Assessment Approach: Effects categories, indicators, thresholds

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

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

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

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

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

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

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

Issue	Effect	Significance Threshold	Indicators
Predator-prey relationships	Pelagic forage availability	Fishery induced changes outside the natural level of abundance or variability for a prey species relative to predator demands	Population trends in pelagic forage biomass (quantitative - pollock, Atka mackerel, catch/bycatch trends of forage species, squid and herring)
	Spatial and temporal concentration of fishery impact on forage	Fishery concentration levels high enough to impair long term viability of ecologically important, nonresource species such as marine mammals & birds	Degree of spatial/temporal concentration of fishery on pollock, Atka mackerel, herring, squid and forage species (qualitative)
	Removal of top predators	Catch levels high enough to cause the biomass of one or more top level predator species to fall below minimum biologically acceptable limits	Trophic level of the catch Sensitive top predator bycatch levels (quantitative: sharks, birds; qualitative: pinnipeds) Population status of top predator species (whales, pinnipeds, seabirds) relative to minimum biologically acceptable limits
	Introduction of nonnative species	Fishery vessel ballast water and hull fouling organism exchange levels high enough to cause viable introduction of one or more nonnative species, invasive species	Total catch levels
Energy flow and balance	Energy re-direction	Long-term changes in system biomass, respiration, production or energy cycling that are outside the range of natural variability due to fishery discarding and offal production practices	Trends in discard and offal production levels (quantitative for discards) Scavenger population trends relative to discard and offal production levels (qualitative) Bottom gear effort (qualitative measure of unobserved gear mortality particularly on bottom organisms)
	Energy removal	Long-term changes in system-level biomass, respiration, production or energy cycling that are outside the range of natural variability due to fishery removals of energy	Trends in total retained catch levels (quantitative)
Diversity	Species diversity	Catch removals high enough to cause the biomass of one or more species (target, nontarget) to fall below or to be kept from recovering from levels below minimum biologically acceptable limits	Population levels of target, nontarget species relative to MSST or ESA listing thresholds, linked to fishing removals (qualitative) Bycatch amounts of sensitive (low potential population turnover rates) species that lack population estimates (quantitative: sharks, birds, HAPC biota) Number of ESA listed marine species Area closures
	Functional (trophic, structural habitat) diversity	Catch removals high enough to cause a change in functional diversity outside the range of natural variability observed for the system	Guild diversity or size diversity changes linked to fishing removals (qualitative) Bottom gear effort (measure of benthic guild disturbance) HAPC biota bycatch
	Genetic diversity	Catch removals high enough to cause a loss or change in one or more genetic components of a stock that would cause the stock biomass to fall below minimum biologically acceptable limits	Degree of fishing on spawning aggregations or larger fish (qualitative) Older age group abundances of target groundfish stocks

Model and data synthesis in assessing ecosystem effects of fishing

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

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

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

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

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

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

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

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

Results

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

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

Measures of top-down control: fishing vs. predators

Current evidence suggests that the main sources of top-down control of forage fish in the Bering Sea and Gulf of Alaska ecosystems come from predatory fish rather than fishing, although individual top predators, such as Pacific cod, may be fully exploited by fisheries. Mueter (Figures 110 and 112 this report) show that annual surplus production (ASP) of groundfish in the Bering Sea and Gulf of Alaska has dropped in recent years. He suggests that, rather than being a measure of ecosystem-level overfishing, this decline in ASP is due to density-dependence in large groundfish populations that are currently maintained above $B_{MSY.}$ This density-dependence may also be a function of aging populations of groundfish, especially in the Bering Sea, as seen in the size compositions of current groundfish populations according to recent stock assessments (Figure 1). Strong recruitment events for large predators in the late 1970s (Pacific cod) and mid 1980s (arrowtooth flounder, rock sole, and flathead sole) followed by lower recruitment in the 1990s has created a biomass of predatory fish that is currently dominated by individuals >50cm fork length (Figure 1A-C). Walleye pollock has shown oscillations of size composition between smaller and larger fish with a period of 8-12 years, perhaps due to cycles of cannibalism (Figure 1D). It is worth noting that the most recent peak in size composition of smaller (<30cm fork length) walleye pollock in 2002-2003 was smaller than previous peaks in 1966-68, 1978-79, and 1991-92 (Figure 1D), perhaps due to the increasing importance of predation on pollock by other predators such as arrowtooth flounder. The trend in predator biomass for Gulf of Alaska is discussed under model reconstructions, below.

Another index that has been suggested as a measure of overall top-down control of the ecosystem due to fishing is the trophic level of the fishery; in particular, the notion of "fishing down the food web" has been popularized in recent years. The trophic level of the catch and the Fishery in Balance (FIB) indices have been monitored in the BS, AI, and GOA ecosystems to determine if fisheries have been "fishing-down" the food web by removing top-level predators and subsequently targeting lower trophic level prey. The FIB index was developed by Pauly et al. (2000) to ascertain whether trophic level catch trends are a reflection of deliberate choice or of a fishing-down the food web effect. This index declines only when catches do not increase as expected when moving down the food web (i.e., lower trophic levels are more biologically productive), relative to an initial baseline year. Although there has been a general increase in the amount of catch since the late 1960s in all three areas of Alaska, the trophic level of the catch has been high and relatively stable over the last 25 years (Figure 109). Unlike other regions in which this index has been calculated, such as the Northwest Atlantic, the FIB index and the trophic level of the catch in the EBS, AI, and GOA have been relatively constant and suggest an ecological balance in the catch patterns (Figure 109).

The single metrics of TL or FIB indices, however, may hide details about fishing events. We, therefore, plotted the trophic level of catches in the BS, AI, and GOA in a similar style to that recently published by Essington et al. (2006; Figure 2). This further examination supports the idea that fishing-down the food web is not occurring in Alaska, and there does not appear to be a serial addition of lower-trophic-level fisheries in the BS or GOA. In general, it appears that fishing events on different species are episodic in the AI and GOA, while pollock steadily dominate catches in the BS throughout the period.

Measures of bottom-up control: Forage fish and predation

Forage fish abundance and availability to predators will have a major impact on the productivity of upper trophic levels. Changes in bottom-up productivity overall may be a current concern in the Bering Sea, as Napp and Shiga (2006) have noted that zooplankton biomass has been anomalously low in the Bering Sea since 2000. No long-term historical surveys exist that are specifically targeted towards forage biomass; the AFSC bottom trawl survey has a low (unknown) catchability for most forage species, as suggested by the fact that estimates of forage fish consumption by groundfish (e.g. capelin, Yang et al. 2005) are orders of magnitude higher than survey estimates of biomass for those species. At the same time, Survey Catch-per-unit-Effort (CPUE) indices for several forage fish (Figure 54; Lauth this report) may be useful as trends in selected forage fish abundances; on their own, the CPUE indices can not show whether the total production of forage fish has changed as a response to observed zooplankton trends.

However, it is possible to use these individual CPUE indices as a sum of total forage fish abundance by using the minimum consumption estimates to calculate the catchability of forage fish by the survey relative to the catchability of forage fish by predatory groundfish. For the eastern Bering Sea, we summed the CPUE indices of forage species shown in Figure 54 by calculating a catchability (q) for each forage species that is the ratio between CPUE of that species in a reference year and the consumption of that species by groundfish in the reference year as estimated from groundfish stomach contents data collected by the AFSC Trophic Ecology Laboratory (see Appendix 1 for calculation methods). This method requires that direct diet estimations be available for a large majority of the consumers of the forage species in question; 1991 was used as the reference year for this analysis due to the breadth of stomach collections performed during year. For walleye pollock and groundfish predators, for which age-structured stock assessments were available, the annual biomass estimates from each stock assessment were used directly.

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

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

Bering Sea

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

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

However, a more worrying trend, in terms of bottom-up production, may be seen in the latter years of these time series. In particular, sandlance biomass dropped abruptly between 1997 and 1998, and the years between 1999 and 2005 are the lowest since 1982. This drop suggests that the decline in zooplankton biomass noted by Napp and Shiga (2006) may indeed represent a decline in overall Bering Sea pelagic productivity since 1999-2000. If true, it is unclear if this is a drop in overall productivity or a shift in productivity to the benthos; there is no specific evidence of increases in benthic productivity in the ecosystem.

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

Gulf of Alaska

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

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

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

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

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

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

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

At the same time, predator biomass in the Gulf of Alaska has increased dramatically, primarily due to increases in arrowtooth flounder biomass (Figure 6A). The total predator density shown in Figure 6A is also considerably higher than that of the eastern Bering Sea (Figure 4A). When viewed by consumption rate rather than absolute biomass, it is worth noting that consumption of forage by whales remains high throughout the time series (Figure 6B), in spite of the substantial reduction of whale biomass in the late 1960s. The dominance of groundfish predators in the Gulf of Alaska suggests that a combination of top-down and bottom-up process oriented research will be important to fully understanding ecosystem dynamics in this system. This apparently high predation may also have important implications for fisheries management, especially for commercially important forage species such as pollock (see below).

Developing indices and thresholds of surplus production and predation

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

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

In both systems, the total mortality (total height of bars in Figure 7A) is higher than production in 2005, indicating a declining trajectory for both stocks. In the Gulf of Alaska, production is less than predation+fishing, indicating that this decline must come at the expense of other species in the ecosystem.

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

Figure 7B shows a reconstructed time trend of biomass (top panel) and fishing mortality and fishing+predation mortality as a fraction of production (bottom panel) for walleye pollock in the Gulf of Alaska. The biomass time trend reproduces that estimated in the most recent GOA pollock assessment (Dorn et al 2005). The blue, horizontal line is a proxy for a single species reference point (F=65%M). This value is shown for reference only; the actual single-species recommended F as a proportion of M for GOA pollock can range from 53% to 83% of the single species M of 0.3, depending on the age structure of the population and the harvest control rule employed by the author (see Dorn et al. 2005 Table 1.20). The blue changing line shows the actual exploitation rate estimated for pollock by dividing the catch by the biomass shown in the top panel of Figure 7B. It is clear that the actual exploitation rates for pollock have been below the proxy we have selected to represent the single species reference point, reflecting conservative single species management, although the stock may be fully exploited in terms of spawning stock biomass.

The red horizontal line in Figure 7B shows 100% of total production for each year in the reconstruction, with 100% being the height of the dotted line from Figure 7A. This estimate is year-specific to account for annual changes in population production. The red changing line shows fishing+predation mortality over time. It is clear from both this changing red line and from Figure 7A that pollock have a much higher proportion of predation mortality than fishing mortality in the GOA. However, the total fishing+predation mortality remained below total production for pollock from the 1960s through the mid 1980s. In 1987, fishing+predation mortality exceeded total production for pollock in the GOA ecosystem. Note that this threshold was not exceeded during the initial decline of pollock prior to 1987 (upper panel). This plot suggests that for species experiencing substantial predation mortality, even conservative single species fishing mortality rates may push total fishing+predation mortality above the productive capacity of the species if this predation is not taken into account. Previously, Dorn et al. (2005) noted that 1987-1990 was the time during which the adult biomass of two predators on adult pollock, Pacific cod and Pacific halibut, began to trend downwards, suggesting that the pollock "deficit production" may have affected dependent predator populations although the direct impacts of climate and recruitment for these species must also be considered. No similar downward trend is apparent for arrowtooth flounder, however arrowtooth do not depend on pollock for the majority of their food.

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

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

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

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

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

Out of 127 species in the Bering Sea management region, 8 are in the above the solid line while 33 are between the two lines (Figure 10). None of the species above the solid line have high fishing pressure, and in fact all of these species are "forage" species that have dropped significantly since 1999 (Figure 3C). This highlights the deficit in forage production in the Bering Sea discussed earlier. Between the two lines are 6 species with substantial fishing: salmon, pollock, Greenland turbot, snow crab (*C. opilio*), rougheye rockfish, and Pacific ocean perch (POP). For these, predation and multispecies reference points should be assessed in greater detail, for example through multispecies modeling examining predation variation.

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

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

Summary of recent trends

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

1.) Climate indicators of PDO or El Nino status

North Pacific In the past three decades the North Pacific climate system experienced one major and at least one minor regime shift (Tables 2-5). A major transformation, or regime shift, occurred in atmospheric and oceanic conditions around 1977, part of the Pacific Decadal Oscillation (PDO), which represents the leading mode of North Pacific sea surface temperature (SST) variability and is related to the strength of the Aleutian low. A climate regime shift occurred in 1989, primarily in the winter PDO index and Arctic Oscillation index. Another potential shift occurred in 1998, and was associated with a change in the sign of the second principal mode of North Pacific SST variability, the Victoria pattern, in winter and the summer PDO index. The atmospheric expression of the Victoria pattern is a north-south pressure dipole, with the negative 500-hPa height anomaly center over the eastern Aleutian Islands and the positive center over the east-central North Pacific (positive mode of the pattern). During the period 1989-1997, atmospheric pressure tended to be above normal in the high latitudes and below normal in the mid-latitudes, which translated to a relative cooling in the Bering Sea. During the summer season, the 1998 shift exhibited itself in a transition from the north-south pressure dipole to a monopole characteristic of the negative PDO pattern. The PDO, however, has not been the primary mode of variability in the North Pacific since 2000.

In 2006-07, the North Pacific atmosphere-ocean system was characterized by mostly modest anomalies of variable sign, with some minor exceptions. As a result, two indices commonly used to represent this system, the North Pacific index (NPI) index for the atmosphere, and the PDO for the ocean, had weak amplitudes. A short-lived El Nino of weak-moderate intensity occurred in late 2006, but its effects appear to have been swamped by the combined effects of a positive state for the Arctic Oscillation in the winter of 2006-07 and the intrinsic variability of the North Pacific atmospheric system. In the winter 2006/07 the basin-wide signals in the North Pacific were not prominent but there were some substantial regional events, such as the development of relatively cool SSTs from the Bering Sea shelf to south of mainland Alaska from winter into spring of 2007. La Nina conditions were developing in the summer of 2007, with probable consequences for the North Pacific climate system in the upcoming 6-9 months.

Arctic The summer of 2007 featured a noteworthy milestone: a record low total area of sea ice in the Arctic. The data from the National Snow and Ice Data Center (NSIDC) are preliminary, but suggest a sea ice coverage as little as about 3 million square kilometers at the end of August 2007 as compared with a previous low value of about 4 million square kilometers in 2005. The lack of sea ice can be attributed to a combination of long-term trends and the weather/circulation of the last year. In particular, the predominantly positive state to the AO during the winter of 2006-07 helped bring about positive air temperature anomalies of about 3˚ C in much of the Arctic. It is interesting that the anomalous melting of Arctic sea ice in the summer of 2007 was largely confined to the month of June. This month featured anomalously high SLP over the Arctic, with especially prominent positive anomalies over Greenland and extending from the north coast of Alaska to over the North Pole. This circulation pattern both suppresses clouds and hence enhances melting by shortwave radiation, and promotes the export of ice down Fram Strait.

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 winters of 2003-2005 were anomalously warm and comparable in scale with major warm episodes in the late 1930s and late 1970s – early 1980s. The spring transition occurred earlier, and the number of days with ice cover after March 15 had a significant downward trend. In 2005, the ice cover index reached the record low value. The lack of ice cover over the southeastern shelf during recent winters resulted in significantly higher heat content in the water column. In 2006 and 2007, however, cooler temperatures resulted in more ice cover. In 2007, the presence of sea ice together with below normal ocean temperatures likely resulted in the first ice edge bloom since 1999. There was a pronounced warming in late spring to the extent that upper ocean temperatures were above normal by the middle of summer. This anomalous warming can be attributed to the relatively high SLP for the region and fewer storms than normal and hence less wind mixing of cold water from depth, and presumably, reduced cloudiness and hence greater solar heating. Considering that a substantial cold pool was also present, the thermal stratification on the Bering Sea shelf was also relatively large. Unlike the northern Bering Sea and Arctic Ocean hot spots, the rate of warming in the southern Bering Sea is slowing down, suggesting a large natural variability component to recent extremes in addition to a background anthropogenic contribution toward warmer temperatures.

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. This region experienced westerly wind anomalies during the winter of 2006-07 and a reversal to easterly wind anomalies during the spring of 2007. Westerly winds act to suppress the poleward flow of warm Pacific water through the Aleutian passes (especially Unimak Pass), while easterly winds enhance these transports. This mechanism is apt to have played a role in the anomalously cold conditions that occurred in the southern Bering Sea from winter into early spring and in the relatively strong warming from spring into summer that followed.

Gulf of Alaska Evidence suggests there were climate regime shifts in 1977 and 1989 in the North Pacific. Ecosystem responses to these shifts in the Gulf of Alaska (GOA) were strong after the 1977 shift, but weaker after the 1989 shift. Variation in the strength of biological responses to climate shifts may be due to the geographical location of the GOA in relation to the spatial pattern of climate variability in the North Pacific. Prior to 1989, climate forcing varied in an east-west pattern, and the GOA was exposed to extremes in this forcing. After 1989, climate forcing varied in a north-south pattern, with the GOA as a transition zone between the extremes in this forcing. The 1989 regime shift did not, therefore, result in strong signals in the GOA. There were both physical and biological responses to both regime shifts in the GOA; however, the primary reorganization of the GOA ecosystem occurred after the 1977 shift. After 1977, the Aleutian Low intensified resulting in a stronger Alaska current, warmer water temperatures, increased coastal rain, and, therefore, increased water column stability. The optimal stability window hypothesis suggests that water column stability is the limiting factor for primary production in the GOA

(Gargett 1997). After 1989 water temperatures were cooler and more variable in the coastal GOA, suggesting production may have been lower and more variable.

The winter of 2006/07 featured anomalous southwesterly winds, which given the prevailing seasonal winds, meant enhanced wind mixing and enhanced positive wind stress curl and hence upward Ekman pumping. The net effect was relatively shallow mixed layer depths in the central Gulf, and deep mixed layer depths close to the coast, at the end of winter of 2007 as compared with the previous year. Physical data collected on the NMFS Gulf of Alaska (GOA) bottom trawl survey support this and indicate that summer bottom temperatures in 2007 at shallow depths (<200 m) were colder and temperatures at depth were warmer than they have been in the recent past (Martin, this report).

Predictions Seasonal projections from the NCEP coupled forecast system model for SST indicate the development of a weak-moderate La Nina by the fall of 2007. This model also suggests relatively cold SSTs in the Gulf of Alaska and Bering Sea from late 2007 into 2008, with a weakening of these anomalies in spring 2008. The corresponding atmospheric anomalies include lower than normal pressure over the Bering Sea in the fall of 2007, and positive pressure anomalies south of mainland Alaska in early 2008. The latter anomalies are consistent with La Nina, based on the historical record. If these model results are correct, there will be westerly wind anomalies across much of the North Pacific from fall 2007 into spring 2008. It should be noted that these kinds of forecast models have more skill in the tropical Pacific, where the atmosphere-ocean system is relatively deterministic, than in the North Pacific, where it is more chaotic and hence inherently less predictable.

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

In the GOA, main pelagic forage taxa include salmon, juvenile and adult pollock, herring, shrimp, eulachon, other forage fish, and squid. Trends vary between taxonomic groups, however those that have been high in recent years relative to the recorded time series include salmon abundance (as indicated by commercial salmon catches, Eggers et al. 2006), forage fish and squid abundance (as indicated by bycatch in commercial groundfish fisheries, Gaichas and Boldt, this report), although forage species nontarget catch has decreased in 2006-2007 (Figure 11). Recent years in the remaining forage indicator time series were within one standard deviation of the time series mean but were much lower than the late 1970s and early 1980s, including pollock age-2 recruits (Dorn et al. 2006), pollock spawning biomass (Dorn et al. 2006), Sitka herring age-3 recruits (Dressel et al. 2006), and shrimp (ADFG small-mesh survey, Litzow 2006) (Figure 11). Eulachon catches were high during 2000-2004, but dropped in 2005 (ADFG small-mesh survey, Litzow 2006). Overall forage trends in the GOA are difficult to assess, given the different survey methods and length of time series. Historical reconstructions of forage demand made from food web models (discussed above) indicate that overall forage biomass in the GOA was highest in the late 1960s, was at a minimum in the early 1980s and was high again in 2005.

Indicators of BSAI forage taxa include salmon abundance (as indicated by commercial salmon catches, Eggers et al. 2006), pollock age-1 recruits and spawning biomass (Ianelli et al. 2006a), Togiak age-4 herring recruits (West and Brazil this report), Atka mackerel age-1 recruits and spawning biomass (Lowe et al. 2006), squid catches (Reuter and Gaichas 2006), and forage fish abundance (as indicated by bycatch in commercial groundfish fisheries, Gaichas and Boldt this report). None of the indicators of forage abundance have been high in recent years, relative to the post-1977 time series mean (Figure 12). Not included in Figure 12 is the updated nontarget catch time series, which indicates catch of forage species increased in 2006-2007 (Gaichas and Boldt, this report) For example, salmon abundance and spawning pollock biomass have been high relative to the pre-1977 mean, but low relative to the post-1977 mean. Squid catches peaked in 1978 and have been at low levels since the late 1980s. Also, as previously discussed, estimated forage biomass in the BSAI indicates there has been an overall decrease in the amount of forage available in recent years (Figure 3).

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

GOA Walleye pollock

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

Atka mackerel

The Atka mackerel fishery is highly localized and occurs at depths less than 200m (Lowe et al. 2005). In the early 1970s, most Atka mackerel catches were made in the western Aleutian Islands (west of 180°W longitude). In the late 1970s and through the 1980s, fishing effort moved eastward with the majority of landings occurring near Seguam and Amlia Islands. In 1984 and 1985 the majority of landings came from a single 1/2° latitude by 1° longitude block bounded in Seguam Pass (Lowe et al. 2005). Areas with large survey catches of Atka mackerel in 2006 included Seguam Pass, Tanaga Pass, Kiska Island, and Stalemate Bank. Atka mackerel have been less patchily distributed in the last three NMFS bottom trawl surveys (2002, 2004, 2006) (Lowe et al. 2006).

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). In addition to trawl closures around sea lion rookeries, spatial dispersion of fishing was accomplished by dividing catch between areas within and outside of critical habitat. The goal of spatial dispersion was to reduce the proportion of each seasonal allowance caught within critical habitat to no more than 40% by the year 2002. No critical habitat 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 critical habitat (Lowe et al. 2003). The regulations implementing this four-year plan lasted only 3 years (through 2001). In 2002, new regulations set the maximum seasonal catch percentage from critical habitat at 60% (Lowe et al. 2004). To compensate, effort within critical habitat 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, additional closures around sea lion haulouts and rookeries were added.

BS walleye pollock

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

Herring

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

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

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

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

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

Squid

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

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

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

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

5.) Removal of top predators

Top predators in the GOA include arrowtooth flounder, sablefish, Pacific cod, sharks and Steller sea lions. Overall predator biomass has increased recently, primarily due to increases in cod and arrowtooth flounder (Thompson et al. 2006, Stockhausen et al. 2005b, Figures 6 and 13). Recent estimates of sablefish recruits and spawning biomass are within one standard deviation of the post-1977 mean

(Hanselman et al. 2006). Shark abundance (as indicated by shark bycatch in groundfish fisheries) has declined since 1996 (Figure 13). Steller sea lion non-pup counts increased slightly between 2004 and 2006 (counts increased only in the western and central GOA and decreased in the eastern GOA; Fritz this report).

Top predators in the BSAI include Greenland turbot (Ianelli et al 2006b), arrowtooth flounder (Wilderbuer and Nichol 2006), Pacific cod (Thompson et al. 2006), northern fur seals (Fritz this report), Steller sea lions (Fritz this report), sharks (as indicated by shark bycatch in groundfish fisheries, Gaichas 2006b), and jellyfish (as sampled in the bottom trawl survey, Lauth this report). The total biomass of groundfish predators, according to stock assessment results, has declined since a peak in 1987, primarily due to a decrease in Pacific cod biomass (Figure 4). Arrowtooth flounder, an important predator of pollock, has been increasing in the BS since the 1980s (Figure 14). Other predators such as northern fur seals, Steller sea lions, sharks, and jellyfish have declined over the recent past (Figure 14). Pollock are an important predator and prey fish; the trends in their population are summarized in the section: "Population trends in pelagic forage biomass".

6.) Introduction of non-native species

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

a. Atlantic salmon (*Salmo salar*) that escape from British Columbian and Washington fish farms have been found in streams near Cordova, Ketchikan, and Yakutat and in the Bering Sea (Fay 2002). Natural spawning of escaped Atlantic salmon has been observed in British Columbian streams, indicating that this could also occur in Alaska. Fay (2002) states: "It is thought Atlantic salmon would most likely compete with native steelhead (*Oncorhynchus mykiss*), cutthroat trout (*Oncorhynchus clarkia*), Dolly Varden (*Salvelinus malma*), and coho salmon (*Oncorhynchus kisutch*), and may also adversely impact other species of Pacific salmon."
b. Green crab (*Carcinus maenas*), native to northern Europe, has become established from California north to Vancouver Island. Fay (2002) states: "It is thought to be capable of surviving environmental conditions at least as far north as the Aleutian Islands." This crab occupies areas close to shore and out-competes other crab species. This could pose a threat to Alaskan tanner and Dungeness crab populations, since they use nearshore areas as nurseries.
c. Chinese mitten crab (*Eriocheir sinensis*), native to China, is now established in California and may have spread to the Columbia River (Fay 2002). Fay (2002) states: "With a catadromous life history…it can move up rivers hundreds of miles where it may displace native fauna, and it is known to feed on salmonid eggs, which could affect salmon recruitment."
d. Oyster spat and associated fauna: Uncertified oyster spat that is imported to Alaska for farming purposes can introduce not only oyster spat (although it is thought that Alaskan waters are too cold for oysters to reproduce), but also other invertebrate larvae, bacteria and viruses (Fay 2002).
e. Bacteria, viruses, and parasites: Fay (2002) states: "Little is known about the threat of the movement of bacteria, viruses, and parasites within or to Alaska. Devastations from the Pacific herring virus in PWS is well known and documented….movement of ballast water from one place

to another within Alaska coastal waters could result in injury to other fisheries. Atlantic Ocean herring disease could also be introduced into Alaska through the import of frozen herring that are used as bait by Alaskan commercial fishers."

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

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

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

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

Discards of Target Species

Discards of target groundfish decreased after 1997 in both the GOA and BSAI, after which it has been relatively stable (Hiatt, this report). Discards in the Gulf of Alaska increased somewhat between 1998 and 2003, but have declined again in recent years. From 1998 to 2005, the biomass of groundfish discarded was higher in the BSAI (average 162,220 t) than in the GOA (average 28,460 t); however, the discard rate was higher in the GOA (approximately 14%) than in the BSAI (approximately 9%) (Hiatt, this report). In 2005, the discards and discard rates were the lowest in the time series (1994-2004) at 15,481 t (8.3%) in the GOA and 98,156 t (4.96%) in the BSAI; Hiatt, this report). In 2006, discards and discard rates decreased slightly in the BS and increased slightly in the GOA.

Discards of Non-Target Species

Overall catch and discards of non-target species (forage, HAPC biota, and non-specified groups) have been roughly stable in the BSAI and GOA since 1997. In both the BSAI and GOA, non-specified catch comprised the majority of non-target catch during 1997-2007 (Figure 79). In the BSAI, the catch of non-specified species and HAPC biota decreased since 2003. The catch of forage species in the BSAI increased in 2006 and 2007. The catch of non-specified species in the GOA has been relatively low in the last few years; whereas, the catch of HAPC biota has been variable. The catch of forage species has undergone large variations, peaking in 2005 and decreasing in 2006 and 2007.

Scavenger Species in the GOA and BSAI:

Birds

Overall, seabird breeding chronology in 2003 early or average, with early nesters predominate in the NB/C, SEBS, and SEAK. The highest number of late nesters was in SWBS, where no birds were early. Seabird productivity in 2003 varied throughout regions and among species, but there was a trend of above average or average productivity in most regions. An exception was SWBS, where 42% of samples (n =

26) had below average productivity. The year 2003 appeared to be an average or above average year for productivity for most planktivores and surface piscivores, but a larger proportion of diving piscivores (38 %, n= 32) had below average productivity. Of the 96 species/site samples, declining seabird populations comprised 22%, while 20% showed increasing trends. The majority of samples showed no discernable change (58% of samples). Planktivores were stable or increasing at all monitored sites, with the exception of least auklets at Kasatochi Island (Dragoo et al. 2006). Among surface piscivores, most populations were stable or increasing, although there were species with decreasing trends in SEBS, SWBS, and GOA. The majority (59%, n = 54) of diving piscivore population trends were stable, although there were more negative trends in the GOA and SEBS.

Gulls

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

Kittiwakes

Scavenging is not the primary feeding mode of kittiwakes but they are opportunistic feeders that often follow fishing vessels and consume offal or discards (S. Fitzgerald, personal communication). In the GOA, black-legged kittiwake populations increased significantly in PWS, but decreased at Chowiet and Middleton Islands (Dragoo et al. 2004). SEBS populations have generally decreased from the mid-1970s until 1999; these decreases were significant at St. Paul Island and at C. Peirce (Dragoo et al. 2004). At St. Paul Island population numbers declined from 1976 to 1999, with a slight upturn in 2002. Population numbers at C. Peirce in the SEBS declined from 1992-99, but were relatively stable during 1999-2002. The SWBS colony at Buldir was the only other colony that showed a significant increase in population numbers from estimates in the 1970s (Dragoo et al. 2004). Productivity of black-legged kittiwakes in 2002 was above average at all colonies except three, Cape Lisburne and St. Lawrence in northern BS, and Buldir in the southwest BS (Dragoo et al. 2004). Productivity was below average in SEBS and GOA in 2005 (Fitzgerald et al. 2006).

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

Fulmars

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

Skates, Sablefish, and Cod: See #5 Removal of top predators

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. The bottom trawl effort in the GOA has been the lowest in the time series in 2004-2006 (Coon, this report). In the BS, bottom trawl effort peaked in 1997 and then declined. Currently, the bottom trawl effort in the BS is relatively stable, and is approximately five times higher than that in the AI or GOA (Coon, this report). Both bottom trawl and longline effort in the BS is also more concentrated than in the AI or GOA (Coon, this report). Most fishing effort in the BS is north of False Pass and along the shelf edge. Fishing effort is concentrated along the shelf edge in the AI and along the shelf edge of the GOA with small areas of effort near Chirikov, Cape Barnabus, Cape Chiniak, and Marmot Flats (Coon, this report).

9.) Diversity measures – Species diversity

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

In the Alaska Region, there are 35 Fish Stock Sustainability Index (FSSI) stocks and an FSSI score of 140 would be achieved if every stock scored the maximum value, 4 (see Fish Stock Sustainability Index and status of groundfish, crab, salmon and scallop stocks, this report). The current overall Alaska FSSI is 114.5, based on updates through October 15, 2007. The overall Bering Sea score is 67.5 of a possible maximum score of 88. This has increased by 2.5 points since last year due to Aleutian Islands Walleye pollock, which are now considered not overfished and not approaching an overfished condition. Previously, these were undefined or unknown for this stock. The BSAI groundfish score is 49.5 of a maximum possible 52 and BSAI king and tanner crabs score 18 of a possible score of 36. The Gulf of Alaska groundfish score is 43 of a maximum possible 48. The sablefish, which are managed as a BSAI/GOA complex, score is 4.

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

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

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

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

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

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

Sharks

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

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

See #5.) for catch trends.

HAPC biota

HAPC biota caught in groundfish fisheries includes seapens/whips, sponges, anemones, tunicates, and corals. Bycatch of HAPC biota in the BSAI has ranged from 922.8 t (in 1999) to 2,548.3 t (in 1997), comprising up to 5.3% of all non-target species caught (Gaichas and Boldt 2006). Bycatch of HAPC biota is substantially lower in the GOA (15.0-46.1 t), and represents up to 0.21% of total non-target catch (Gaichas and Boldt 2006). Sponges, anemones, and some corals represented the majority of the HAPC biota caught in the GOA; whereas, tunicates and sponges, with some anemones, were the dominant HAPC biota caught in the BSAI. There was no apparent temporal trend in catches of any HAPC biota in the GOA. The catch of seapens/whips increased in the BSAI from 1997 to 2001. The lowest bycatch in the BSAI occurred in 1999 due to decreased catches of tunicates.

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

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

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

Community diversity measures

Average species richness and diversity of the groundfish community in the Gulf of Alaska increased from 1990 to 1999 with both indices peaking in 1999 and sharply decreasing in 2001 (Mueter, this report). Species richness and diversity on the Eastern Bering Sea shelf have undergone significant variations from 1982 to 2006 (Mueter, this report). The average number of species per haul has increased by one to two species since 1995, while the Shannon Index increased from 1985 through 1998 and decreased sharply in 1999. Spatial shifts in distribution from year to year appear to be the primary drivers of changes in species richness. The increase in species richness, which was particularly pronounced on the middle shelf of the BS, has been attributed to subarctic species spreading into the former cold pool area as the extent of the cold pool has decreased over recent decades (Mueter & Litzow, in press). However, species diversity has been low in recent years, compared to the 1990s, which suggests that species remain patchily distributed such that a given haul may be dominated by one or a few species.

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

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

Fishing on spawning aggregations or older age groups has the potential to affect the genetic diversity and/or size structure of some fish populations. In the GOA and BS, female arrowtooth flounder represent the majority of catches in survey and fishery data due to lower availability or higher natural mortality of males (Turnock et al. 2002, Wilderbuer and Sample 2002). Spawning walleye pollock populations have been the focus of the winter fishery in the GOA since the 1980s and in the BSAI since the 1990s (Dorn et al. 2002, 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). Also, 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). It is unknown at this time whether this has affected the genetic structure of fish populations in Alaska.

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 1982 to 2006. The eastern Bering Sea groundfish community appears to have fewer small individuals and more large individuals through time, which is primarily due to nontarget fish. Initial analyses indicate that the CPUE of skates increased in the 1980s, thereby increasing the number of large fish sampled in the survey. Continuing analyses will explore this further. Factors other than fishing, such as effects from environmental forcing, may have had an influence on the community size spectrum.

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

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

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

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

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

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

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

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

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

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

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

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

Total catch, PDO, Pollock, Sablefish, Salmon, catch, TL, Eulachon, MLD, AOI, Herring, COMU, Northerns, BLKI, COD, Pandalid, ATF, FHS, POP, log(CPUE), SSL, Forage fish, Discard rate, Squid, Bottom trawl, Seabird

70		72		74		76		78		80		82		84		86		88		90		92		94		96		98		00		02		04		06
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-	-	o	o	+	o	+	+	++	+	+	o	+	-	o	-	--	--	--	o	o	o	+	-	-	-	o	-	-	o	o	-	-	-	-		
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o	-	-	-	-	-	-	o	o	o	o	o	o	+	+	+	+	o	o	+	+	++	+	++	++	++	++	+	++	+++	+	+++	+	+++			
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Legend

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

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

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

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

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

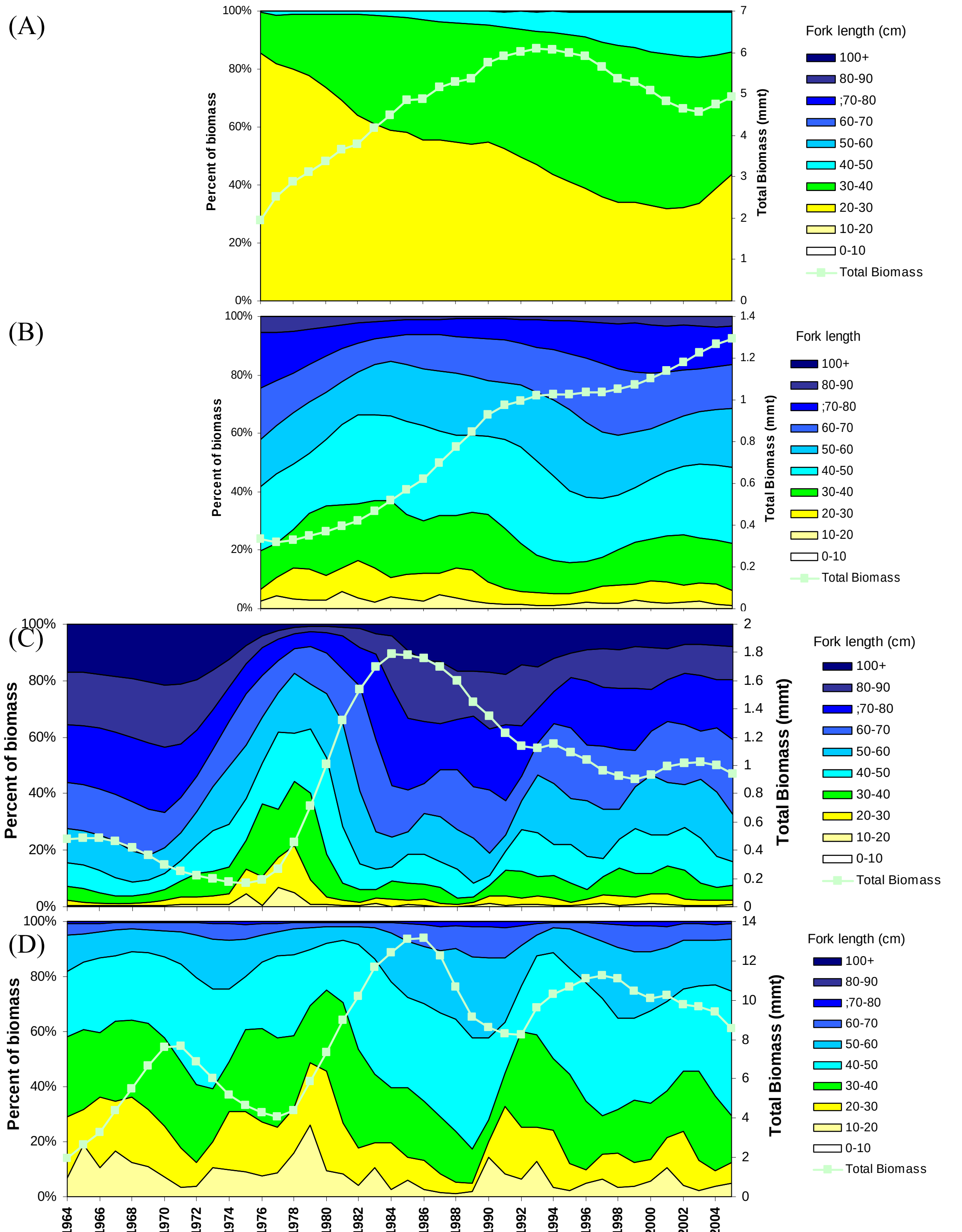


Figure 1. Relationships of population biomass trends and population age structure for major EBS stocks. White line in each figure shows assessed EBS biomass (mmt) of (A) combined rock sole (Wilderbuer and Nichol 2005a), yellowfin sole (Wilderbuer and Nichol 2005b), and flathead sole (Stockhausen et al.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

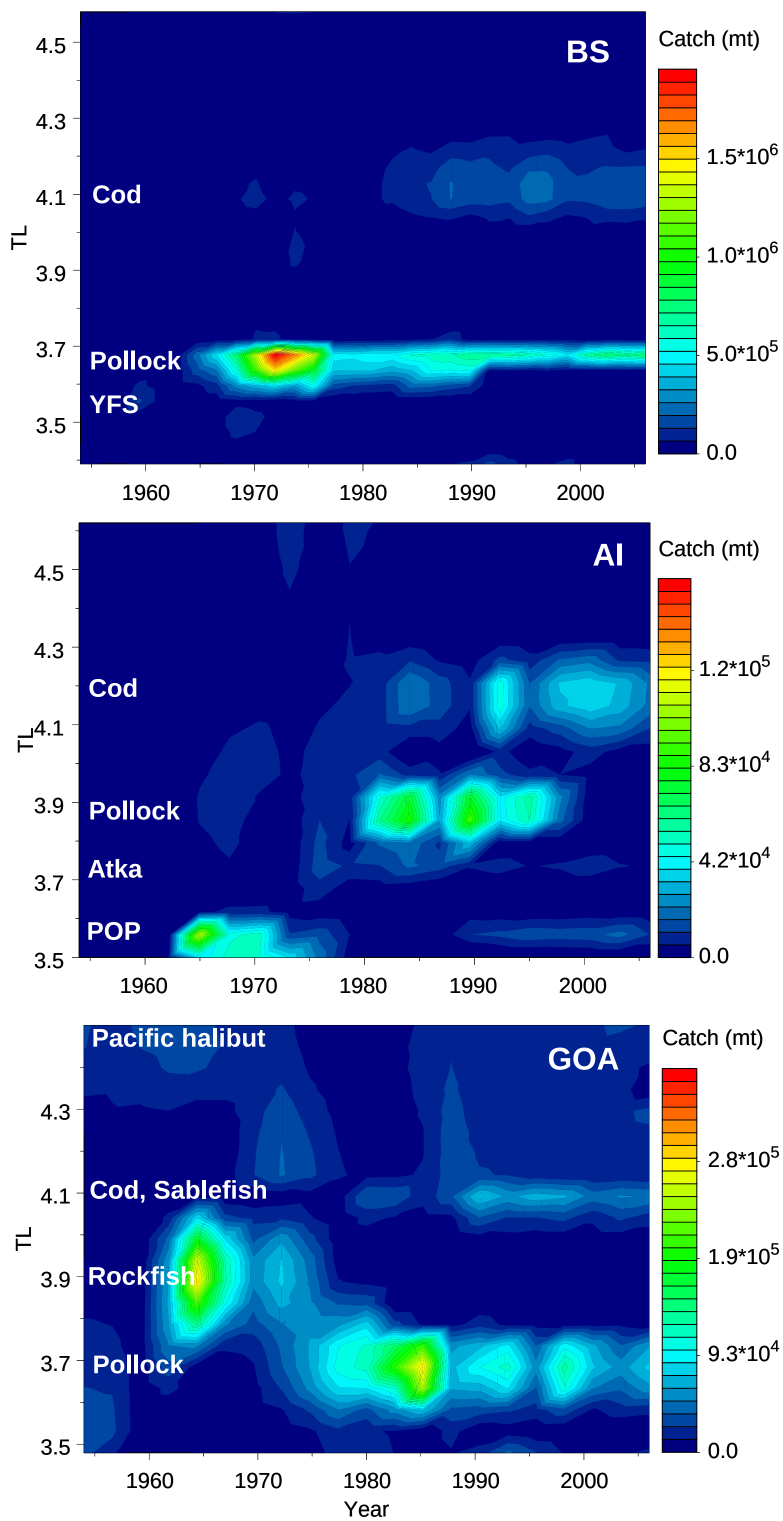


Figure 2. Trophic level of the catch in Alaska: Total catch of all species plotted as colour contours by trophic level and year for the Bering Sea, Aleutian Islands, and Gulf of Alaska. The species comprising the main catches and their approximate trophic levels are labeled on the left side of the graphs.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

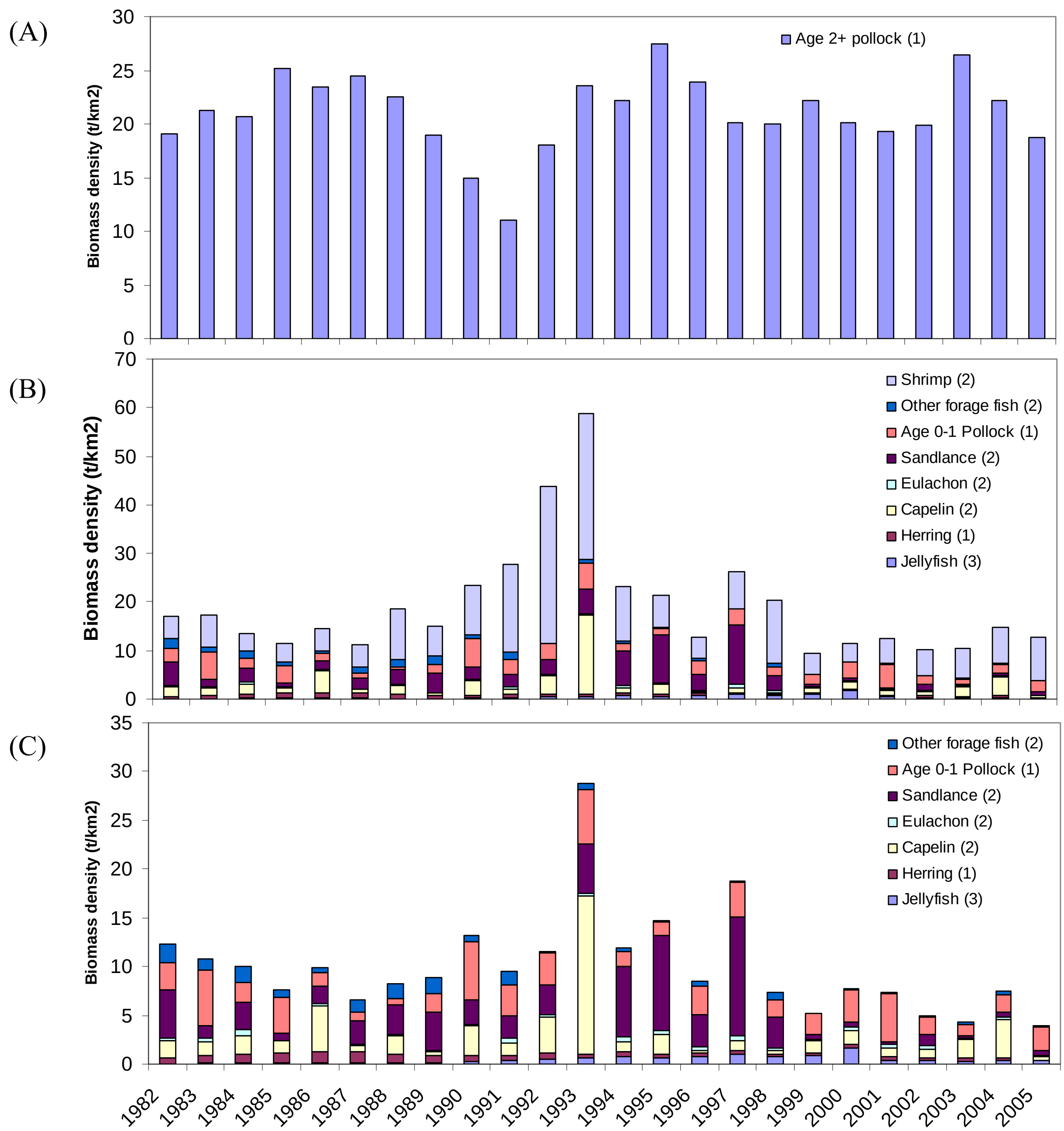


Figure 3. Trends in Eastern Bering Sea biomass density (t/km^2) of selected forage species, 1982-2005. Age 2+ pollock densities (A) are taken from the stock assessment (Ianelli et al. 2005a), as are densities of juvenile pollock in B and C). Densities for other species are trawl survey estimates corrected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

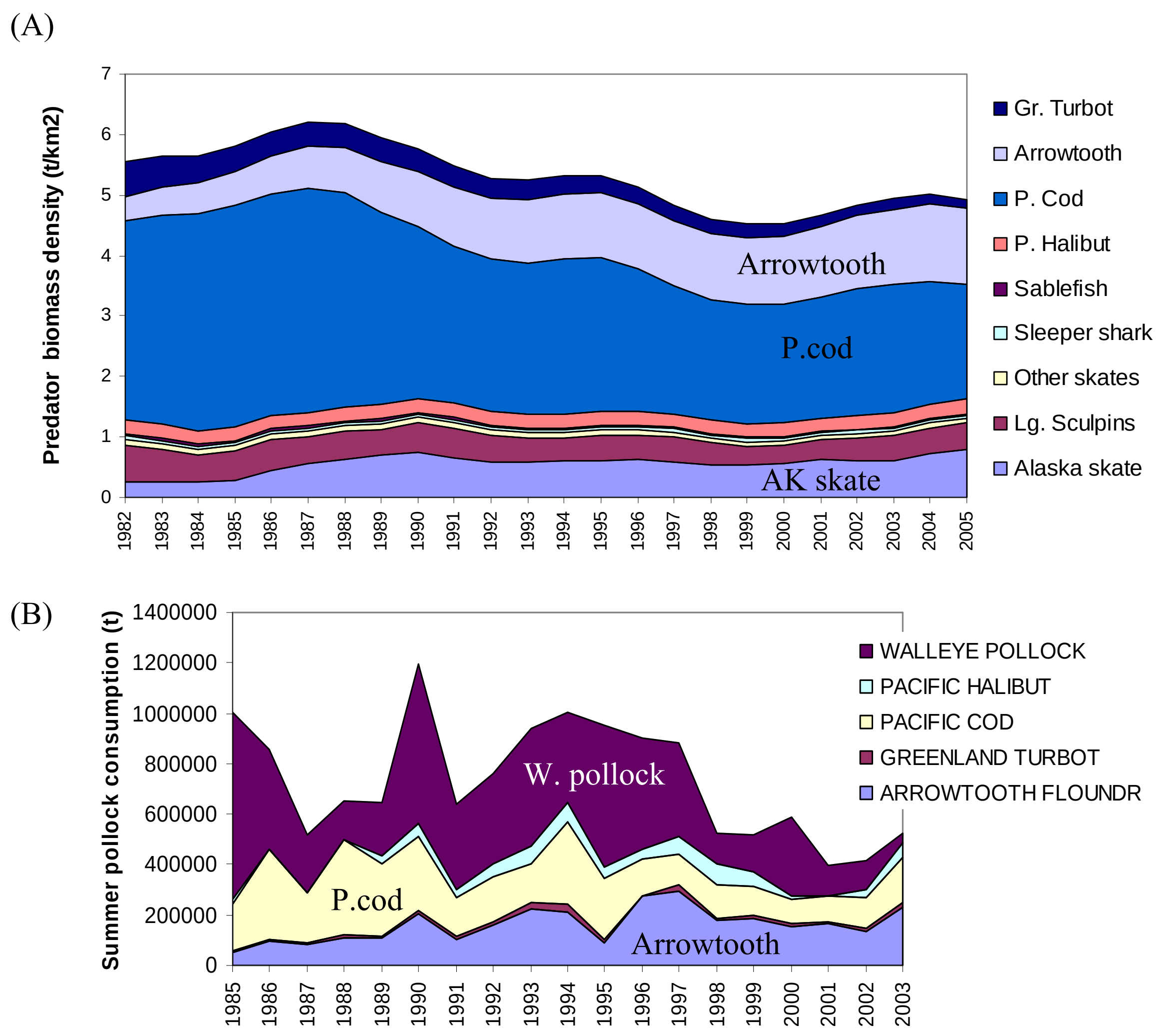


Figure 4. Trends in EBS predator biomass and consumption of pollock by predators. (A) Biomass density estimates (t/km^2) of selected eastern Bering Sea groundfish predators from stock assessments or trawl surveys, 1982-2005. (B) Estimates of summer consumption of Bering Sea walleye pollock (t/summer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

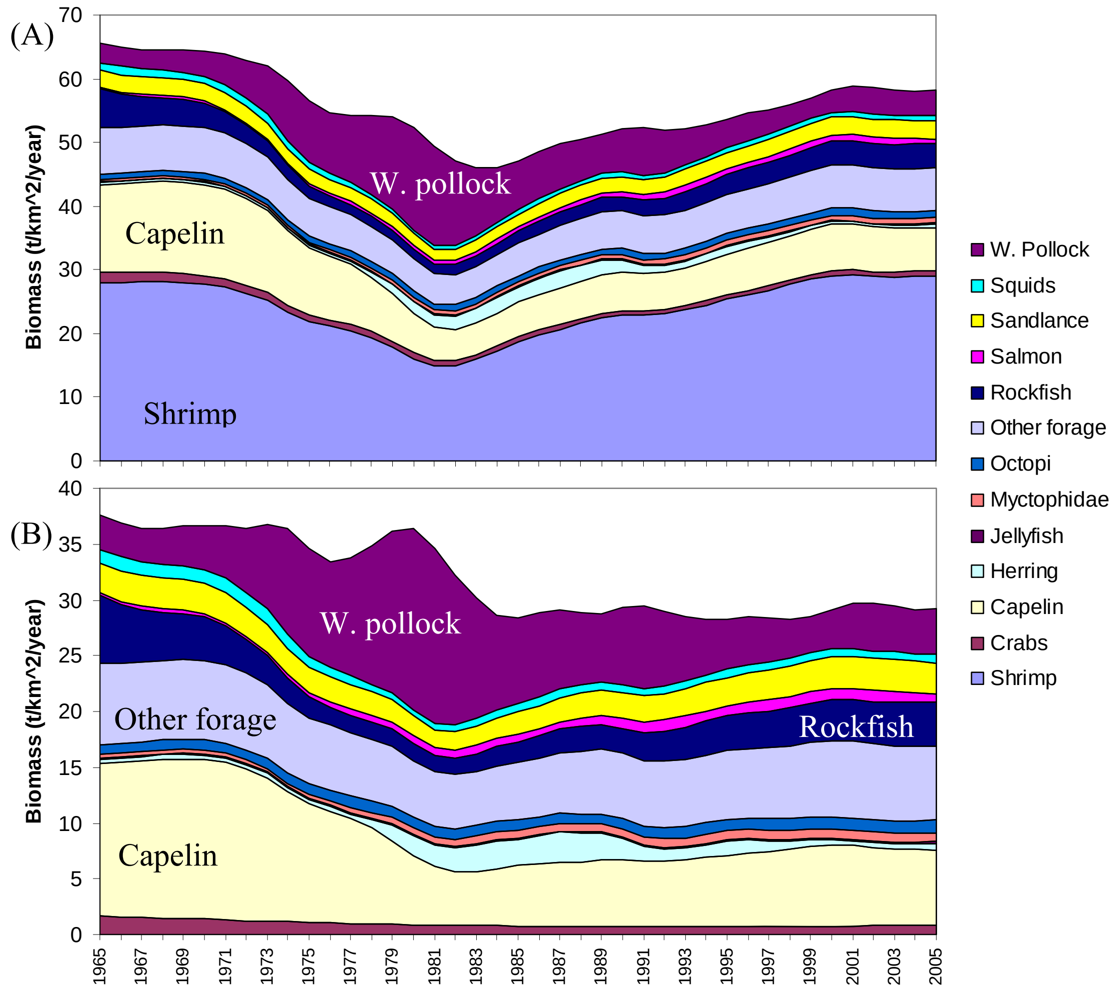


Figure 5. Trends in GOA forage species. Reconstructed Gulf of Alaska forage densities (t/km^2), as calculated from stock assessments (walleye pollock, Pacific herring, and rockfish) and from a maximum likelihood estimation from biomass dynamics models as described in the text (other species). (A) Forage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

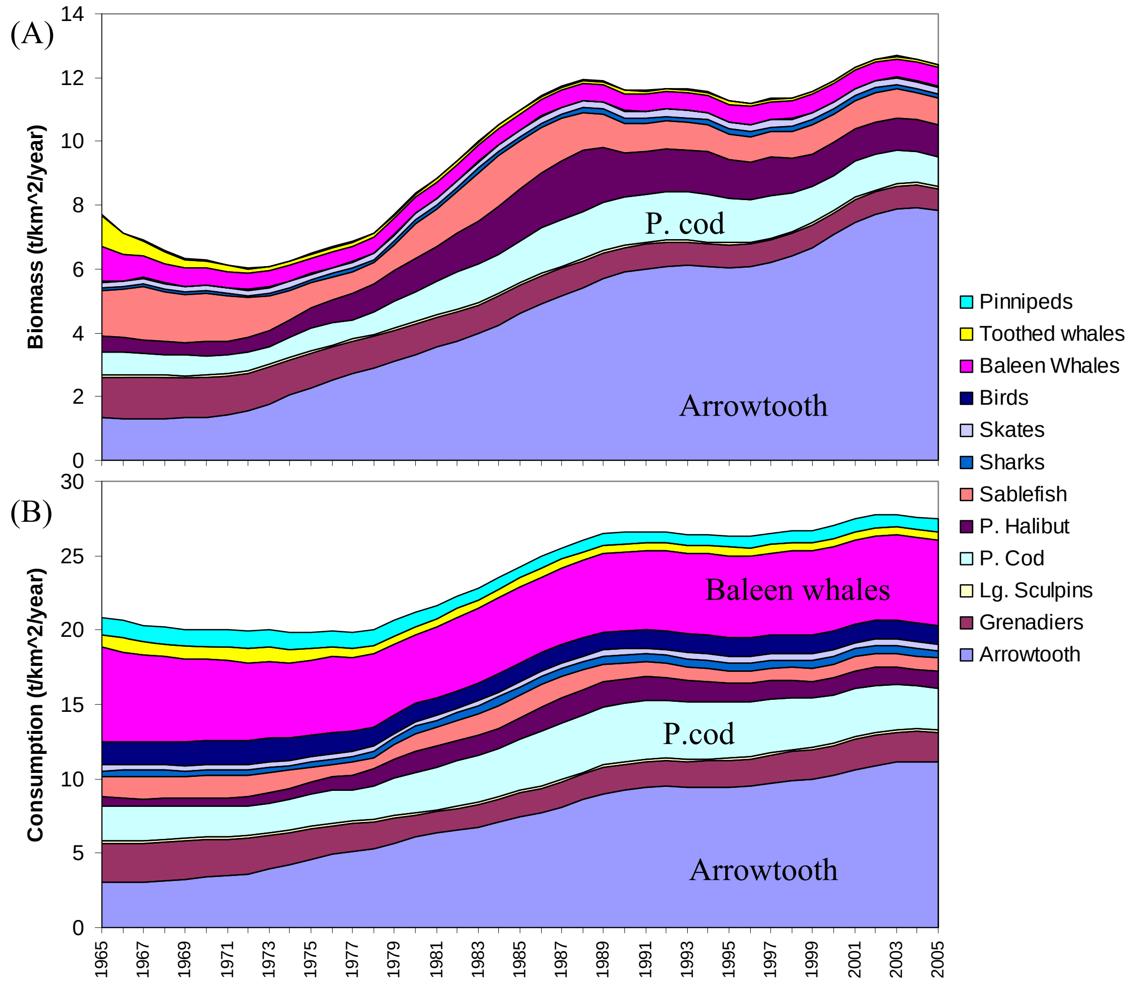
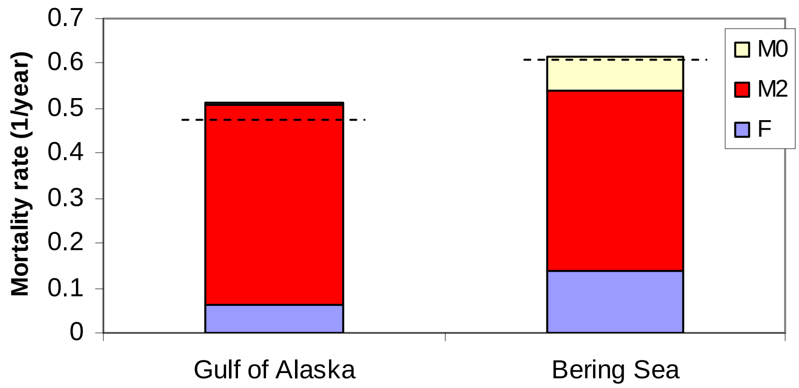


Figure 6. Trends in GOA predator biomass and total consumption. (A) Reconstructed Gulf of Alaska forage biomass densities (t/km^2), as calculated from stock assessments (arrowtooth flounder, Pacific cod, Pacific halibut, and pinnipeds) and from a maximum likelihood estimation from biomass dynamics models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

(A)



(B)

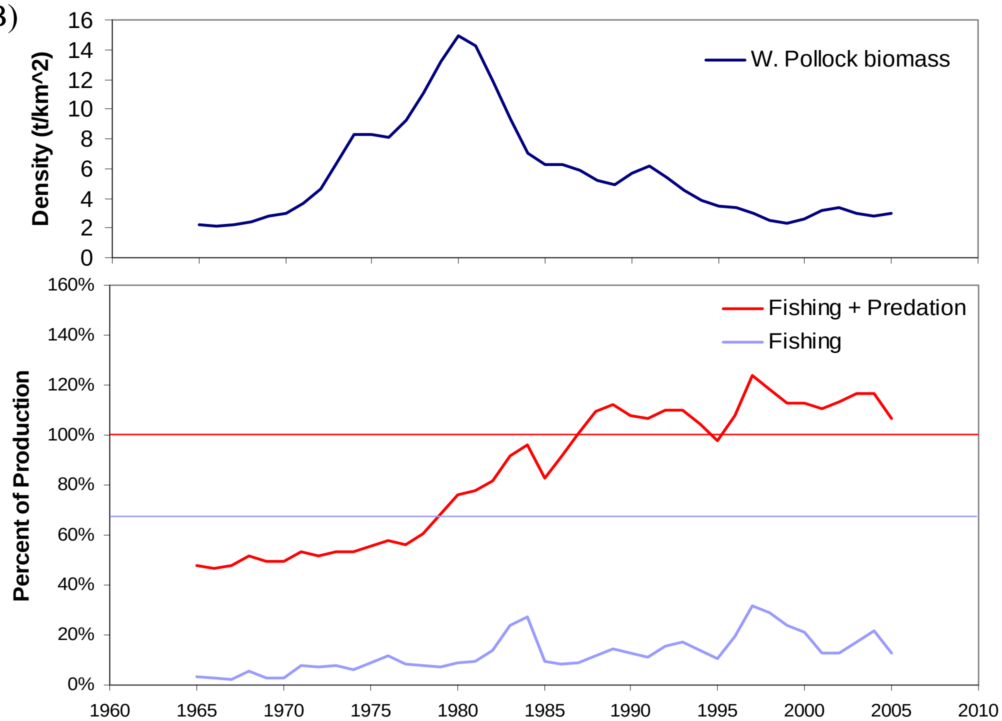
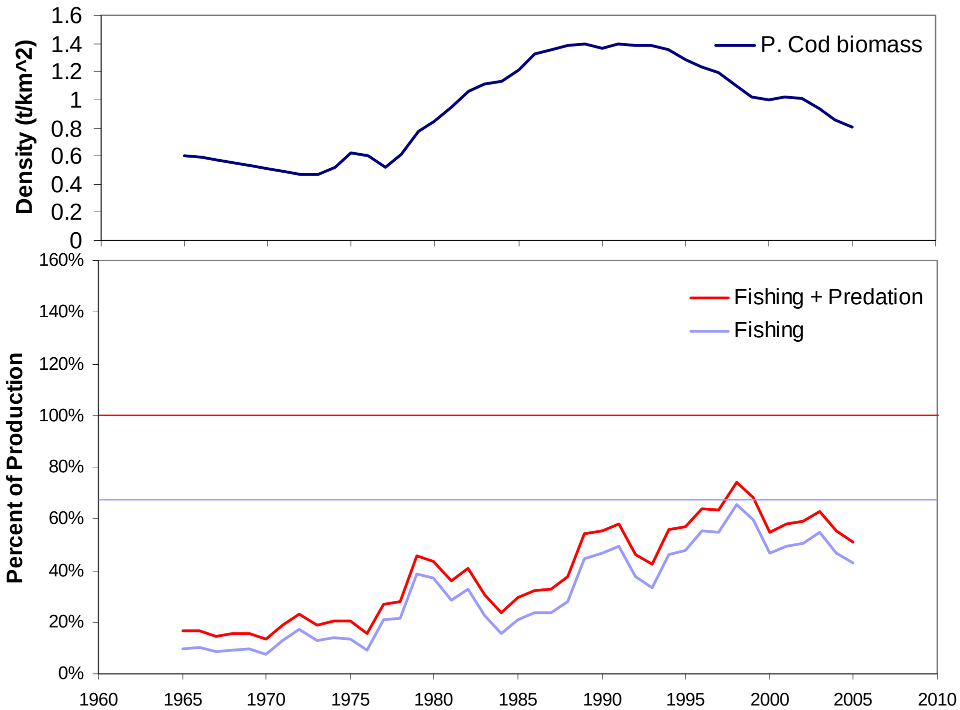


Figure 7. Estimates of fishing and predation mortality for pollock. (A) Mortality components of walleye pollock of the Bering Sea and the Gulf of Alaska in 2005, showing fishing mortality (F, exploitation rate on age 2+ pollock) as estimated from the stock assessment, predation mortality (M2) estimated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

(A)



(B)

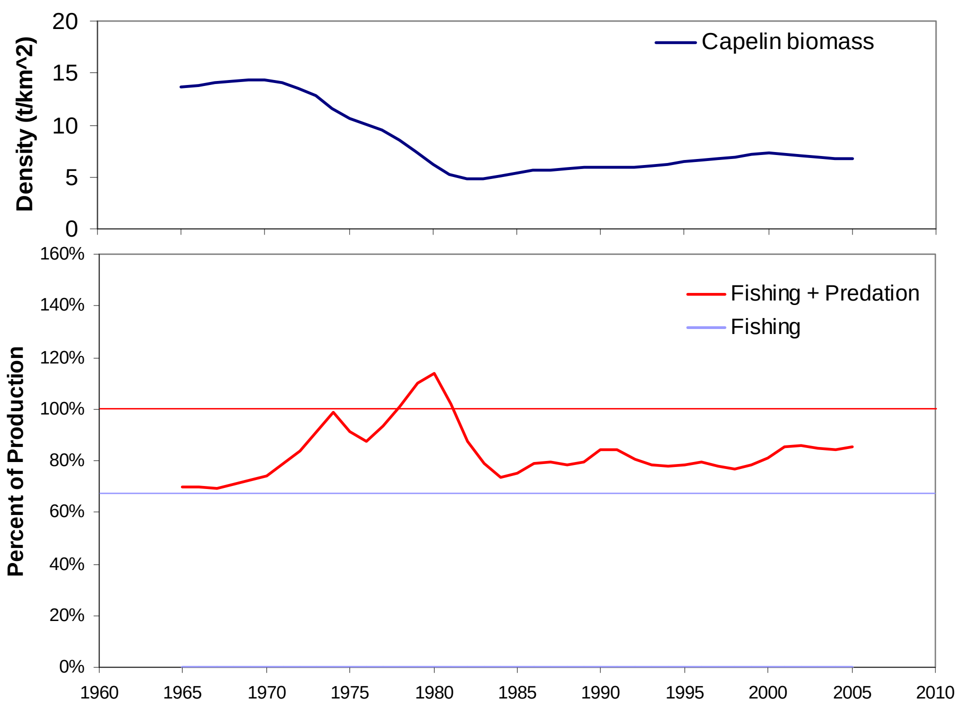
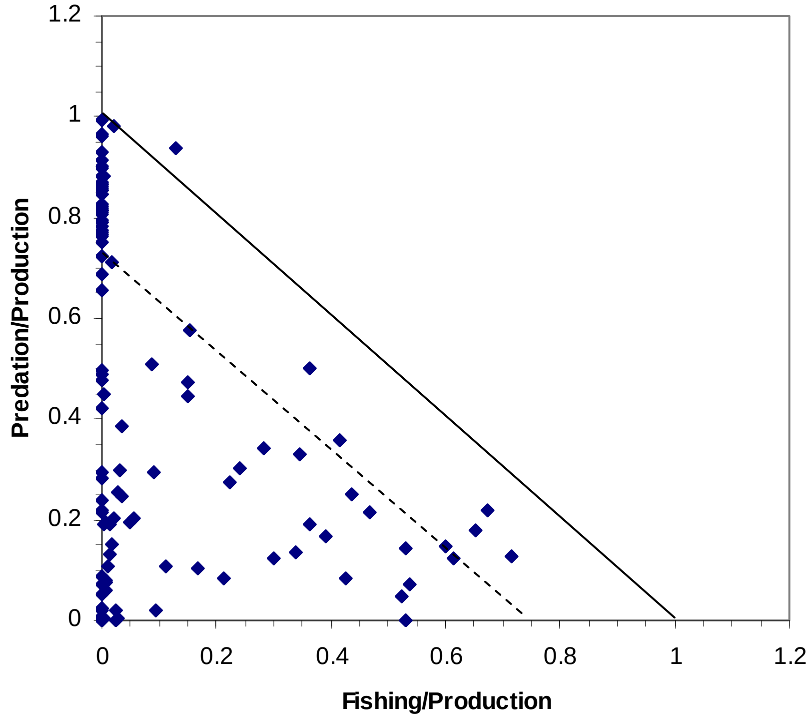


Figure 8. (A) Upper panel: Biomass density (t/km^2) of GOA Pacific cod from stock assessment. Lower panel: time series of fishing and predation as a fraction of total production rate, resulting from biomass dynamics model run (maximum likelihood parameter set). (B) Upper panel: Biomass density (t/km^2)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



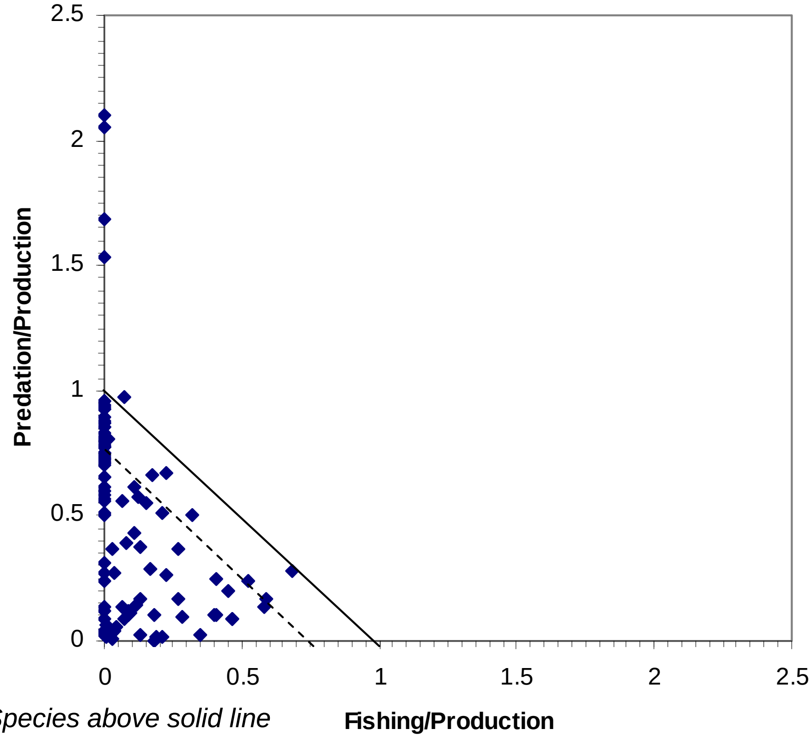
Species above solid line

Sei whales
W. Pollock
King Crab

Species between dotted and solid lines

Euphausiids	Pteropods	P. Halibut_Juv
Gelatinous filter feeders	Myctophidae	Pelagic microbes
Pelagic Amphipods	Capelin	Macroalgae
Herring_Juv	Lg Phytoplankton	Misc. crabs
Misc. Crustacean	Oth. managed forage	P. Cod_Juv
Pandalidae	Bivalves	Eelpouts
Benthic Amphipods	Chaetognaths	Bathylagidae
Shortspine Thorns	Grenadiers	Snails
Misc. fish shallow	Dusky Rock	Dogfish
Eulachon	NP shrimp	Fish Larvae
Oth. pelagic smelt	Misc. worms	Hermit crabs
W. Pollock_Juv	Copepods	Mysids
Squids	Hydroids	Octopi
Sablefish	Sandlance	Sharpchin Rock

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



Species above solid line

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

Species between dotted and solid lines

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

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

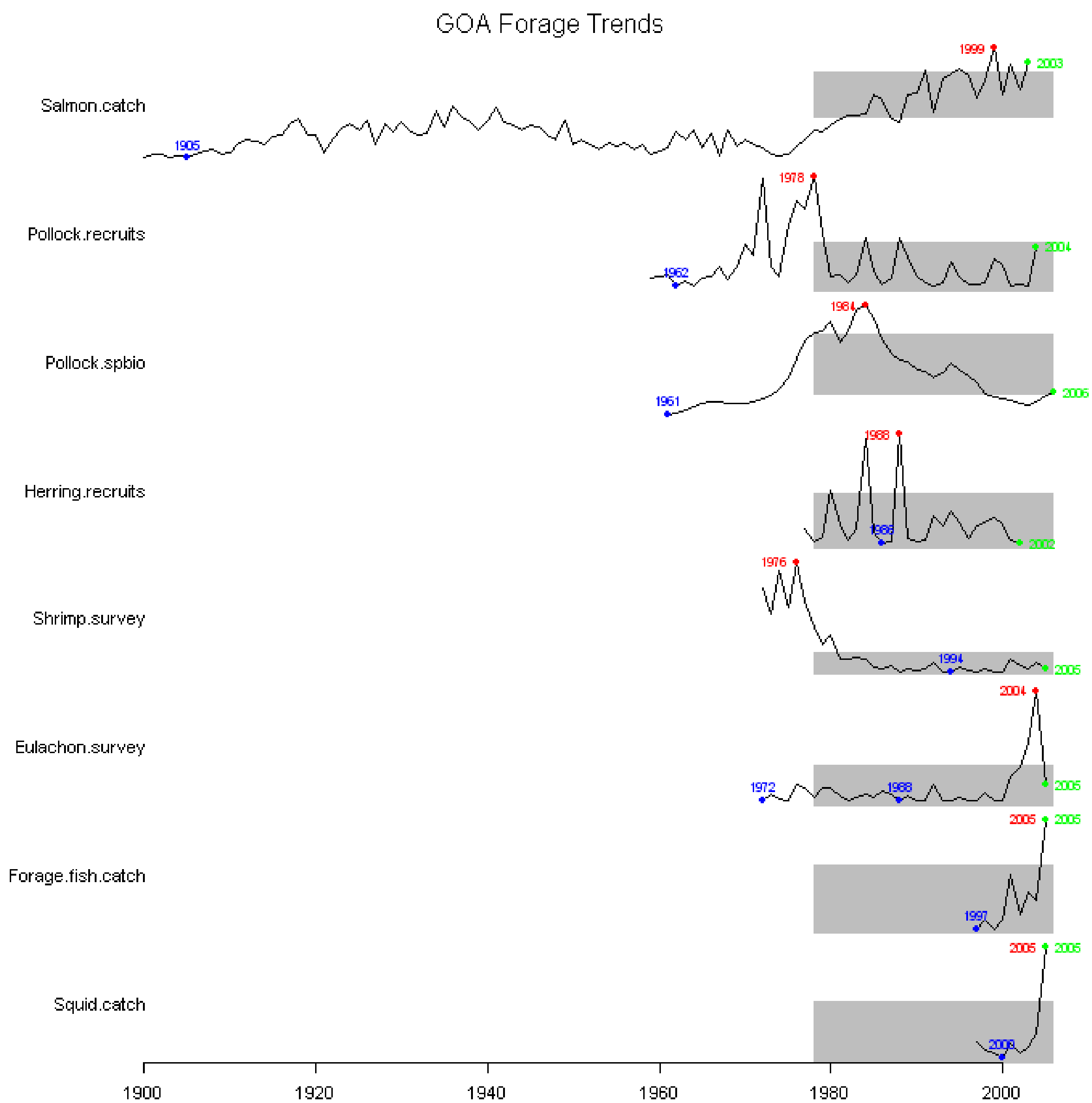


Figure 11. Trends in indicators of forage groups in the Gulf of Alaska. Years of highest (red), lowest (blue), and most recent (green) data points in the time series are labeled. Grey boxes represent one standard deviation around the mean for the duration of each individual time series extended to the 1978-2006 time period. See text for data sources.

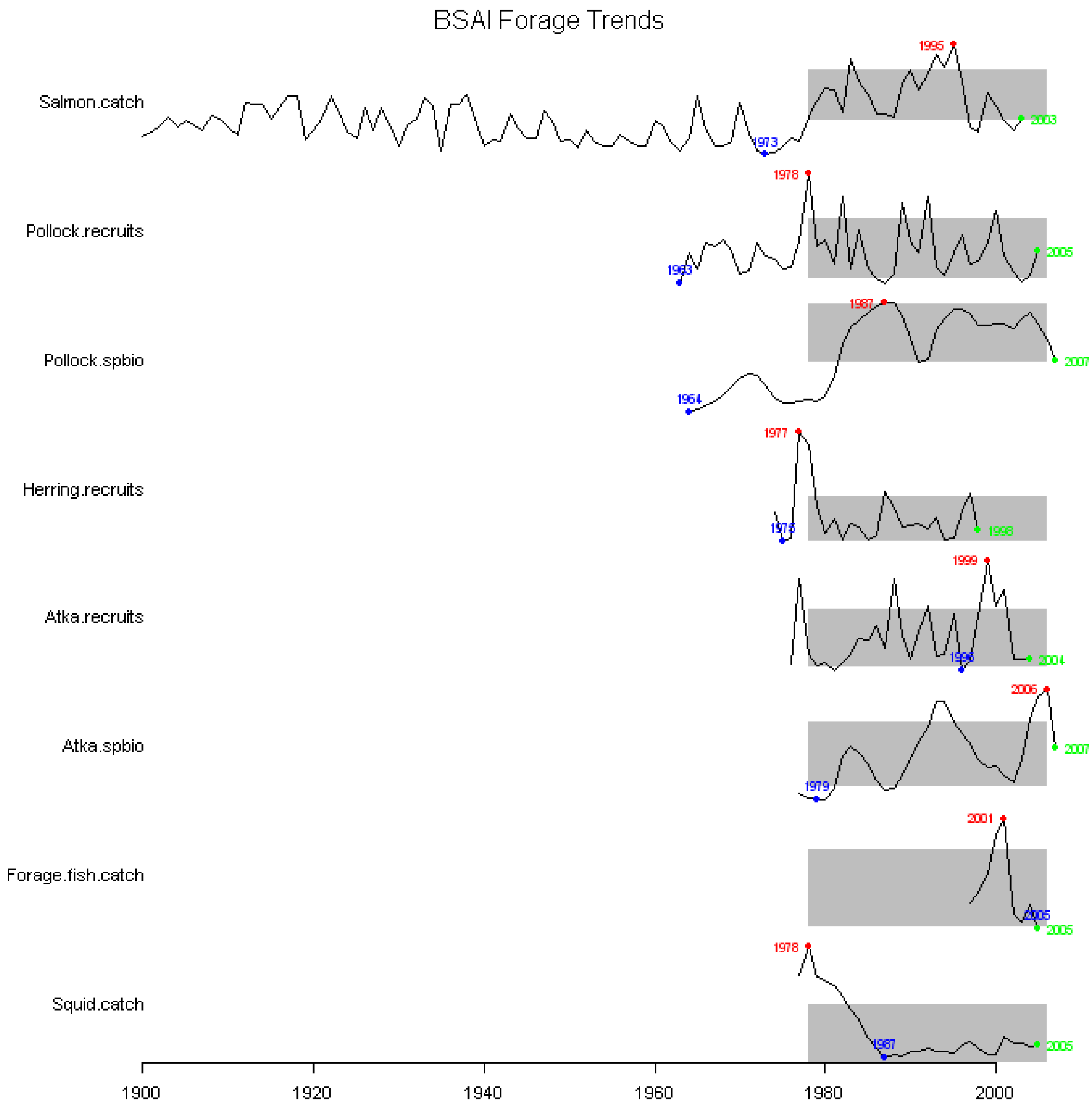


Figure 12. Trends in indicators of forage groups in the Bering Sea and Aleutian Islands. Years of highest (red), lowest (blue), and most recent (green) data points in the time series are labeled. Grey boxes represent one standard deviation around the mean, 1978 to the most recent data point. See text for data sources.

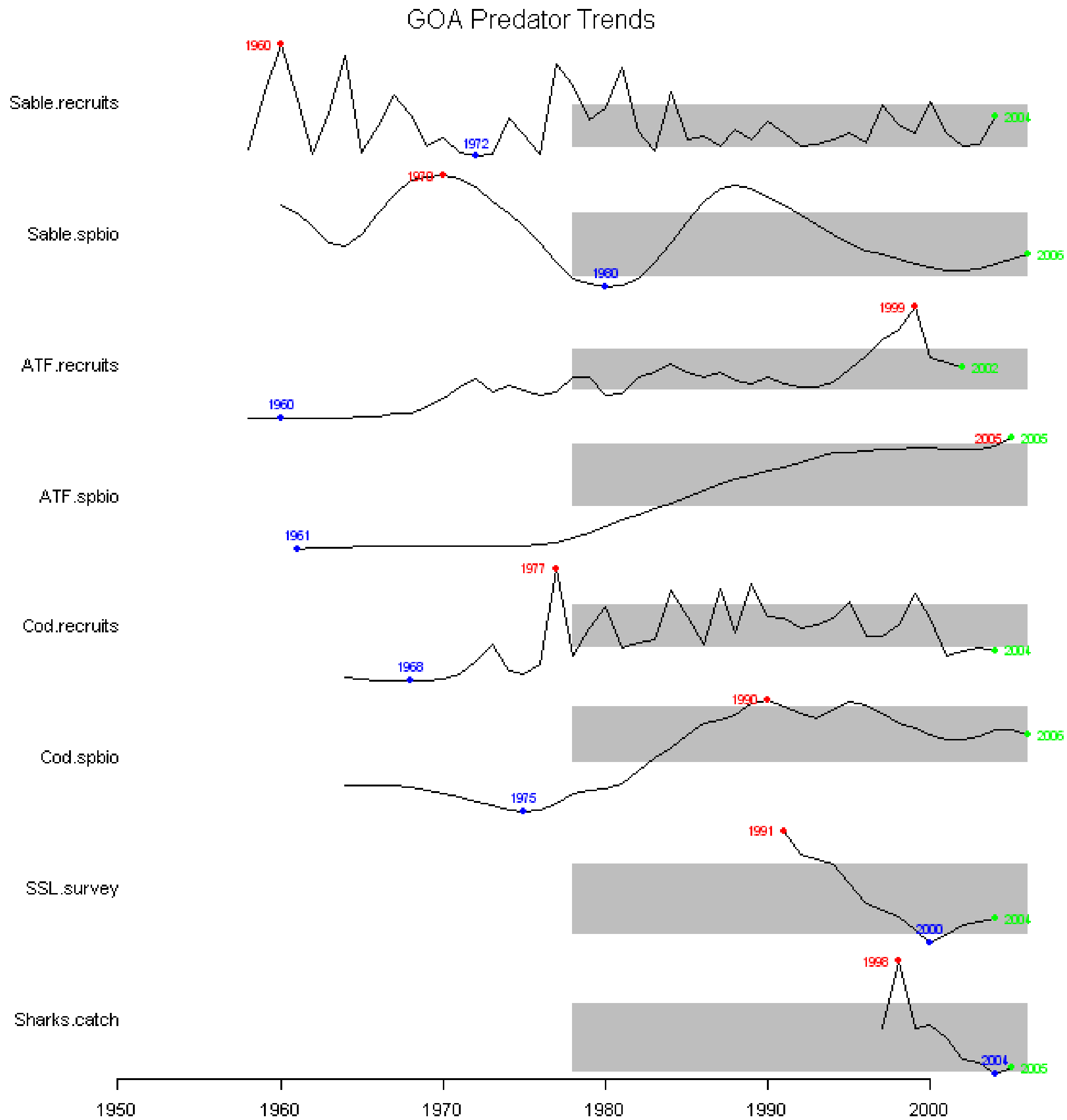


Figure 13. Trends in indicators of main predator groups in the Gulf of Alaska. Years of highest (red), lowest (blue), and most recent (green) data points in the time series are labeled. Grey boxes represent one standard deviation around the mean, 1978 to the most recent data point. See text for data sources.

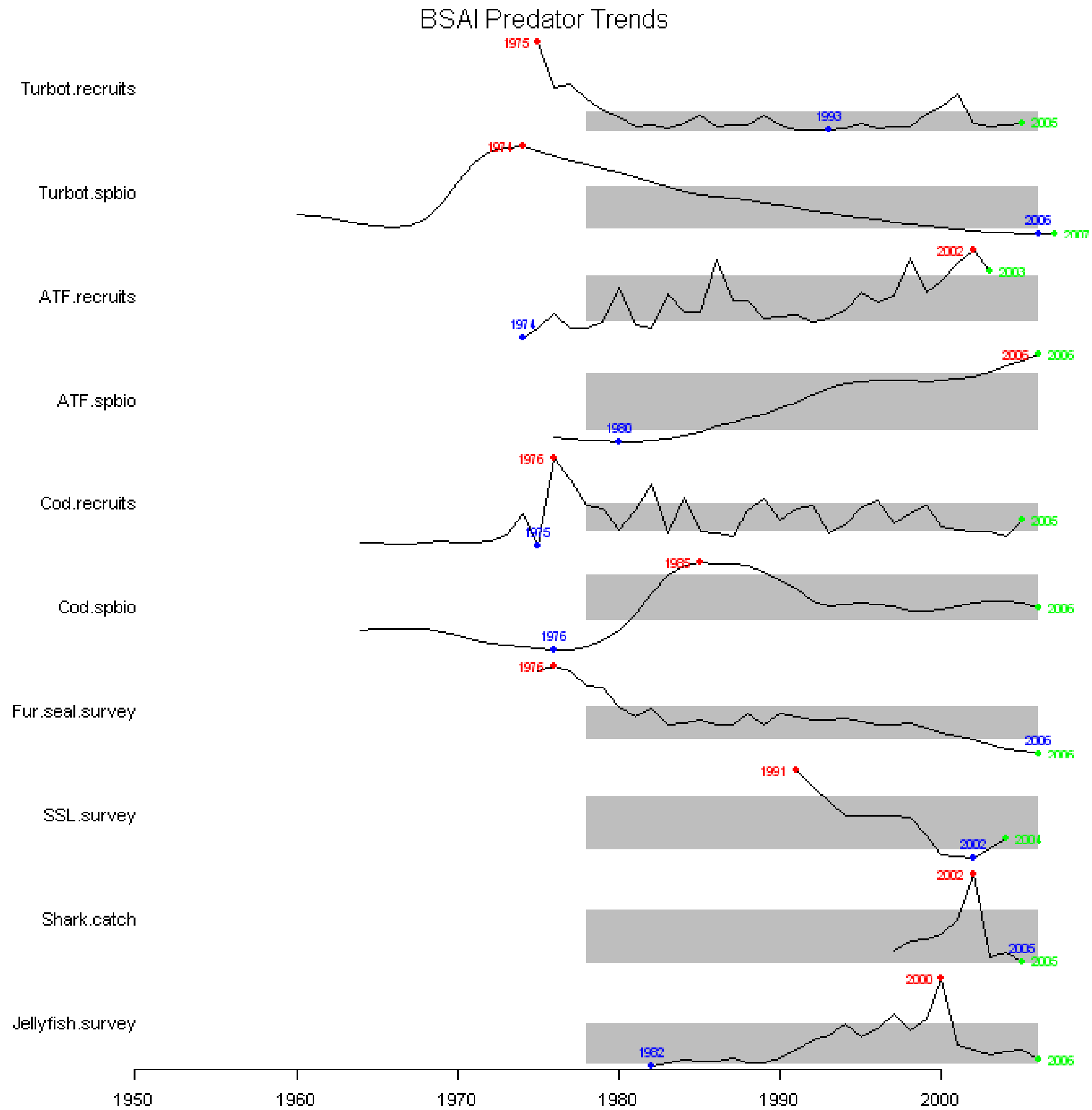


Figure 14. Trends in indicators of main predator groups in the Bering Sea and Aleutian Islands. Years of highest (red), lowest (blue), and most recent (green) data points in the time series are labeled. Grey boxes represent one standard deviation around the mean, 1978 to the most recent data point. See text for data sources.

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

INDICATOR	OBSERVATION	INTERPRETATION
Physical Oceanography		
Arctic Oscillation Index	Currently near neutral; AOI implicated in the 1988/89 climate shift	Negative values are associated with warm winters
Pacific Decadal Oscillation	Currently slightly positive but near the long-term mean.	When positive SST anomalies tend to be positive along the N. Amer. coast, extending to the SEBS
SST Anomalies	Relatively cool SSTs from the Bering Sea shelf to south of mainland Alaska from winter into spring of 2007.	BS cold due to more sea ice and late ice retreat relative to previous 6 years (except 2006)
EBS summer bottom temperature	The 2007 average summer bottom temperature was well below the 1982-2006 average	Bottom temperatures are affected by sea ice and may in turn affect pollock distribution
EBS ice cover index	Positive sea ice extent anomalies in January 2006 and ice extent was south of its median position (1979-2000)	Colder waters on shelf, may result in southward shift of shelf ecosystems. With more ice in 2006, May SST were cooler
Ice retreat index	Ice retreated early 1996-2005 (except in 1999). In 2007, the ice retreated late, but not quite as late as in 2006.	The EBS may be shifting to an earlier spring transition. There may have been an ice-associated spring bloom in 2007.
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	2006 temperatures were average	Average year
GOA summer temperature	2007 temperatures were cooler at the depths shallower than ~200 m and warmer at deep depths	2007 was a cool year on the shelf
PAPA Trajectory Index	Surface water circulation in the eastern GOA winter 2007 shows slightly northward values yet still near normal conditions compared to some of the earlier extremes	Surface water circulation in the GOA has been near average in the last five years but has become slightly positive (northward) in 2007.
Seasonal rainfall at Kodiak	Conditions dry Jan-Mar and wet Apr-May.	Survival potential of age-0 walleye pollock is "average to strong", because rainfall promotes eddies in the ACC, which are beneficial to pollock
Wind mixing south of Shelikof Strait	2007 wind mixing was below avg. for the first two months of winter and low for the final two months of spring	Survival potential of age-0 walleye pollock is "average". 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
Eddies in the GOA	Eddy kinetic energy (EKE) low in 2005-2006 and returned to higher values in 2007.	Eddies may be areas of high productivity and may increase cross-shelf transport of heat, salinity, nutrients, phytoplankton.

INDICATOR	OBSERVATION	INTERPRETATION
Eddies in the AI	Particularly strong eddies were observed south of Amukta Pass in 1997/1998, 2004, and 2006/2007	Eddies influence flow into the Bering Sea through the Aleutian Passes affecting the Aleutian North Slope Current and Bering Slope Current and the transport of heat, salinity, nutrients, phytoplankton.
Habitat		
Area closed to trawling BSAI and GOA	2006 had same closures as 2005 plus new closures to protect EFH. Largest closure: AI Habitat Conservation area. 2007 same as 2006.	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 2006 remained low.	Less trawling on bottom than prior to 1998
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 increased slightly in 2006.	Generally stable levels of longline effort in 1990's to 2006
Pot effort in GOA	Slight decrease in 2006.	Effort levels higher than in the early 1990s.
Total exploitation rate in GOA	Rates have remained relatively constant since the mid-1980s at less than 5%	Generally stable exploitation rates. Rates are lower than in the BS due to low exploitation of arrowtooth flounder in the GOA
HAPC biota bycatch in GOA groundfish fisheries	Has been variable in recent years	About constant in GOA 1997-2005, with an peak in 2002.
HAPC biota biomass indices from GOA bottom trawl survey	Frequency of occurrence of sea anemones and sponges has increased	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 2006 decreased and was the lowest since 1991.	Less trawling on bottom relative to the past 16 years.
Groundfish bottom trawling effort in AI	About the same in 2006 compared to 2005 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 BS	Lower in 2006 relative to past 10 years.	Effort levels in 2006 similar to that in the mid-1990s.
Longline effort in AI	Effort in 2006 increased slightly.	Effort levels in 2006 similar to that in the last 5 years.
Pot effort in BS	Increased effort in 2006 to highest effort since 1996.	Effort levels increasing.
Pot effort in AI	Increased in 2006 to the highest effort level since 1992.	Effort levels increasing.
Total exploitation rate in BS	Rates increased to 11% in 2006	Exploitation rates have remained relatively constant since the mid-1980s

INDICATOR	OBSERVATION	INTERPRETATION
HAPC biota bycatch in EBS/AI groundfish fisheries	Decreased since 2004	2007 catch lowest in time series.
HAPC biota biomass indices in EBS bottom trawl survey	These groups have been better identified in the survey in the 1990s to present	Survey may provide biomass index for seapens, anemones, and sponges. More research needed to understand trends
HAPC biota biomass indices in the AI bottom trawl survey	Survey may provide biomass index for seapens, anemones, and sponges.	More research needed to understand trends
Target Groundfish		
Groundfish fleet	Total number of vessels (868) actually fishing in 2006 was lowest since 1994.	Slight decrease in number of vessels since 2000.
Groundfish discards GOA	increased somewhat between 1998 and 2003, but have declined again in recent years, with a slight increase in 2006	Fairly stable rates of discarding since 1998.
Groundfish discards BSAI	Decreased slightly in 2006	Continued slight decline in discards since 1998
Total groundfish catch EBS	Total catch in 2004 as in 1990s, pollock dominant; pollock similar to 2003	Catch biomass about the same from 1984-2004
Total groundfish catch AI	Total catch in 2004 similar to 2003, Atka mackerel dominant	Total catch returning to lower levels
Total biomass EBS/AI	Total about the same in 2005 as in 1997, increase in pollock biomass, pollock dominant	Relatively high total biomass since about 1981
EBS recruit per spawner	Above average recruitment 1994-2000, but lower since 2001.	Groundfish recruitment higher 1994-2000 than the present
BSAI groundfish stock status	In 2006, 0 overfished, none subjected to overfishing	All major stocks are not overfished and none are being subjected to overfishing
Total groundfish catch GOA	Total catch lower in 2004 is similar to 2003; slight increase in pollock catch.	Total catch similar from 1985 through present
Total biomass GOA	Biomass declined 1982-01, slight increase in 2002 to 2005 to about same level as 1996, arrowtooth dominant and increasing; slight increase in pollock biomass in 2005.	Relatively low pollock biomass compared to peak in 1982
GOA recruit per spawner	Recruitment index below average across all stocks since 2001	Some groundfish recruitment is low.
GOA groundfish stock status	In 2006, 0 overfished, and none subjected to overfishing	All major stocks are not overfished and none are being subjected to overfishing

INDICATOR	OBSERVATION	INTERPRETATION
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	
GOA zooplanton	Zooplankton biomass peaked in 2002 during 1998-2003	Trends depend on shelf or slope habitat as well as month.
Forage		
Forage bycatch EBS	Increased in 2006 and 2007	2007 catch highest in time series
Larval fish in GOA	Decadal trend in abundance of many species; elevated abundance in late 1980s to mid-1990s relative to early and mid-1980s for some species	Larval abundance in late spring is linked to species-specific combinations of environmental variables, with seasonal variation in linkages
Forage biomass indices from EBS bottom trawl survey	In 2007, relative CPUE of eulachon highest in last 4 years.	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	Decreased in 2006 and 2007	Variable catches; 2007 average catch
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 and 2006 values were similar to those in 2001 in central GOA	Survey may provide biomass index eulachon. More research needed to interpret trends
Forage biomass indices from ADFG inshore small mesh survey in GOA	Capelin CPUE remained low in 2005; eulachon CPUE continued the trend of recent high values	Catches through 2005 do not show any significant deviation from the groundfish-dominated community state
Miscellaneous and other managed species		
GOA Jellyfish from ADFG small mesh survey	CPUE high since 1985; CPUE in 2005 remained high.	

INDICATOR	OBSERVATION	INTERPRETATION
EBS Jellyfish	2001-2007 were low relative to 1992-2000. Decrease in 5 of 6 commonly caught species in 2006.	Continuation of low levels of jellyfish biomass; similar to levels in the 1980s
NMFS bottom trawl survey - EBS	Survey may provide biomass index for some species	More research on life history characteristics of species needed to interpret trends
NMFS bottom trawl survey - AI	The 2006 survey had the highest jellyfish CPUE for all survey years, with a large increase in the eastern AI	More research needed to interpret trends
Crab stock status - BSAI	2 stocks overfished (Pribilof Is. and St. Mathew Is. blue king)	Mixed crab stock status
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 1960s and early 1970s); weak year classes in 1980s and 1990s.	Recruitment may partly relate to regime shifts (1977 and 1989)
Scallop stock status	1 stock- not overfished	
PWS Herring stock status	Pre-fishery run biomass estimate peaked in 1989; stock collapsed afterwards and remains low	Fishery remains closed for fall 2006 and spring 2007.
SEAK Herring stock status	The 2004 and 2005 estimates of spawning biomass were the two highest in 25-year time series. Every stock except Seymour Canal exhibited low recruitment in 2004 and 2005.	Decreasing population biomass can be expected for most stocks unless recruitment increases substantially in upcoming years
Togiak Herring stock status	2006 abundance and age 4 recruits increased slightly from 2005	Abundance is still below 1978-02 average; but population is considered stable because high abundance in 1980s may be a result of the model used.
Salmon stock status	0 stocks overfished, 5 stocks not overfished, 0 stocks unknown	Generally, Alaskan salmon stocks have been at high levels of abundance in the last 20 years; except some stocks, such as Yukon River chum, and some sockeye runs
Salmon Populations (AK Native Traditional Knowledge)	Decrease in Yukon River salmon populations 1989-1998	
ADF&G large mesh inshore-GOA	Arrowtooth flounder are main component of offshore catches, while Tanner crab have replaced flathead sole as the largest catch in the bays	Increasing dominance of arrowtooth flounder offshore, changing community in bays.
ADF&G small mesh inshore survey-GOA	Pandalid shrimp CPUE in 2005 continues to be low; in 2005 smooth pink shrimp (*Pandalus jordani*) were caught in two bays	Appearance of smooth pink shrimp may possibly indicate a northward distribution shift in response to recent warming of the Gulf of Alaska
NMFS bottom trawl survey-GOA	Survey may provide biomass index for some species	More research needed to interpret trends

INDICATOR	OBSERVATION	INTERPRETATION
Prohibited species bycatch	There was a large increase in bycatch of other salmon and herring in 2003-2005. Decreased bycatch of other king crab and herring; increased bycatch of bairdi, tanner and red king crabs, and chinook salmon, and bycatch mortality of halibut was similar to 2004.	In 2005, there was a decrease in the bycatch of 2 prohibited species an increase in 5 species.
BSAI Non-specified species bycatch	Decreased since 2003	2007 lowest catches in the time series
GOA Non-specified species bycatch	Low in the last 3 years	Low catch of non-specified taxa
Marine Mammals		
Alaskan sea lion western stock non-pup counts	Increases between 2004 and 2007 in the E ALEU, W GULF and C GULF have largely been offset by decreases in the eastern C ALEU and E GULF	Western stock is stable or declining.
Northern fur seal pup counts	Annual rate of decline on Pribilof Islands during 1998-2006 was 6% per year. During 1995-2007, pups born on Bogoslof increased by 20%.	Pribilof Island pup production at low levels not seen since 1916. Bogoslof pup production increased. Neither trend is due to immigration/emigration alone.
Bowhead Whales	In 2001, noted increase and a record high count of 121 calves in Western Arctic stock	Suggest a steady recovery of the Western Arctic stock
Harbor seals	Populations thought to be lower than they were in the 1970s and 1980s	Suggest the populations of the AI and GOA and perhaps BS have not recovered.
Seabirds		
Seabird breeding chronology	Overall seabird breeding chronology was early or average, with early nesters predominate in the NB/C, SEBS, and SEAK. The highest number of late nesters was in SWBS, where no birds were early.	Earlier hatching times are associated with higher breeding success
Seabird productivity	Varied by region and species, but there was a trend of above average or average productivity in most regions, except SWBS	Variable chick production
Population trends	Mixed: majority showed no discernable trend through to 2003.	Variable depending on species and site
Seabird bycatch	2004 longline bycatch is decreasing or stable in the BS, AI, and GOA.	Unclear relationship between bycatch and colony population trends

INDICATOR	OBSERVATION	INTERPRETATION
Aggregate Indicators		
Trophic level catch EBS and AI	Constant, relatively high trophic level of catch since 1960s	Not fishing down the food web
Trophic level catch GOA	Constant, relatively high trophic level of catch since 1970s	Not fishing down the food web
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 1990s
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 and richness have been highly variable since 1980	Depends on the spatial distribution of species
Groundfish species richness and diversity - GOA	Species richness and diversity increased from 1990-99, decreased after 1999 and recently increased. Species diversity and richness show similar trends.	Relative species composition is stable
Combined standardized indices of groundfish recruitment	Above-average recruitment mid-late 1970s to late 1980s, below-average recruitment early 1990s (GOA) or most of 1990s (BSAI); above-average recruitment in the GOA 1994-2000 (except 1996). Below average since 2001. Similar but less pronounced trend evident in Bering Sea	Recruitment are a function of both spawner biomass and environmental variability
Combined standardized indices of groundfish survival	Similar patterns as recruitment. Indices for GOA and BSAI were unusually high in 1984, when 19 out of 23 stocks were above-average.	Trends in survival rate indices, which are adjusted for differences in spawner biomass, are presumably driven by environmental variability but are even more uncertain than recruitment trends
Groundfish productivity BS	Decreased from 1978-2005; this is a significant decrease in the BSAI when pollock are removed from analysis.	Could be due to density-dependent response to observed increases in biomass
Groundfish productivity GOA	Lower than in BS and less variable; decreased slightly from 1978-2005.	
Total trawl survey fish and invertebrate CPUE BS	Minimum in 1985; Peaked in 1993/1994, long-term increase from 1982-2006	Increased overall abundance of some species 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 and remained high in 2005	Increased overall abundance of some species of demersal and benthic species

APPENDIX 1: Model Details

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2. Estimates of unaccounted mortality (M_0).

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

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

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

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

3. Maximum likelihood estimation for a biomass dynamics model

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

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

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

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

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

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

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

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

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

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

1. For 1965-2005, stock assessment biomass for species with age-structured assessments and catches are assumed to be "perfectly known" and the annual process error (change in biomass) required to follow these biomass trends is calculated and applied. Functional response parameters are fit to minimize this process error: a future extension of this method may be to apply a nonlinear Kalman filter to allow for error specification within each time trend.
2. For species with no age-structured stock assessments the difference between the dynamic model-predicted 1990-93 average biomass and the initial food web model biomass (e.g.

coming from trawl survey data or consumption estimates) was considered as observation error.

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

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

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

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

4. Diet composition calculations

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

v = survey
a = assessment
R = ration estimate

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

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

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

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

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

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

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

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

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

5. Ration Calculations

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

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

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

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

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

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

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

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

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

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

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

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

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

6. Production rates

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

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

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

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

ECOSYSTEM STATUS INDICATORS

The purpose of this section is to provide new information and updates on the status and trends of ecosystem components to stock assessment scientists, fishery managers, and the public. The goals are to provide stronger links between ecosystem research and fishery management and to spur new understanding of the connections between ecosystem componenets by bringing together many diverse research efforts into one document. As we learn more about the role that climate, humans, or both may have on ecosystems, we will be able to derive ecosystem indicators that reflect this new understanding.

Physical Environment

Ecosystem Indicators and Trends Used by FOCI

Edited by S. Allen Macklin, NOAA/PMEL
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Last updated: September 2007

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 (2007) conditions. This section begins with an overview of North Pacific climate for 2007, 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.

North Pacific Climate Overview

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Last updated: September 2007

***Summary**. The North Pacific atmosphere-ocean system was characterized by mostly modest anomalies of variable sign from autumn 2006 through summer 2007, with some minor exceptions. As a result, two indices commonly used to represent this system, the North Pacific index (NPI) for the atmosphere, and the Pacific Decadal Oscillation (PDO) for the ocean, also had weak amplitudes. A short-lived El Nino of weak-moderate intensity occurred in late 2006, but its effects appear to have been swamped by the combined effects of a positive state for the Arctic Oscillation in the winter of 2006-07 and the intrinsic variability of the North Pacific atmospheric system. While the basin-wide signals in the North Pacific were not prominent, there were some substantial regional events, including strong (weak) upwelling along the west coast of the U.S. in the summer of 2006 (2007), and the development of relatively cool SSTs from the Bering Sea shelf to south of mainland Alaska from winter into spring of 2007. La Nina conditions were developing in the summer of 2007, with probable consequences for the North Pacific climate system in the upcoming 6-9 months.*

1. SST and SLP Anomalies

The state of the North Pacific from autumn 2006 through summer 2007 is summarized in terms of seasonal mean sea surface temperature (SST) and sea level pressure (SLP) anomaly maps (Figures 15-18). These fields are observed reasonably well and can be used to represent the spatial distribution of air-sea interactions. The SST and SLP anomalies are relative to mean conditions over the periods of 1971-2000 and 1968-1986, respectively. The SST data is from NOAA's Optimal Interpolation (OI) analysis; the SLP data is from the NCEP/NCAR Reanalysis projects. Both data sets are made available by NOAA's Earth System Research Laboratory at http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl As will be shown below, the basin-scale anomaly patterns during the past year tended to be of weak-moderate amplitude.

The autumn (September-November) of 2006 included positive SST anomalies of typically 0.5-1˚C magnitude in the western North Pacific and relatively cool SSTs in a narrow band along the U.S. west coast (Figure 15a). The corresponding pattern of anomalous SLP featured a band of relatively high pressure extending from the Sea of Okhotsk to the Gulf of Alaska and coastal British Columbia, with a peak magnitude of greater than 6 hPa near the dateline (Figure 15b). The sense of the overall pattern in the SLP was to drive anomalous easterly winds across most of the North Pacific between 30 and 50˚ N.

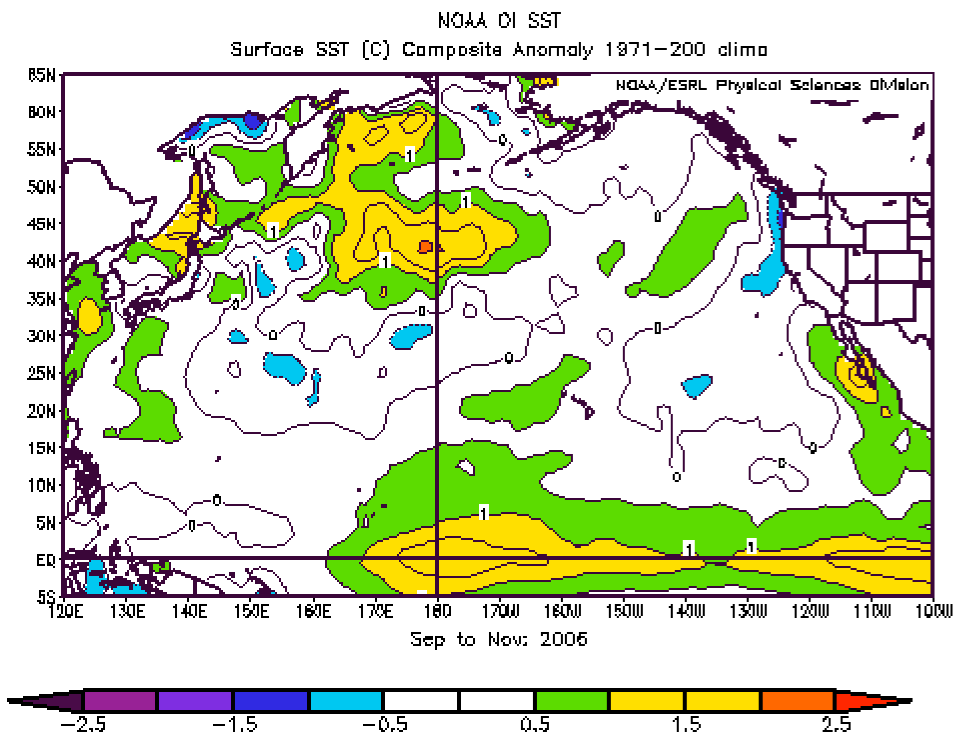

Figure 15a. SST anomalies for September-November 2006.

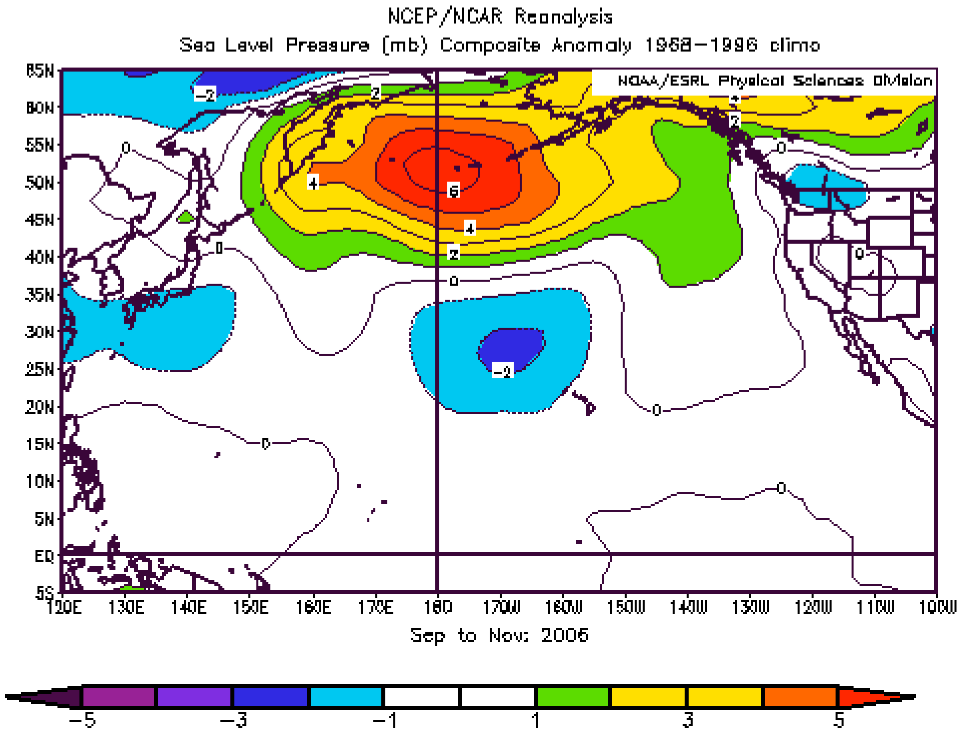

Figure 15b. SLP anomalies for September-November 2006.

During the following winter (December-February of 2006-07), the SST anomalies in the western North Pacific became weak, except for moderately positive values near and southeast of Japan (Figure 16a). This period was also marked by the development of weakly cooler SSTs in the eastern North Pacific in a broad band extending from Alaska to the subtropics. The wintertime SLP featured negative anomalies centered near Bering Strait and positive anomalies stretching across the entire Pacific from northern Japan to the western U.S (Figure 16b). The anomalous north-south gradient in SLP was accompanied by westerly wind anomalies (not shown), implying anomalous equatorward Ekman transports, which in turn, is broadly consistent with the observed cooling in seasonal mean SST anomalies in the North Pacific north of 40˚N.

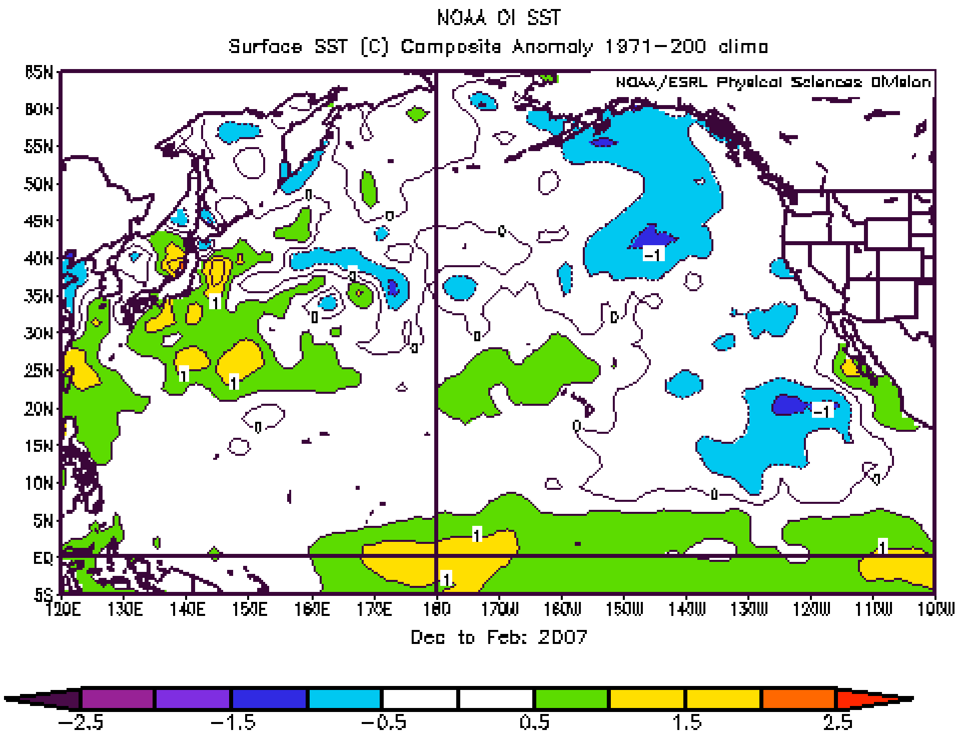

Figure 16a. SST anomalies for December 2006-February 2007.

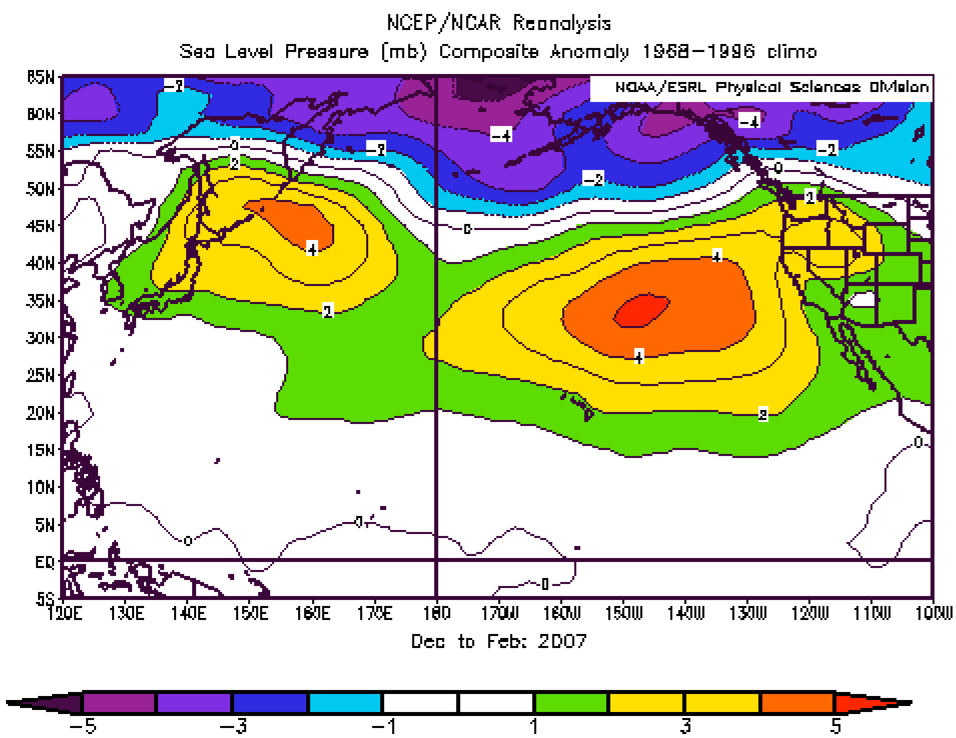

Figure 16b. SLP anomalies for December 2006-February 2007.

The distribution of SST in spring (March-May) of 2007 (Figure 17a) indicates continued cooling in the western North Pacific and warming in a band extending from the subtropical western North Pacific towards California. The concomitant SLP anomaly map (Figure 17b) shows a reversal from the previous season, specifically, an anomalous high over the Bering Sea and anomalous troughing from Japan into the Gulf of Alaska (Figure 17a). A secondary anomalous high was located off the coast of Oregon.

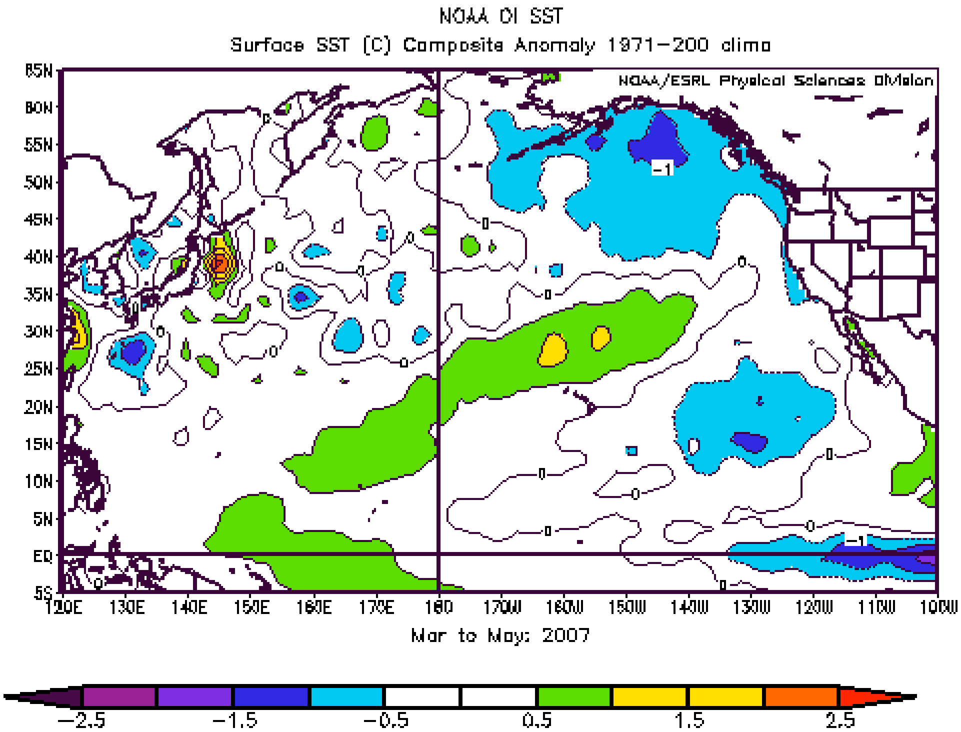

Figure 17a. SST anomalies for March-May 2007.

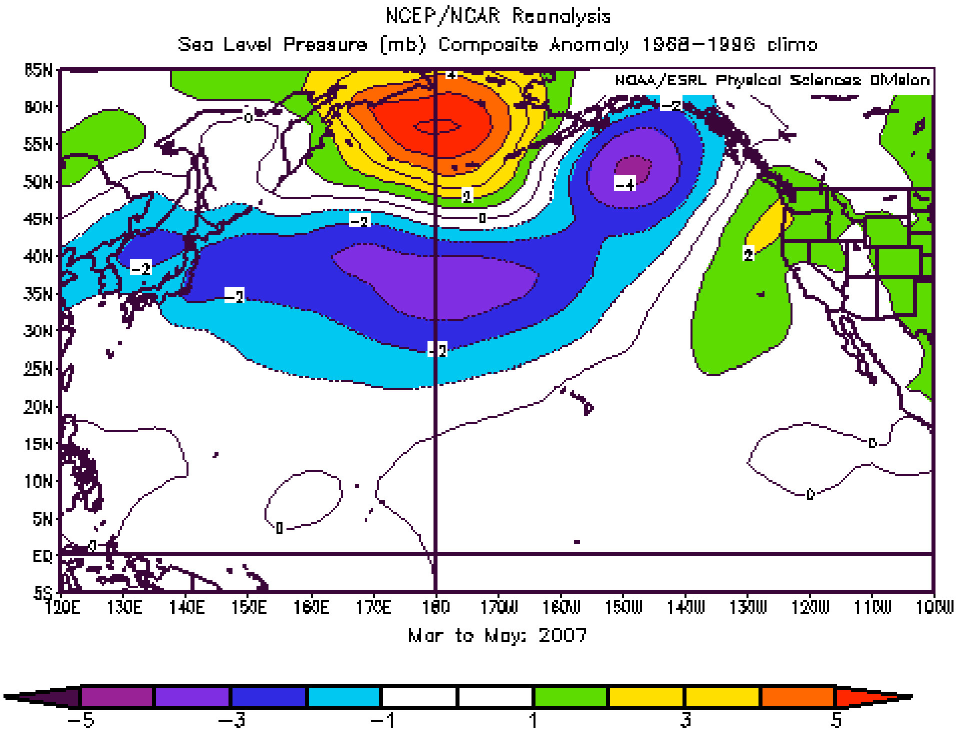

Figure 17b. SLP anomalies for March-May 2007.

The pattern of anomalous SST in summer (June-August) 2007 includes positive values in the western and northern portions of the Bering Sea, negative values in the western North Pacific centered near 35˚ N and in the eastern North Pacific south of Alaska centered near 40˚ N, a continuation of the positive anomalies from the western subtropical North Pacific towards California, and finally, negative anomalies in the eastern subtropical North Pacific (Figure 18a). The magnitudes of these anomalies were generally larger than during the previous spring, which is not unusual in that the summertime oceanic mixed layer is shallow, and hence relatively sensitive to the surface heat fluxes (which are dominated by the shortwave radiation component). The SLP distribution for summer (Figure 18b) indicates the maintenance of relatively high pressure over the Bering Sea, and low pressure anomalies in the northwestern portion of the North Pacific basin and off the coast of the Pacific Northwest.

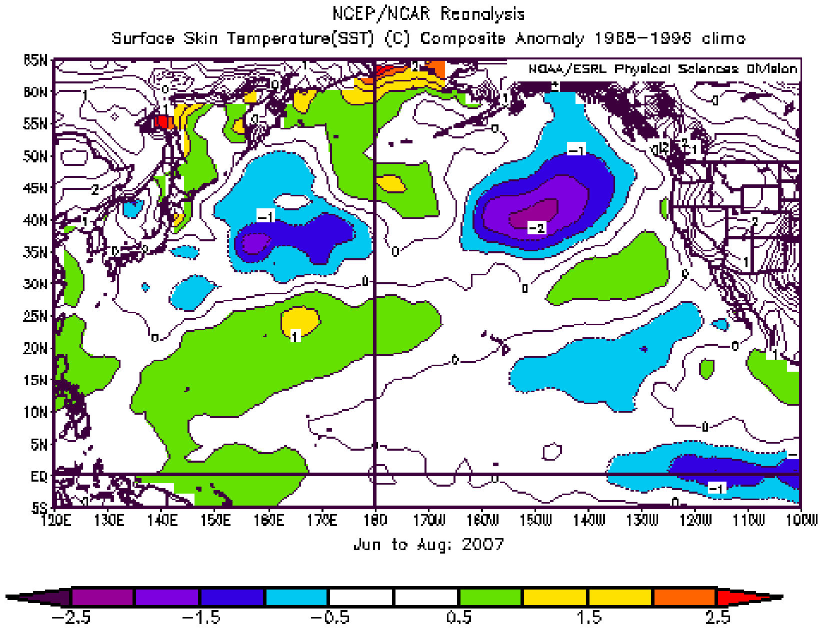

Figure 18a. SST anomalies for June-August 2007.

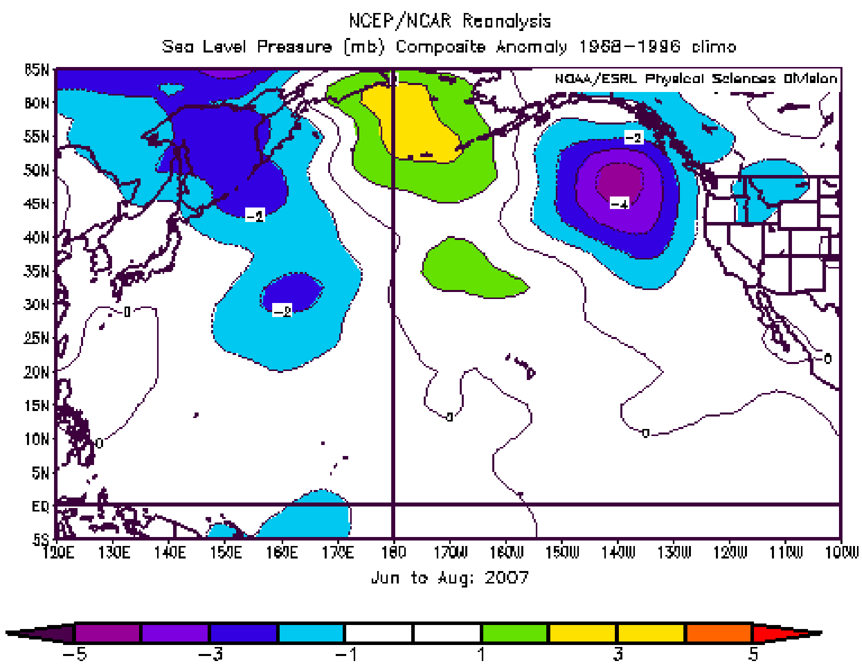

Figure 18b. SLP anomalies for June-August 2007.

2. Climate Indices

The SST and SLP anomaly maps for the North Pacific presented above can be placed in the context of the overall climate system through consideration of climate indices. For the present purposes we focus on four indices: the NINO3.4 index to characterize the state of the El Nino/Southern Oscillation (ENSO) phenomenon, the Pacific Decadal Oscillation (PDO) index (the leading mode of North Pacific SST variability), and two atmospheric indices, the North Pacific index (NPI) and Arctic Oscillation (AO).

ENSO underwent substantial evolution over the last year (Figure 19). Over most of 2006, the trend in the NINO3.4 index was positive, resulting in weak-moderate El Nino conditions near the end of 2006. But this was a short-lived event in that neutral conditions returned by early spring 2007. A cooling trend resumed in summer 2007 after a short period of small change; as will be discussed below it now appears probable at least a weak La Nina will form by the fall/winter of 2007-08. As shown in Figure 19, the El Nino of late 2006 was of lower amplitude than the 2002-03 event, and stronger at its peak, but of shorter duration, than the warm conditions that occurred in the winter of 2004-05. An important point here is that the observed SST and SLP anomalies that occurred in the North Pacific during the fall through winter of 2006-07 bear little resemblance to the canonical patterns associated with previous El Ninos.

The PDO was of rather modest amplitude over the last year (Figure 19). It transitioned from moderately positive in early 2006 to moderately negative in the summer/early fall of 2006 and has slowly increased to weakly positive values during the summer of 2007. In general, the SST anomalies for the North Pacific have not projected strongly on the spatial pattern associated with the PDO since 2000, with the exception of the period of the El Nino winter of 2002-03.

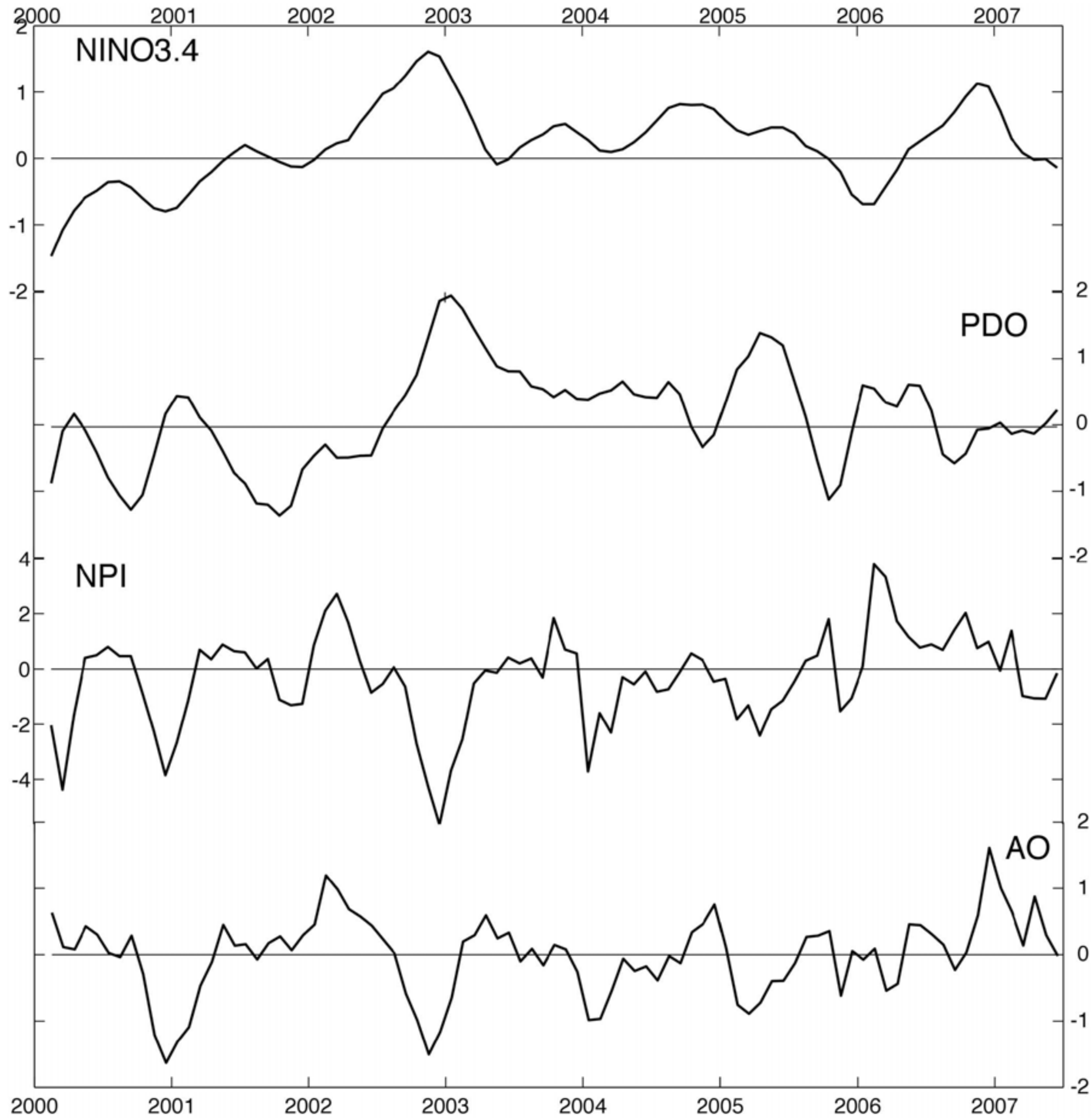

Figure 19. Time series of the NINO3.4, PDO, NPI, and AO indices. Each time series represents monthly values smoothed by 3-month running means. More information on these indices is available from NOAA's Earth Systems Laboratory at http://www.cdc.noaa.gov/ClimateIndices/.

The NPI is one of several measures used to characterize the strength of the Aleutian low. The time series of the NPI with the annual cycle removed (Figure 19) indicates positive values in early 2006 (i.e., high SLP anomalies in the central North Pacific and hence a weak Aleutian low), with an overall declining trend until late spring of 2007. The lack of a strong signal in the NPI since early 2006 is consistent with the SLP anomaly maps presented above, which indicate mostly dipole patterns bracketing, rather than co-located with the position of the mean Aleutian low (with the exception of fall 2006; Figure 15b). The NPI tends to be negative (positive) during El Ninos (La Ninas), but the time series of the NPI and NINO3.4 indices since 2000 show that deviations from this relationship are not uncommon, further illustrating the complexity of the climate variability of the North Pacific.

The AO signifies the strength of the polar vortex, with positive values signifying anomalously low pressure over the Arctic and high pressure over the Pacific and Atlantic at a latitude of roughly 45° N, and hence anomalously westerly winds across the northern portion of the Pacific and Alaska. The AO includes considerable energy on daily to decadal time scales; the time series of the three-month running mean plotted in Figure 19 shows it was in a mostly negative state in early 2006 and was strongly positive for a brief period in the middle of the 2006-07 winter. At this time, the AO and EL Nino may have been working at cross-purposes in terms of their individual effects on the strength (and position) of the Aleutian low, which might help explain the lack of the usual, monopole-type SLP anomaly pattern. The AO trended downward during 2007 to a near-neutral state by summer. If this trend continues, the atmospheric circulation for the Northern Hemisphere will be less zonally symmetric than usual and instead feature relatively high-amplitude waves and meridional flow. Further discussion of the year ahead is provided in Sec. 4.

3. Regional Highlights

a. **West Coast of Lower 48** – During the summer of 2006, strong and especially persistent upwelling-favorable winds occurred from Vancouver Island south to central California. The oceanic response included a tongue of relatively cold water along the coast (as shown earlier in Figure 15a), and a region of hypoxia on the shelf extending from Oregon north into Washington farther than ever found before. Particularly unusual was the lack of relaxation events in the upwelling winds during the summer of 2006; the implications of this are uncertain but it is suspected that it was disruptive to organisms that rely on these events for retention in the coastal domain. On the other hand, the summer of 2007 brought relatively weak upwelling to the same region. By way of comparison, there was also weak upwelling in 2005, but during that particular year it was a case of delayed onset of upwelling in spring, rather than weak upwelling in summer. The delayed onset of upwelling in 2005 had substantial impacts on the coastal ecosystem; the ecosystem's response to anomalous winds in 2007 is unknown at the time of this writing.

b. **Gulf of Alaska** – Significant anomalies in the forcing of the Gulf of Alaska during the last year occurred in the winter of 2006-07 and the spring of 2007. The former period featured anomalous southwesterly winds, which given the prevailing seasonal winds, meant enhanced wind mixing and enhanced positive wind stress curl and hence upward Ekman pumping. The net effect was relatively shallow mixed layer depths in the central Gulf, and deep mixed layer depths close to the coast, at the end of winter of 2007 as compared with the previous year, based on data from ARGO profiling floats (http://www.pac.dfo-mpo.gc.ca/sci/osap/projects/argo/Mixlayer_e.htm). During spring 2007, anomalously low SLP was present in the central Gulf of Alaska, which promotes anomalous downwelling in the coastal zone, and a relatively strong Alaska Coastal Current (ACC). It bears noting that the scarcity of sub-surface data for the shelf regions of the Gulf of Alaska precludes making definitive statements about the actual state of the ACC during 2007.

c. **Alaska Peninsula and Aleutian Islands** – This region experienced westerly wind anomalies during the winter of 2006-07 in association with the SLP anomaly dipole shown in Figure 16b, and a reversal to easterly wind anomalies during the spring of 2007. Westerly winds act to suppress the poleward flow of warm Pacific water through the Aleutian passes (especially Unimak Pass), while easterly winds enhance these transports. This mechanism is apt to have played a role in the anomalously cold conditions that occurred in the southern Bering Sea from winter into early spring (Figure 16a), and in the relatively strong warming from spring into summer that followed.

d. Bering Sea – The Bering Sea experienced a relatively cold winter and spring. There was a pronounced warming in late spring to the extent that upper ocean temperatures were above normal by the middle of summer. This anomalous warming can be attributed to the relatively high SLP for the region (Figures 17b and 18b) and fewer storms than normal and hence less wind mixing of cold water from depth, and presumably, reduced cloudiness and hence greater solar heating. Considering that a substantial cold pool was also present, the thermal stratification on the Bering Sea shelf was also relatively large. A more complete treatment of the Bering Sea, with a focus on the winter of 2006-07 in the context of the climate record, is provided later in this document.

e. Arctic – The summer of 2007 featured a noteworthy milestone: a record low total area of sea ice in the Arctic. The data from the National Snow and Ice Data Center (NSIDC) are preliminary, but suggest a sea ice coverage as little as about 3 million square kilometers at the end of August 2007 as compared with a previous low value of about 4 million square kilometers in 2005. The lack of sea ice can be attributed to a combination of long-term trends and the weather/circulation of the last year. In particular, the predominantly positive state to the AO during the winter of 2006-07 helped bring about positive air temperature anomalies of about 3˚ C in much of the Arctic (not shown). It is interesting that the anomalous melting of Arctic sea ice in the summer of 2007 was largely confined to the month of June. This month featured anomalously high SLP over the Arctic, with especially prominent positive anomalies over Greenland and extending from the north coast of Alaska to over the North Pole. This circulation pattern both suppresses clouds and hence enhances melting by shortwave radiation, and promotes the export of ice down Fram Strait.

4. Seasonal Projections from NCEP

Seasonal projections from the NCEP coupled forecast system model (CFS03) for SST are shown in Figure 20. The SST anomaly maps indicate the development of a weak-moderate La Nina by the fall of 2007. This result agrees with the consensus ENSO forecast (not shown) from the host of dynamical and statistical models in present use. This model also suggests relatively cold SSTs in the Gulf of Alaska and Bering Sea from late 2007 into 2008, with a weakening of these anomalies in spring 2008. The corresponding atmospheric anomalies (not shown) include lower than normal pressure over the Bering Sea in the fall of 2007, and positive pressure anomalies south of mainland Alaska in early 2008. The latter anomalies are consistent with La Nina, based on the historical record. If these model results are correct, there will be westerly wind anomalies across much of the North Pacific from fall 2007 into spring 2008. It should be noted that these kinds of forecast models have more skill in the tropical Pacific, where the atmosphere-ocean system is relatively deterministic, than in the North Pacific, where it is more chaotic and hence inherently less predictable.

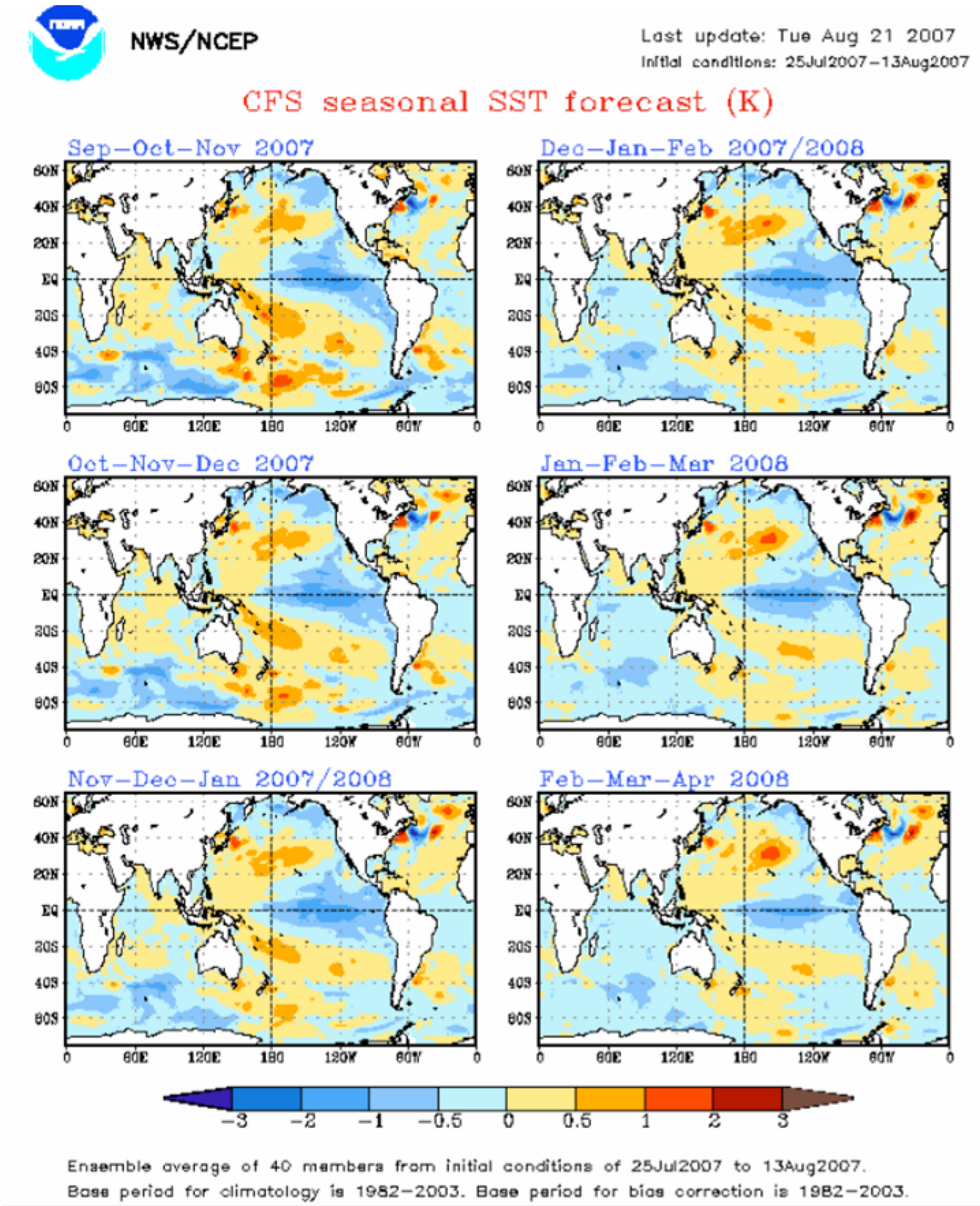

Figure 20. Seasonal forecast of SST anomalies from the NCEP coupled forecast system model.

GULF OF ALASKA

Pollock Survival Indices -FOCI

Contributed by S. A. Macklin, NOAA/PMEL
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Last updated: August 2007

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 southwestern exit region of Shelikof Strait, are determined numerically. Although data sources have changed somewhat over the years, chiefly with information used to estimate wind-mixing energy, every effort has been expended to make inter-year comparisons accurate and reliable.

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

Seasonal rainfall at Kodiak

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Last updated: August 2007

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

The time series of FOCI's pollock survival index based on measured precipitation is shown in Figure 21. 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. In 2005, precipitation remained somewhat above average but less so than in the previous two years. The 2006 season began with lower than normal precipitation during January, February and March. This decreased the potential for formation of baroclinic instabilities prior to and during spawning. April and May brought a return toward normal, however the potential for instabilities forming from increased freshwater input to coastal water was still lower than expected. June was wet, and this may have presented favorable habitat for late larval- and early juvenile-stage walleye pollock. On the other hand, 2007 was a year of extremes. The season began with a greater than seasonal drying trend from January through March, with March being the fourth driest March since these records began in 1962. This decreased the potential for formation of baroclinic instabilities prior to and during spawning. April and May brought record rain, with April 2007 being the all-time wettest April and May 2007 the fourth wettest. June was near normal. The spring may have presented favorable habitat for late larval- and early juvenile-stage walleye Pollock, although one might question the contribution of such extreme rain to favorable larval survival.

Based on this information, the forecast element for Kodiak 2007 rainfall is "average to strong" recruitment on the 5-category continuum from 1 (weak) to 3 (strong), and “strong” using three categories. Interestingly, the precipitation-based survival index does not appear to track any of the long-term climate indices, e.g., AO, PDO, with any consistency, possibly because of the way winter and spring precipitation are used in the model. In the 3-yr running mean of the precipitation survival index, there is a change from decreasing to increasing survival potential in 1989. In that year, there was an abrupt shift in the AO.

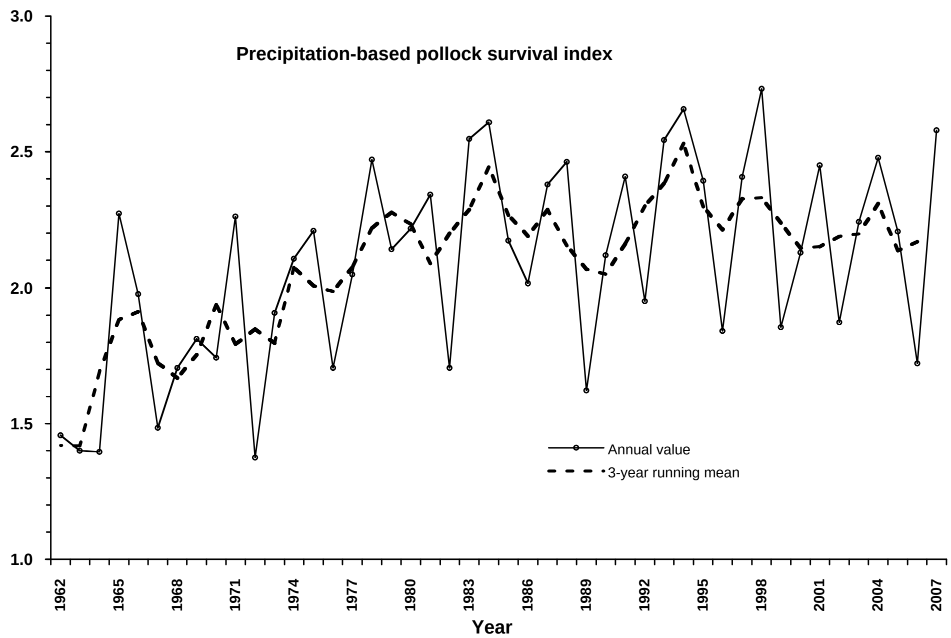

Figure 21. Index of pollock survival potential based on measured precipitation at Kodiak from 1962 through 2007. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Wind mixing at the southwestern end of Shelikof Strait

Contributed by S. A. Macklin, NOAA/PMEL

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Last updated: August 2007

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 southwestern 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 22. For 2007, wind mixing was below the long-term average for the first two months of winter, near to above average for the end of winter and beginning of spring, and low for the final two months of spring 2007. This year's scenario produced a wind mixing score of 1.96, which equates to "average". As with precipitation at Kodiak, there is wide interannual variability with a less noticeable and shorter trend to increasing survival potential from 1962 to the late 1970s. Recent survival potential has been high relative to the early years of the record. Except for March 2003, March 2005, June 2006 and April 2007, monthly averaged wind mixing in Shelikof Strait has been below the 30-year (1962-1991) mean for the last ten January through June periods (1998-2007). This may be further evidence that the North Pacific climate regime has shifted in the past decade.

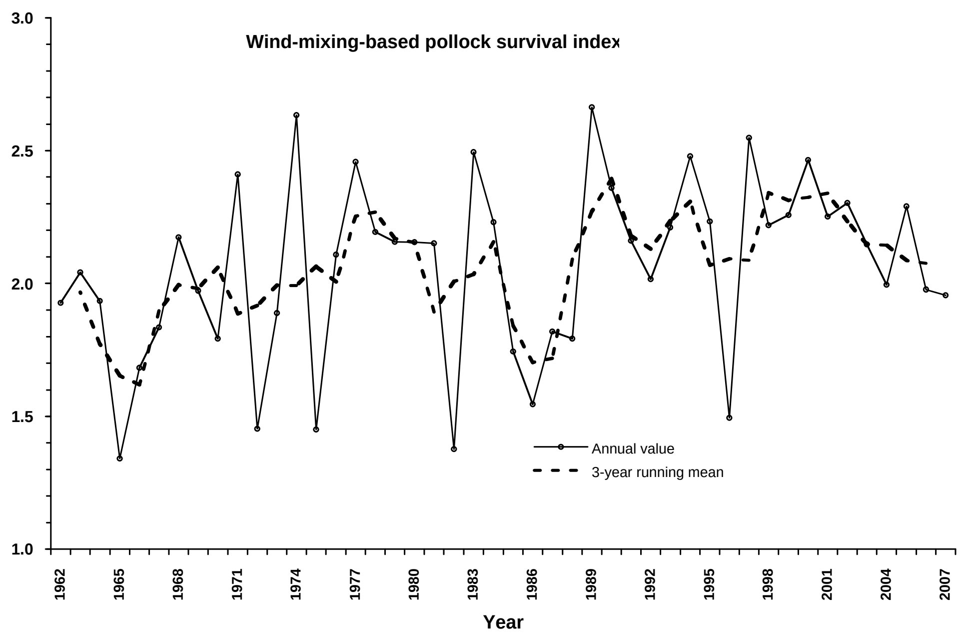

Figure 22. Index of pollock survival potential based on modeled wind mixing energy at [57°N, 156°W] near the southwestern end of Shelikof Strait from 1962 through 2007. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Eddies in the Gulf of Alaska – FOCI

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Last updated: August 2007

Eddies in the northern Gulf of Alaska have been shown to influence distributions of nutrients (Ladd et al. 2005, Ladd et al. 2007) 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 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. Ladd (2007) extended that analysis and found that, in the region near Kodiak Island, eddy energy in the years 2002-2004 was the highest in the altimetry record (1993-2006).

Since 1992, the Topex/Poseidon/Jason/ERS satellite altimetry system has been monitoring sea surface height (SSH). Eddy kinetic energy (EKE) can be calculated from gridded altimetry data (merged TOPEX/Poseidon, ERS-1/2, Jason and Envisat; (Ducet et al. 2000)). A map of eddy kinetic energy in the Gulf of Alaska averaged over the altimetry record (updated from Ladd 2007) shows three regions with local maxima (labeled a, b, and c in Figure 23). 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). Eddies that move along the shelf-break often feed into the third high EKE region (c; Figure 23). By averaging EKE over region c (see box in Figure 23), we obtain an index of energy associated with eddies in this region (Figure 24).

The seasonal cycle of EKE averaged over Region (c) exhibits high EKE in the spring (March-May) with lower EKE in the autumn (September-November). EKE was particularly high in 2002-2004 when three large persistent eddies passed through the region. Prior to 1999, EKE was generally lower than the ~14-year average, although 1993 and 1997 both showed periods of high EKE. Low EKE values were observed for 2005-2006 indicating a reduced influence of eddies in the region. Higher EKE values were observed in spring 2007 as an eddy moved through the region. This may have implications for the ecosystem. Phytoplankton biomass was probably more tightly confined to the shelf during 2005-2006 due to the absence of eddies, while in spring 2007 phytoplankton biomass likely extended farther off the shelf. In addition, cross-shelf transport of heat, salinity and nutrients were likely to be smaller in 2005-2006 than in spring 2007 (or other years with large persistent eddies). The altimeter products were produced by the CLS Space Oceanography Division; downloaded from http://www.aviso.oceanobs.com/.

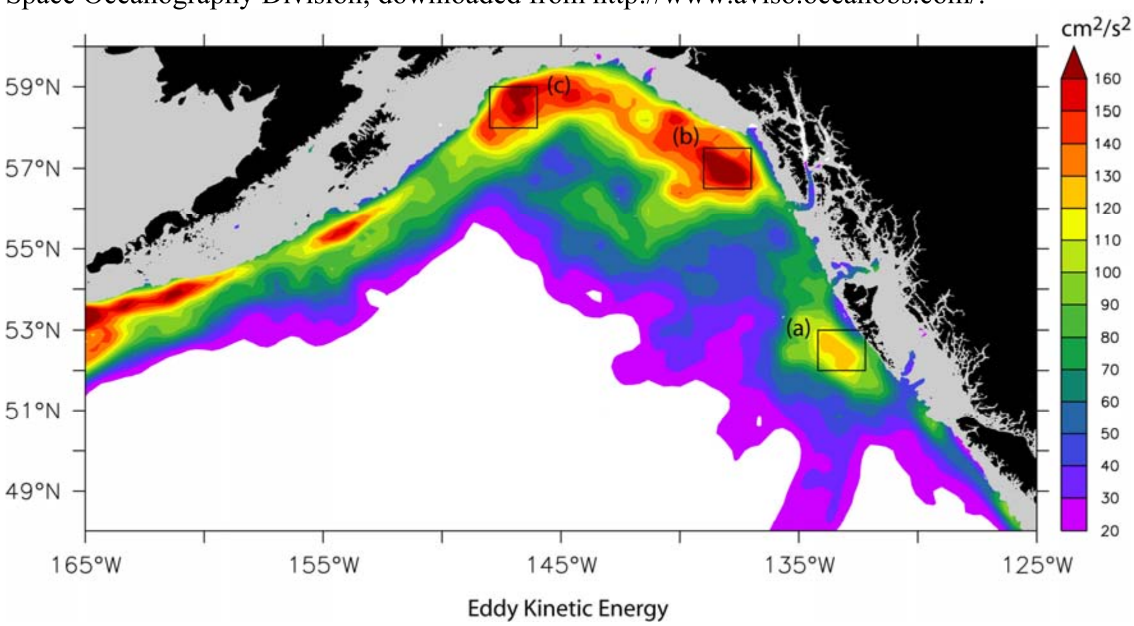

Figure 23. Eddy Kinetic Energy averaged over October 1993-October 2006 calculated from satellite altimetry. Region (c) denotes region over which EKE was averaged for Figure 24.

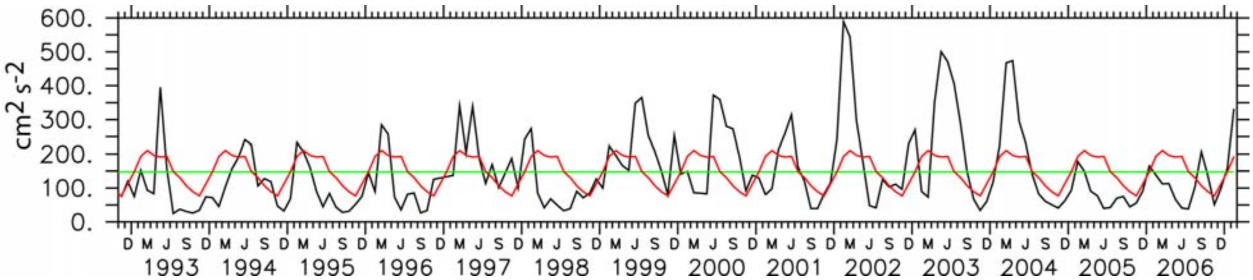

Figure 24. Eddy kinetic energy ($cm^2 s^{-2}$) averaged over Region (c) shown in Figure 23. Black (line with highest variability): monthly EKE. Red: seasonal cycle. Green (straight line): mean over entire time series.

Ocean Surface Currents – Papa Trajectory Index

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Last updated: August 2007

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

The Papa Trajectory Index (PTI) is an example of long-term time-series data computed from a single location in the Gulf of Alaska. OSCURS was run 105 times starting at Ocean Station Papa (50º N, 145º W) on each December first for 90 days for each year from 1901 to 2006 (ending February 28 of the next year). The trajectories fan out northeastwardly toward the North American continent and show a predominately bimodal pattern of separations to the north and south. The plot of just the latitudes of the end points versus time (Figure 25) illustrates the features of the data series and the variability of the winter Alaska Current.

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

In the winter of 2003 and 2004 the long expected change in modes from north to south narrowly occurred in the 5-year running mean centered on the winter 2003. This was strongly influenced by the extreme southward 2002. Since then every year has been near the average showing this speculation about the future to be wrong. This winter (2007) the stronger northward current has caused the running mean plot to return and cross the average line.

The century plot of the 5-year running mean shows four complete oscillations with distinct crossings of the mean; 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 2007 calculations and shows circulation still near normal with a slight jump back to the northward side after only 2 years of being slightly south of the mean. The 5-year running mean has fallen to the mean value four times since 1975 (1980, 1987, 1991, and 1995), only to rise again and stay in the northern mode. Once the 5-year running mean crosses the zero line it usually stays there for several years.

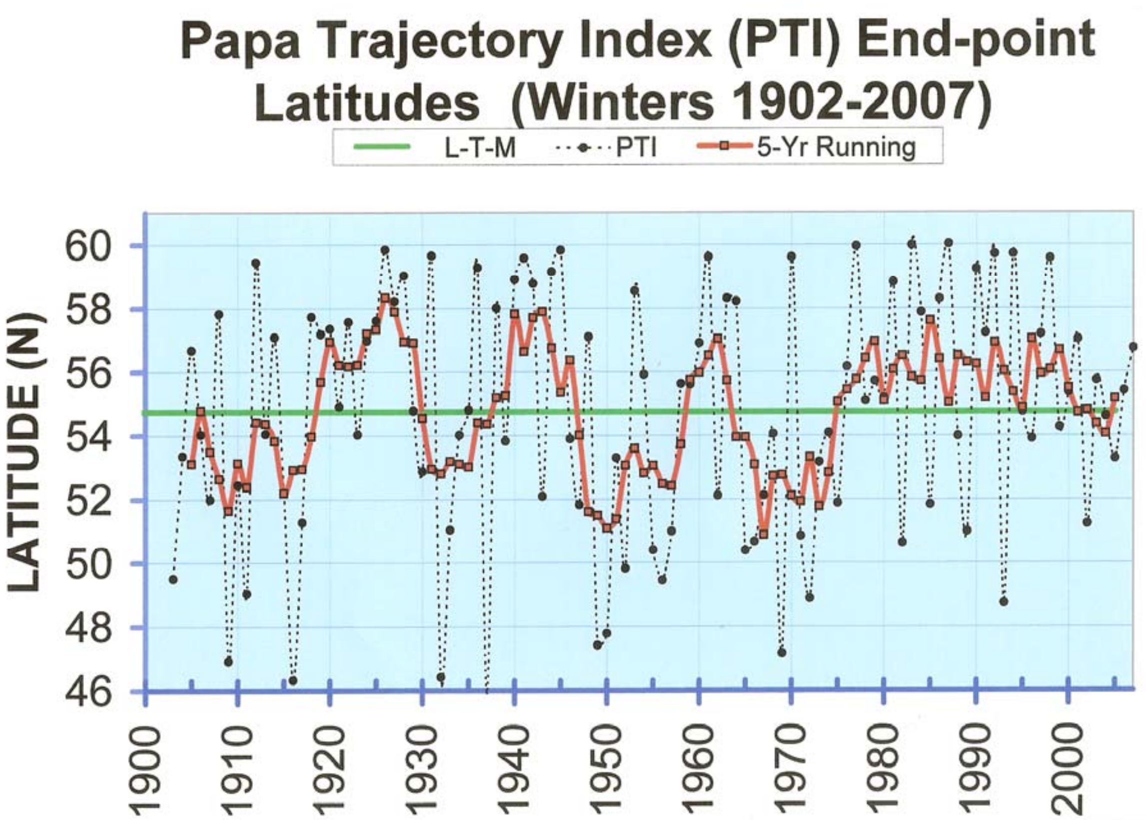

Figure 25. Annual, long-term mean and 5-year running mean values of the PAPA Trajectory Index (PTI) time-series from winter 1902-2007. Large black dots are annual values of latitude of the end points of 90-day trajectories which start at Ocean Weather Station PAPA (50º N, 145º W) each December 1, 1901-2006. 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 (northeastward) 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

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Last updated: October 2007

Ocean circulation in the Gulf of Alaska (GOA) is dominated by two current systems, the Alaska Current and the Alaska Coastal Current (Stabeno et al. 2004). The Alaska Current is driven by the West Wind Drift of the subarctic gyre in the North Pacific basin and flows to the north-northwest from the NMFS bottom trawl survey boundary at Dixon Entrance. It is characterized by numerous eddies and meanders until forced to the southwest around Prince William Sound, forming the origins of the Alaska Coastal Current. The majority of this water flows through Shelikof Strait, with the remainder passing to the south of Kodiak Island, forming the origins of the Alaska Stream which continues to flow to the west along the Aleutian Islands (Stabeno et al. 1995, Shumacher et al. 1989). In addition, tidal forces dominate circulation in some local areas, particularly around Cook Inlet and in and around many of the bays along the Alaska Peninsula.

Water temperature data have been routinely collected on survey bottom trawl hauls using micro-bathythermographs since 1993. In earlier years, temperature data were often collected near trawl haul sites using expendable bathythermographs, although these earlier data were not considered in this analysis. Groundfish assessment survey periods have ranged from early May to late September, and sampling has usually progressed from west to east. Notable exceptions exist to this general pattern, particularly for the two surveys in the 1980s involving Japanese vessels. The beginning date of the survey over the period included in the analysis has ranged from the middle of May to the first week in June, while the last day of the survey has ranged from the third week in July to the first week of September. In addition, the area covered by the survey and the depths sampled have not been consistent in all years.

These differences in sampling patterns in time and space complicate inter-annual comparison due to the strong relationship between date of collection and water temperature at all depths throughout the GOA survey area. In order to account for these problems and make inter-annual comparisons more meaningful, an attempt was made to remove the effect of date of collection on water temperature, in effect standardizing temperatures to an approximate median date for most GOA surveys (July 10). This was achieved by using generalized additive modeling techniques to model the effects of day of year and depth on temperature. The model was then used to predict the temperature at a new date (July 10) at the same depth, and the residuals of the original model were added to the prediction for the final estimate. All further analyses used these predicted temperatures. In order to facilitate visualization of the modeled temperatures, the data were binned into 0.5 degree longitude and multiple depth increments and a mean temperature in each increment was calculated. Depth increments were much finer at shallower depths to capture the rapid changes in water temperatures often seen in these depths. The results are shown in Figure 26.

The inter-annual differences in sampling areas and depths, clearly shown in Figure 26, complicate comparisons between years, however some patterns are clearly discernible. Water temperatures observed during the 2007 survey exhibited a much different pattern than other surveys as cooler water infiltrated shallower depths, often with warmer water below. The very warm near-surface temperatures that were observed in 2003 and 2005 were largely absent in 2007. In all years prior to 2007, water temperatures at depths greater than 400 m have generally been cooler than 4 degrees C. In 2007, water warmer than 4 degrees C extended to almost 600 m most of the time. The pattern of water temperatures in 2007 more closely resembles the pattern in 1993 than any other year, although the intrusion of colder water into shallower depths is much more pronounced in 2007. This pattern is consistent with the GAK1 time series of water temperatures (http://www.ims.uaf.edu/gak1/) where water temperatures in the spring and summer of 2007 at depths between 150-250 m were colder than at any time since the early 1970s. Figure 27 shows the colder water pattern in 2007 as well, particularly in the 100 – 200 m depth range.

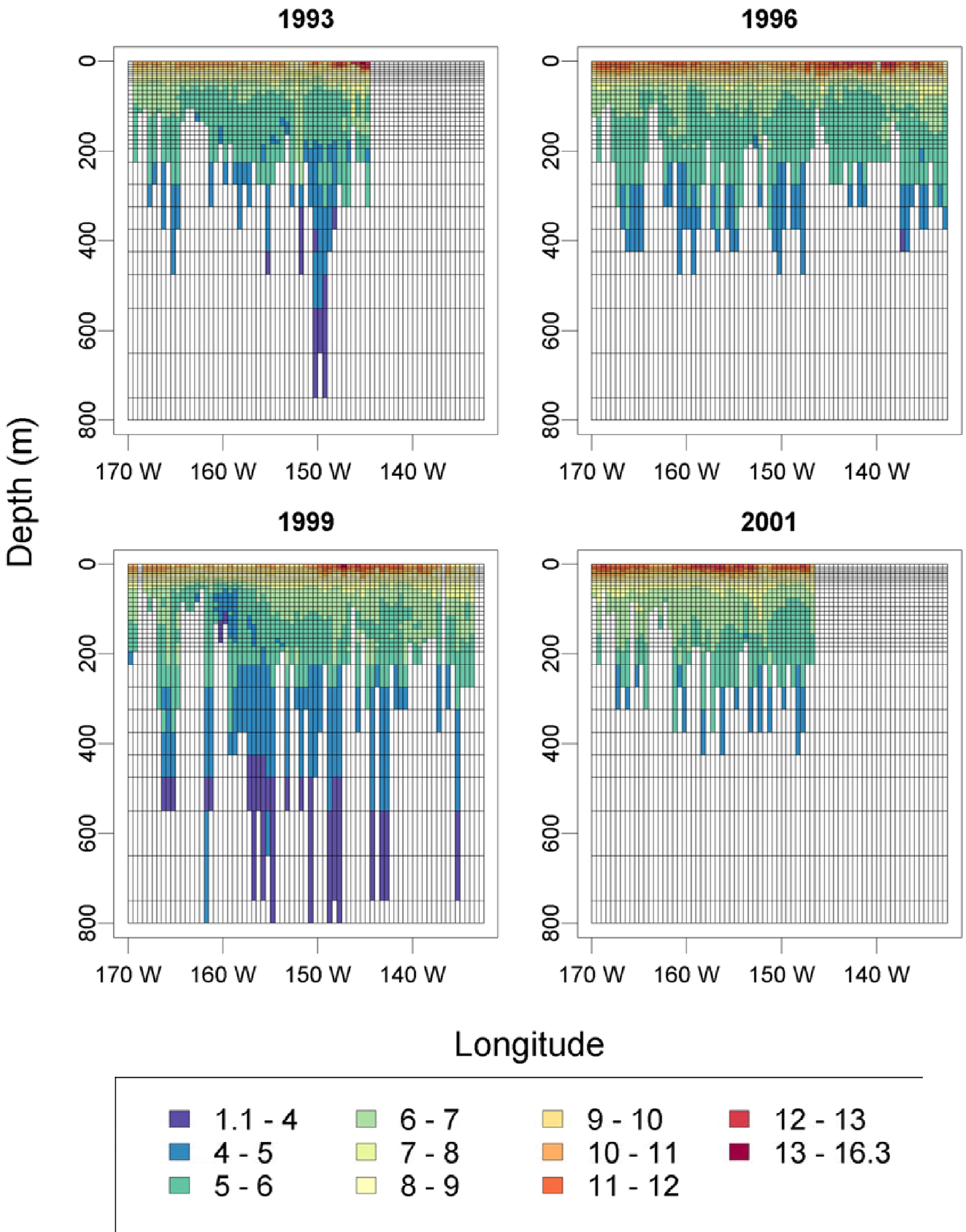

Figure 26. Date adjusted temperature profiles by ½ degree longitude intervals for years 1993-2007.

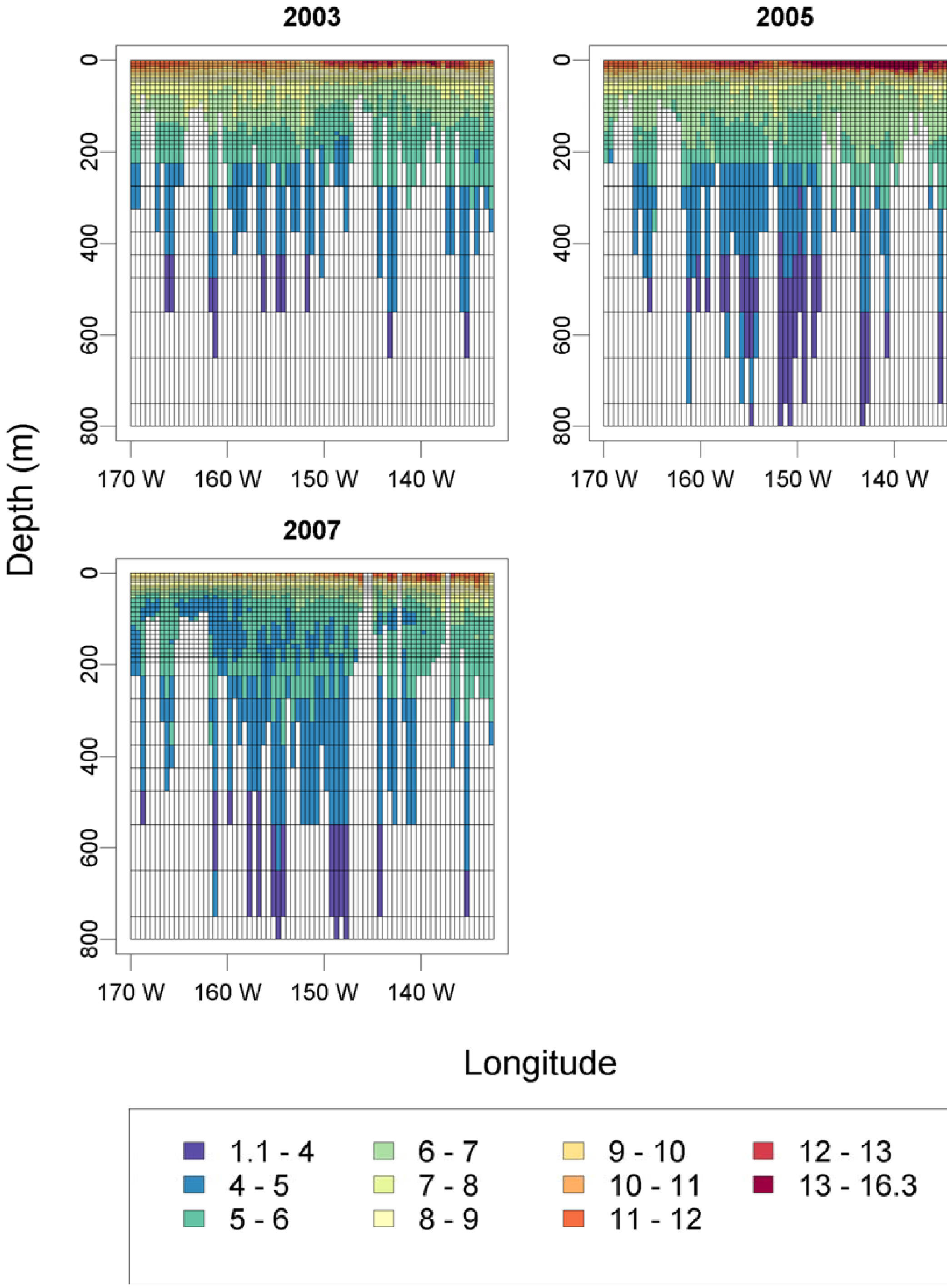

Figure 26 cont. Date adjusted temperature profiles by ½ degree longitude intervals for years 1993-2007.

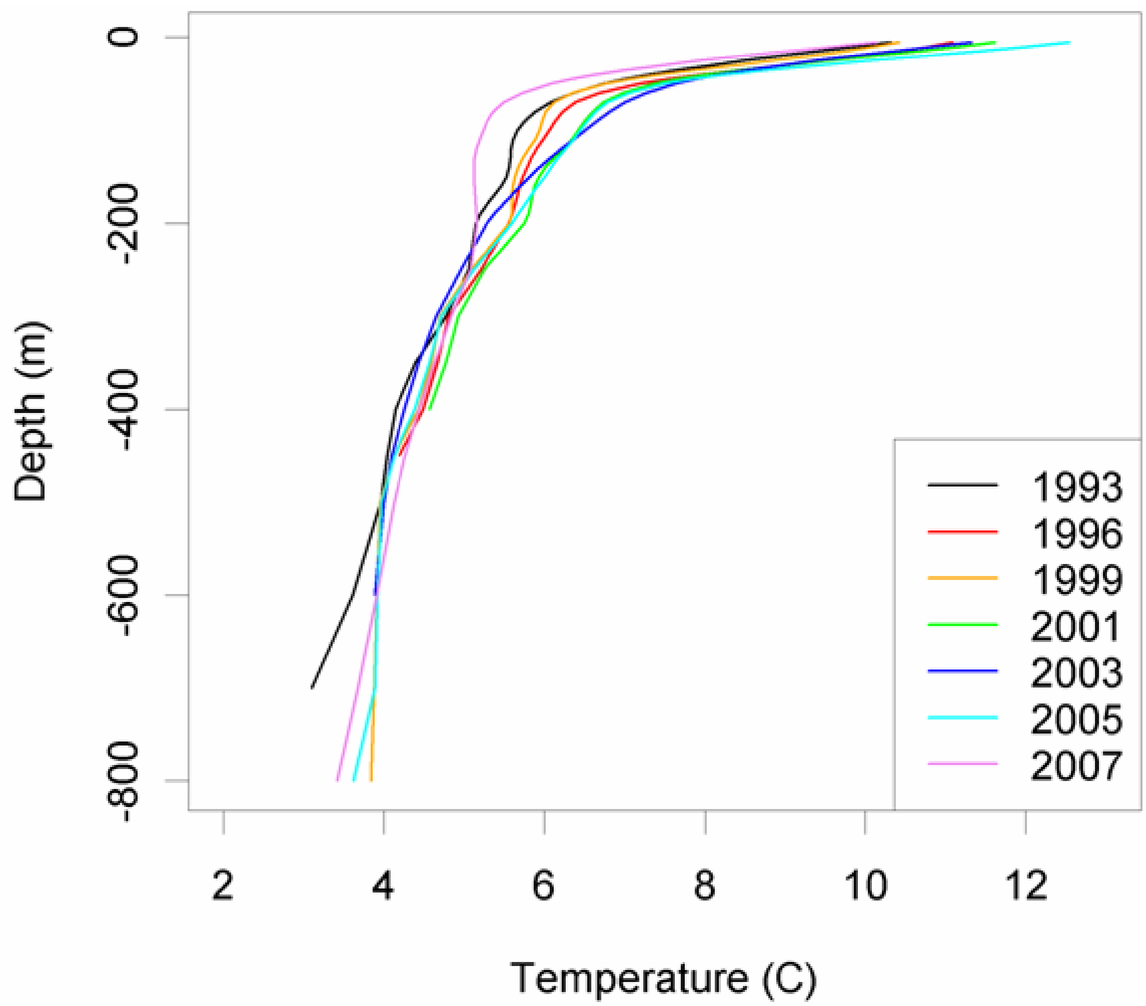

Figure 27. Date adjusted temperature smoothed mean profiles for depths to 800 m for years 1993-2007.

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

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Last updated: October 2007

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

Hydrographic station GAK 1 is located at 60˚N, 149˚W, at the mouth of Resurrection Bay in the northern Gulf of Alaska. Temperature and salinity measurements have been made at various times of the year at this location since 1973. We have estimated the deepest winter mixed layer depths (MLDs) using the Freeland et al. (1997) algorithm. This algorithm performs well at estimating winter MLDs (each winter is defined here as December of one year and January to May of the following year), but overestimates the summer and spring MLDs. For our purposes, this method is adequate as it also conserves the integrated mass, and thus the potential energy of the water column (Sarkar et al. 2005, Sarkar 2007).

The deepest winter MLDs at GAK 1 from 1974 to 2006 (Figure 28) range from a minimum of 105 m in February 2003 to a maximum of 214 m in March 1987. The mean value is 163 m, with a standard deviation of 29 m. The record has only one missing value; that for the winter of 1979-1980. The deepest MLD of the 2002-2003 winter is the shallowest of the 32 year record. However, the winters of 2003-2004, 2004-2005 and 2005-2006 had deeper than average mixed layers.

The deepest winter MLDs from 1974 to 2006 show a deepening linear trend. Nevertheless, this trend is not statistically significant. Thus the only conclusion is that during 1974-2006, 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 significantly.

The winter of 2006-2007 has been very unusual in the northern Gulf of Alaska. The entire water column in the vicinity of GAK 1 has been much colder than in the recent past, though not quite as cold as in the early 1970s (www.ims.uaf.edu/gak1). This is could be due to a change in the circulation pattern in the entire region, as similar changes are being noted at other locations in the Gulf of Alaska. In addition, upper water column salinity has been higher at GAK 1. The increased salinity (less freshwater discharge) and lower water temperatures suggests a reduction in the alongshore circulation that brings warmer water northward from the southern regions of the Gulf of Alaska. The anomalous low temperatures and high upper water column salinity have affected the density structure of the water column, changing the shape of the density profiles. Because of this, the Freeland et al. (1997) algorithm can no longer reliably indicate the deepest winter MLD and the time series cannot be updated for this season.

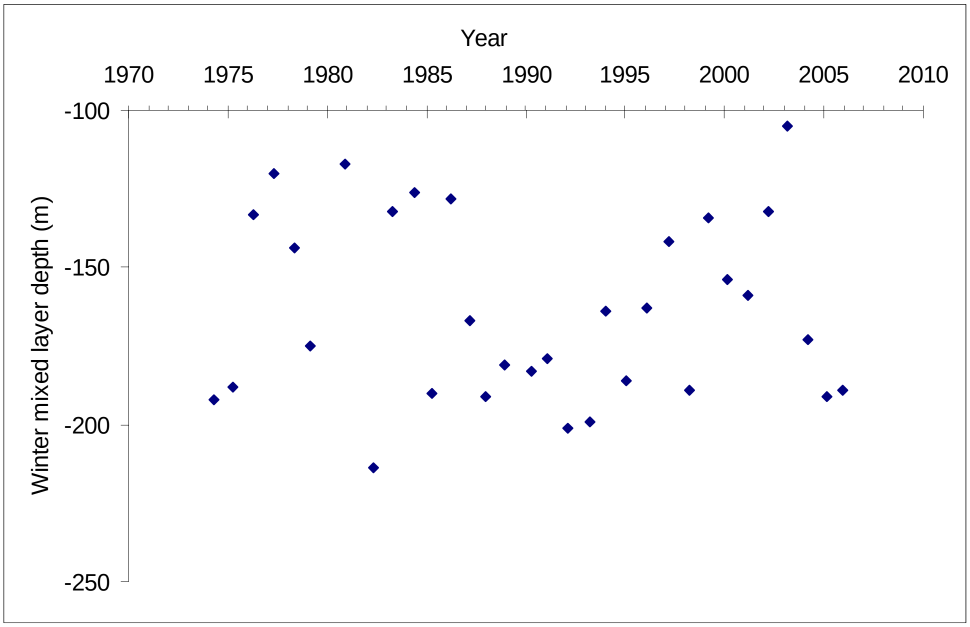

Figure 28. Winter mixed layer depth (m) at GAK 1 from 1974-2006.

EASTERN BERING SEA

Eastern Bering Sea Climate– FOCI

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Last updated: August 2007

Summary. *The year 2007 with cold temperatures and considerable ice cover, again illustrates that the eastern Bering Sea is characterized by large monthly and interannual variability, driven by large scale climate patterns. The years 2006 and 2007 had relatively cold winters (except for February 2007), with near neutral sea-level pressure anomalies. Spring 2007 was cold and sea ice lasted for almost two months just to the north of the Pribilof Islands, contrasting with previous years since 2000. The presence of sea ice together with below normal ocean temperatures likely resulted in the first ice edge bloom since 1999. Unlike the northern Bering Sea and Arctic Ocean hot spots, the rate of warming in the southern Bering Sea is slowing down, suggesting a large natural variability component to recent extremes in addition to a background anthropogenic contribution toward warmer temperatures.*

Surface temperatures are easily measured and provide an available long term measure of the state of the climate. Winter and spring 2007 surface air temperatures (SAT) were colder than normal, while 2006 was close to climatological normal conditions; both years contrast to the warm years of the recent decade. After a relatively cold December 2006 and January 2007 (Figure 29 top), both had negative monthly anomalies close to -3.0 °C as measured at St. Paul Island, the February SAT was 4.2 °C above average, more than one standard deviation above normal for the month. By March the temperature plunged again with negative anomalies of -3.8 °C. Late spring SAT anomalies were still on the cold side, which may be related to the presence of the sea ice. On long time scales (Figure 29, bottom), cold anomalies have their first major appearance in 2006 and 2007 since 2000, but are not in the range of pre-1977 conditions.

The winter (December-March; DJFM) 2007 was one of the coldest winters since 1976 with seasonal averaged SAT of -5.1 °C, a -1.4 °C departure from 1961-2000 mean SAT at St. Paul. The other two cold winters were 1995 (-5.1 °C), and 2000 (-5.0 °C). The Bering Sea pressure index (BSPI), defined as the area-weighted averages of Sea Level Pressure (SLP) between 55-65°N, and 170E-160°W in the southeast Bering Sea, approached a neutral value in 2007 (Figure 30). Negative values of the BSPI indicate predominance of low pressure with either more or stronger storms. With this close-to-zero anomaly, it seems that a decade of major below normal SLP conditions came to an end, yet there is no indication of a return to climate regime conditions prior to 1977.

Spring was anomalously cold in the southeast Bering Sea during 2007 (Figure 31A). For comparison Figure 31B shows the SAT anomaly field in spring averaged over the warm years of 2000-2005. The proximate cause of the cold spring in 2007 is shown by the SLP field in Figure 32. The Siberian high pressure region (orange and yellow colors) was displaced to the east and the Aleutian low pressure area, normally found south of the Bering Sea, is now displaced into the Gulf of Alaska. This unusual situation brings cold air from Alaska, blowing over the southeast Bering Sea, as winds tend to blow parallel to these color contours in the pressure field. What also stands out for 2007 in Figure 31 is that the warm temperatures of 2000-2005 continued in the northern Bering and Chukchi Seas, but not in the southeast Bering Sea.

Seasonal sea ice is a defining characteristic of the Bering Sea shelf. The presence of sea ice influences the timing of the spring bloom and bottom temperatures throughout the year. Ice extent in 2007 (Figure 33) is close to the normal conditions (1979-1999), in contrast to the warm years of 2000-2005. At the end of April, 2007 the sea ice was further south than in 2006 to the north and west of the Pribilof Islands, but Bristol Bay had more sea ice in 2006. Based on antidotal *in situ* reports, however, the ice in 2006 and 2007 is not totally returned to previous normal conditions. It appeared thinner and generally broken up. This thin ice may help explain the rapid melt back in 2007. The Ice Retreat Index, defined as sea ice present over 56-58°N, 163-165°W after March 15, shows the recent increase in 2006 and 2007 relative to 2000-2005, but that it was not unusual compared to earlier years (Figure 34). With regard to sea ice, again the southeast Bering Sea is showing different conditions than north of Alaska. By mid August 2007, sea ice in the Arctic had already passed the previous record summer minimum extent.

Along with cold air temperatures and extensive sea ice, ocean temperatures at the M2 mooring site were sharply lower in winter 2006 through winter 2007 compared with 2000-2005 (Figure 35), while 2005 was the warmest year on record. The cold pool (Figure 36), defined by bottom temperatures < 2°C, influences not only near-bottom biological habitat, but also the overall thermal stratification and ultimately the mixing of nutrient-rich water from depth into the euphotic zone during summer. The extent of the cold pool for summer 2007 rivals 2006 as the most prominent since 1999.

Further information from the M2 mooring, the vertical distribution of temperature and chlorophyll fluorescence measurements over time (Figure 37), relate to biological productivity. Prior to 2000, ice was observed in the location of M2 on the southeast Bering Sea shelf almost every winter (black shading of temperatures). In February 2006, ice lasted only a few days, did not remain into the spring, and the primary productivity bloom occurred in late May/early June in open water. Yet, ice was present in the region near M2, supporting an extended cold pool (dark blue colors near the bottom in summer during 2006). Although there was no sea ice at M2 during January 2007, satellite data suggests that the ice was relatively close. During the temperature rebound in February, sea ice was not present, but it was present again during March/April 2007. Water column conditions in the winter of 2007 were colder than 2006; the presence of sea ice over M2 probably resulted in an ice-associated spring bloom over the mooring in 2007. Unfortunately, we do not have chlorophyll fluorescence data from M2 in the spring of 2007, as the fluorometer failed.

The most important aspect of the physical environmental in the eastern Bering Sea during 2007 were cold air temperatures (except for February), more extensive sea ice, and cold M2 ocean temperatures relative to the previous decade, but not suggesting a return to pre 1977 conditions.

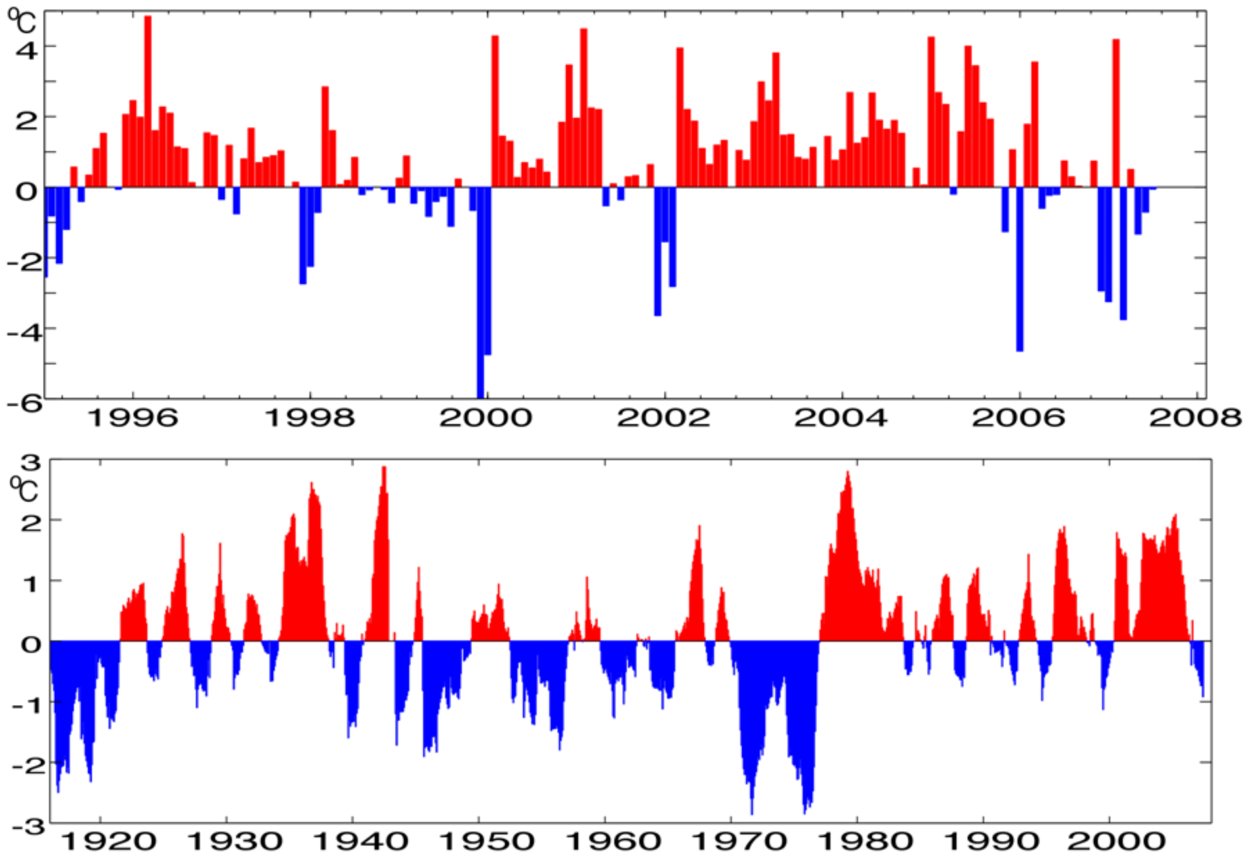

Figure 29. Mean monthly surface air temperatures anomalies in St. Paul, Pribilof Islands, a) unsmoothed, January 1995 through July 2007, and b) smoothed by 13-month running averages, January 1916 through July 2007. The base period for calculating anomalies is 1961-2000.

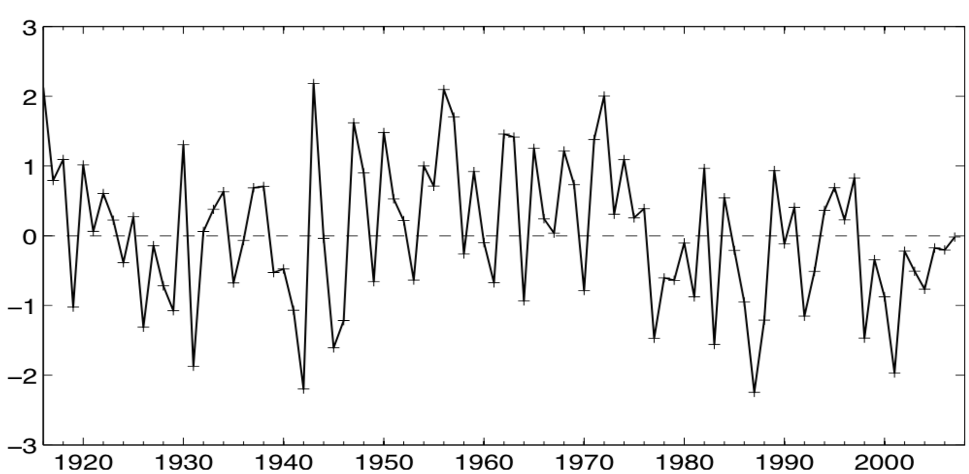

Figure 30. The BSPI is defined as area-weighted Sea Level Pressure anomalies between 55-65 deg.N, and 170E-160 deg.W.

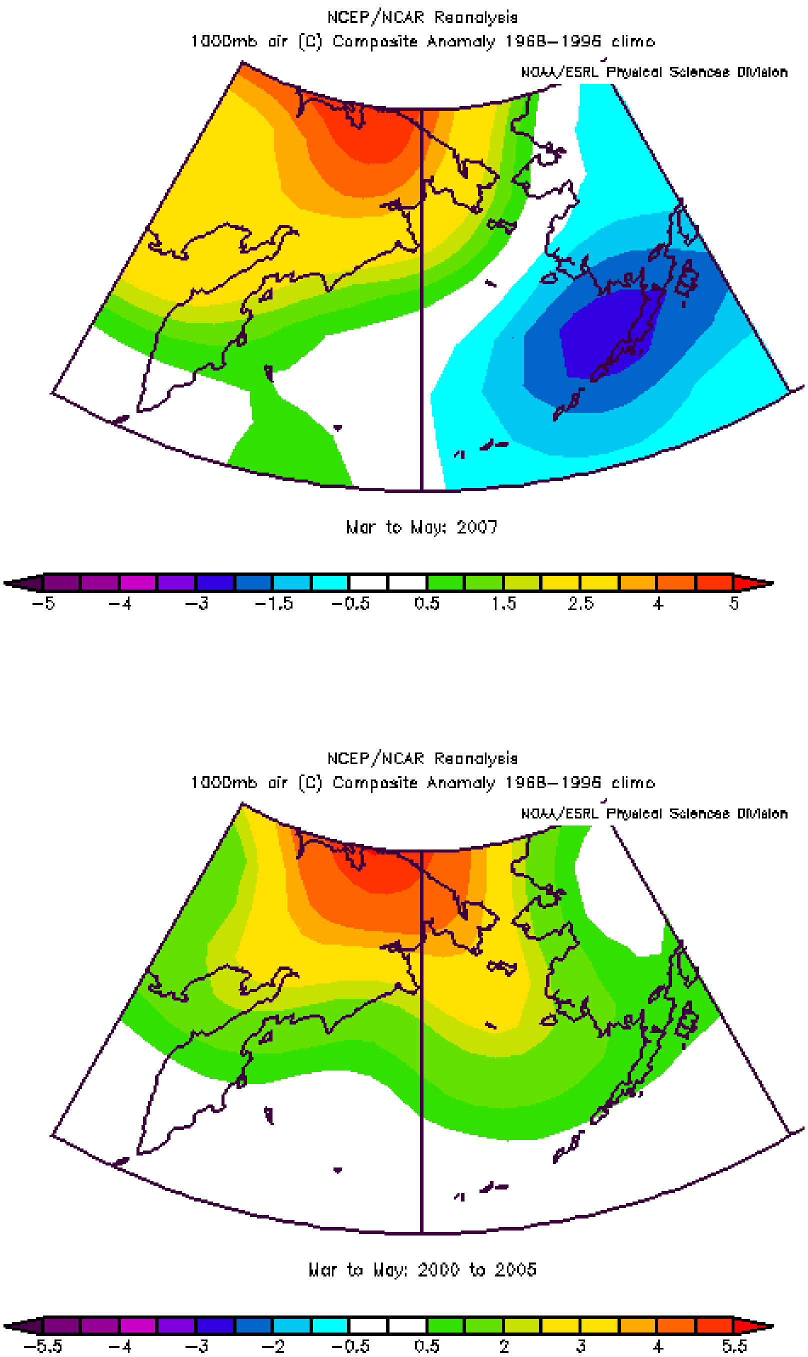

Figure 31 A (top) Surface air temperature anomaly over the greater Bering Sea region for spring 2007. Cold surface air temperature anomalies were present in the southeastern Bering Sea (blue shading). Note the contrast to the warm anomalies in eastern Siberia. B (bottom) In contrast to 2007, temperatures throughout the entire greater region were relatively warm in spring during the six year period, 2000-2005.

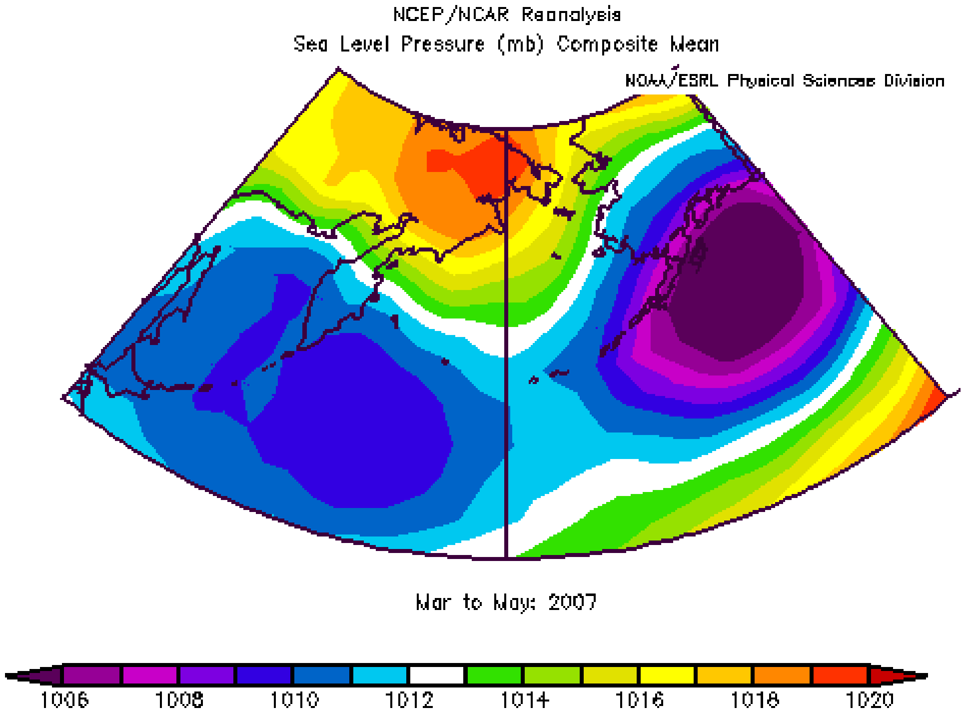

Figure 32. Sea level pressure (SLP) field for spring 2007. Note the position of the 'Aleutian low" in purple, now in the Gulf of Alaska, and high pressure (yellow) extending into the northwestern Bering Sea. This distribution of SLP creates cold winds blowing from Alaska over the southeastern Bering Sea.

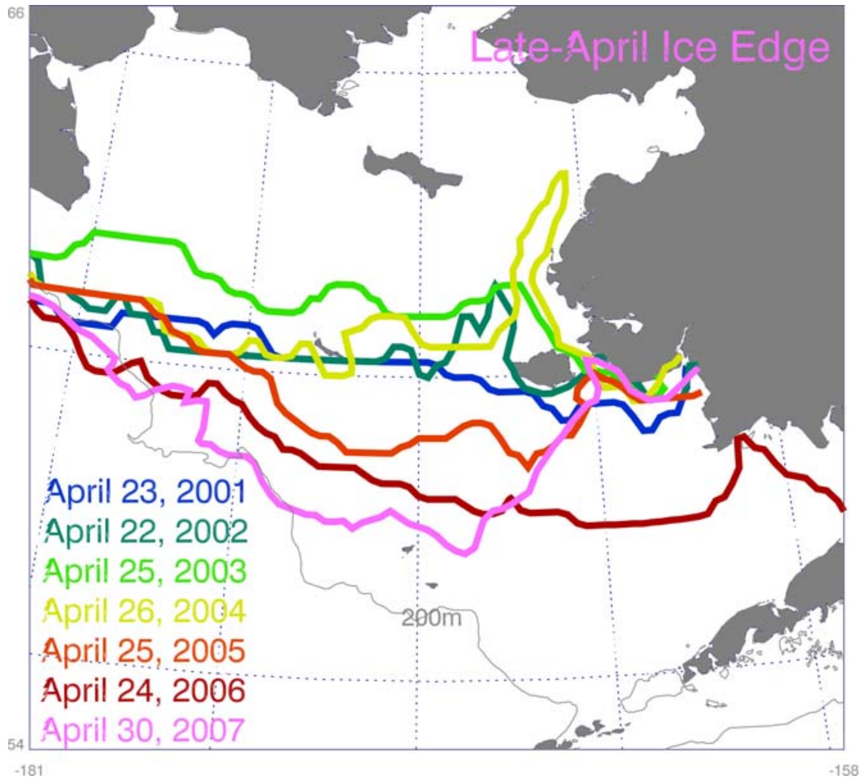

Figure 33. Recent springtime ice extents in the Bering Sea. Ice extent in 2006 and 2007 exceed the minimums of the early 2000s.

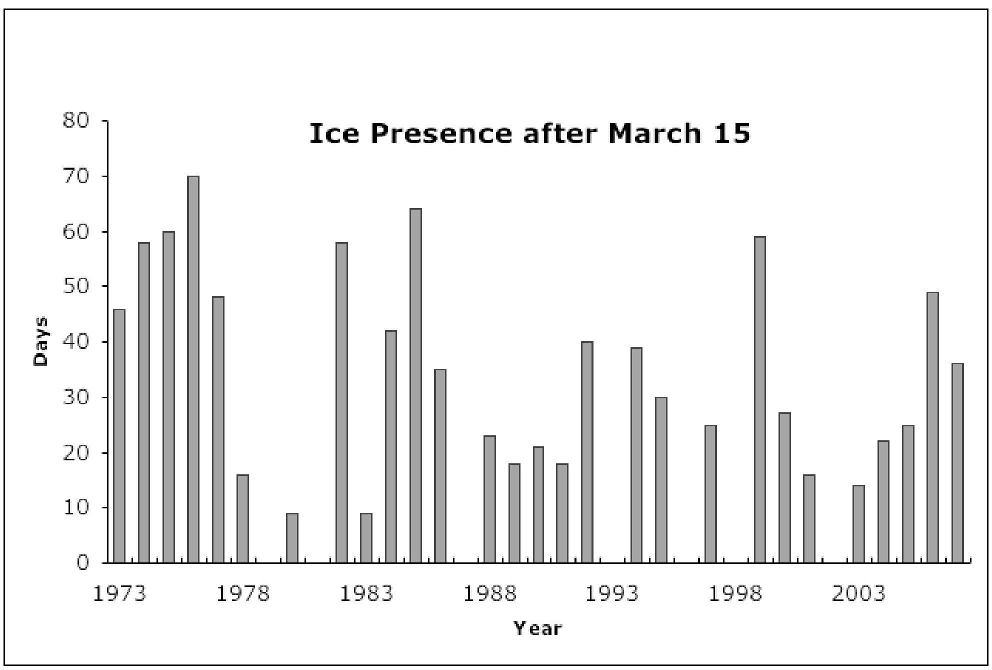

Figure 34. Sea ice retreat index, which is defined as ice presence over 56-58°N, 163-165°W box surrounding Mooring 2 after March 15.

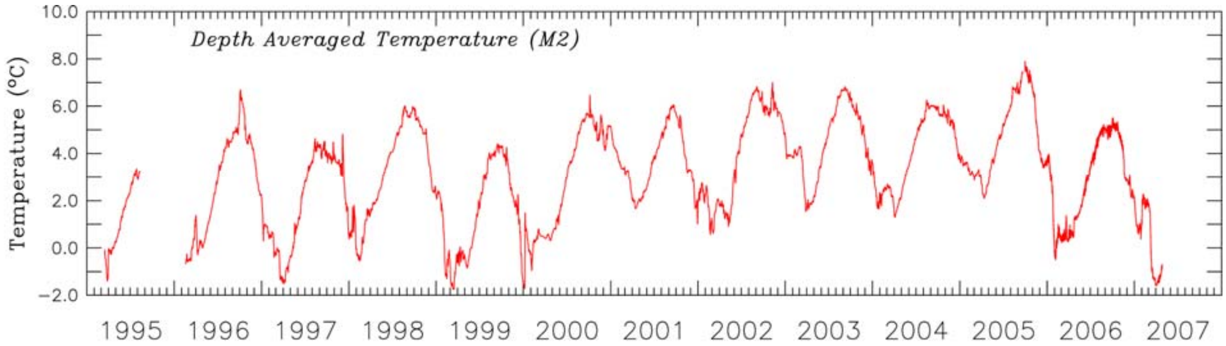

Figure 35. Depth averaged temperature measured at Mooring 2, 1995-2007 (°C).

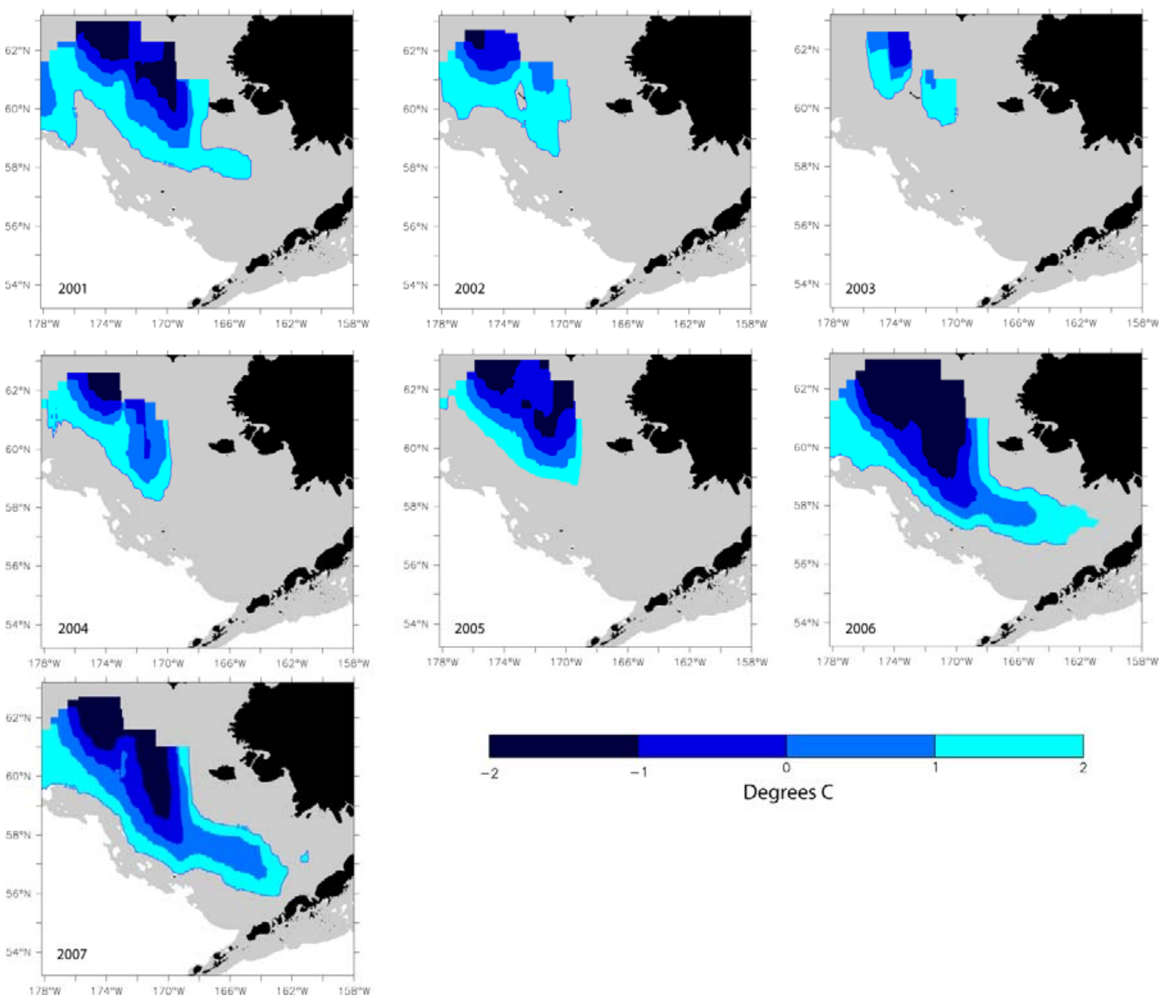

Figure 36. Cold Pool locations in southeast Bering Sea from 2001 to 2007.

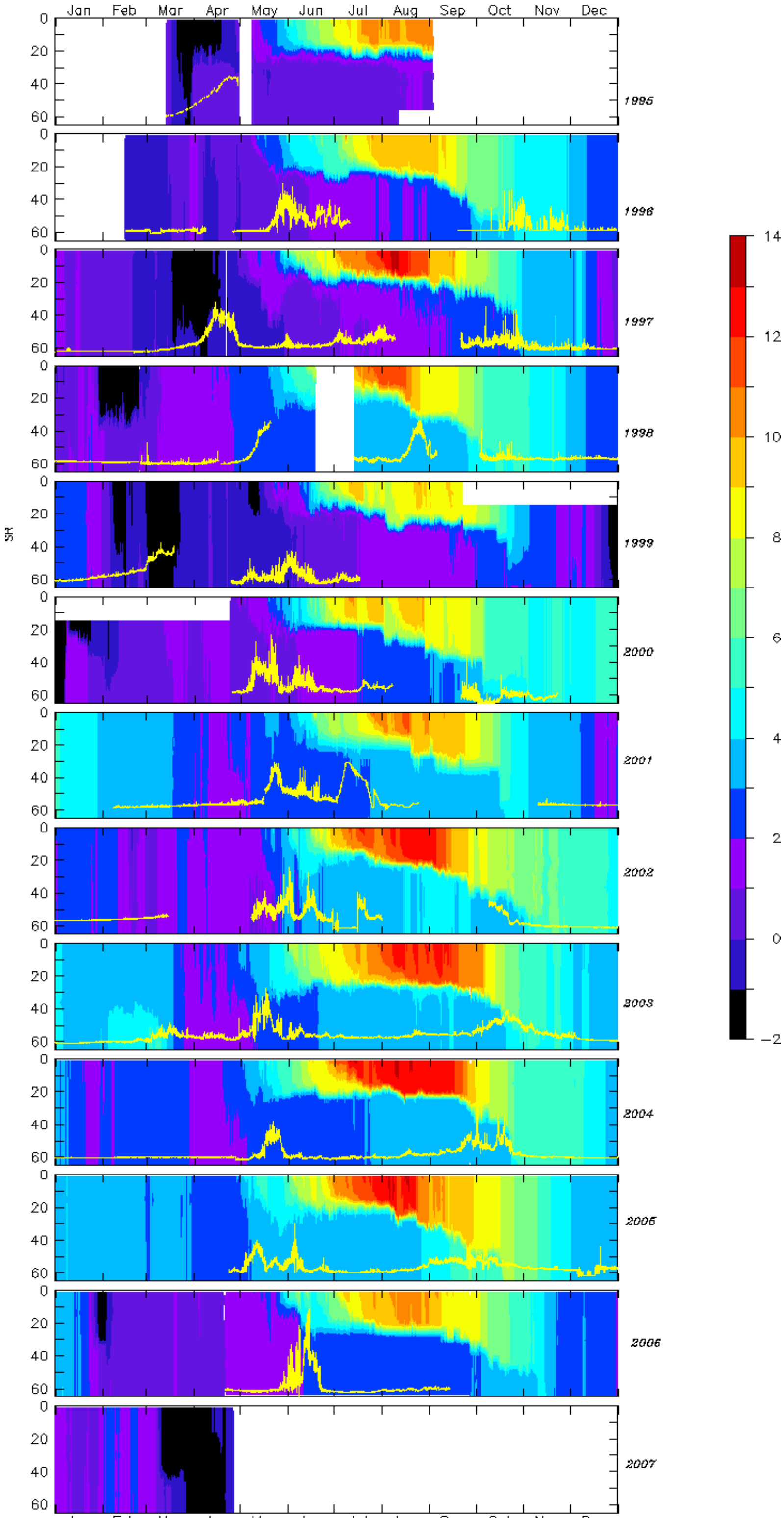

Figure 37. Temperature measured at Mooring 2, 1995-2007 (°C). Temperatures < 1°C (black) occurred when ice was over the mooring. The yellow line is fluorescence measured at ~11 m.

Summer bottom and surface temperatures – Eastern Bering Sea

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Last updated: October 2007

The annual AFSC bottom trawl survey for 2007 started on 10 June and finished on 2 August. The average bottom temperature was 1.79°C, which was well below the 1982-2006 mean of 2.59°C (Figure 38). Bottom temperature anomalies from the long-term station means were negative over most of the shelf region except for the eastern portion of the middle inner shelf (Figure 39). Maximum anomalies occurred in middle domain where bottom temperatures were < -1°C. The 'cold pool', usually defined as an area with temperatures < 2°C, extended a little bit further to the south and east into Bristol Bay compared to 2006.

The average surface temperature, 6.31°C, was 0.72°C higher than 2006 but lower than the long-term mean 6.71°C. A majority of the 2007 survey stations had decreases in water temperatures in the surface waters (Figure 39). The largest surface temperature differences (< -4°C) were in the upper half of the middle and inner domains.

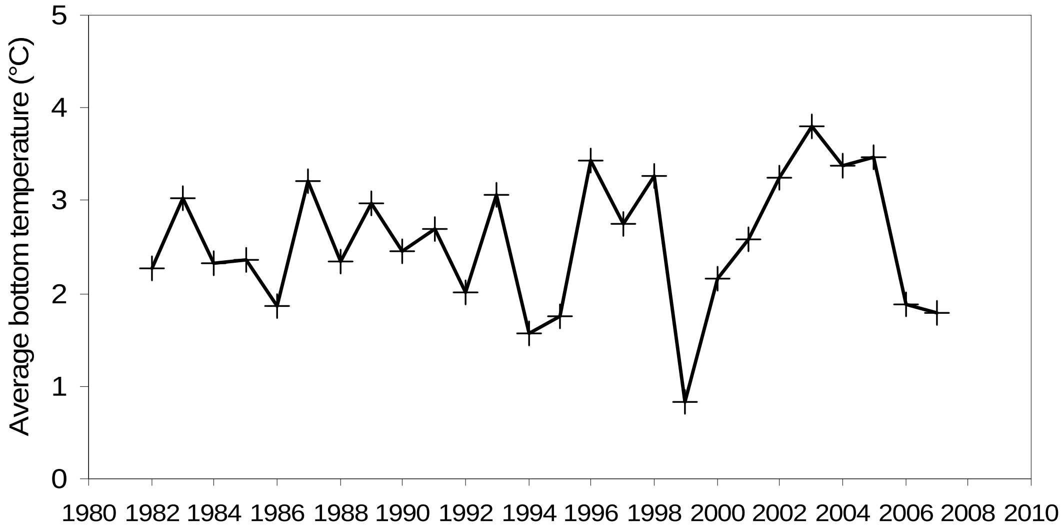

Figure 38. Mean summer bottom temperature (°C) in the standard bottom trawl survey area of the eastern Bering Sea Shelf, 1975-2006. Temperatures for each tow are weighted by the proportion of their assigned stratum area.

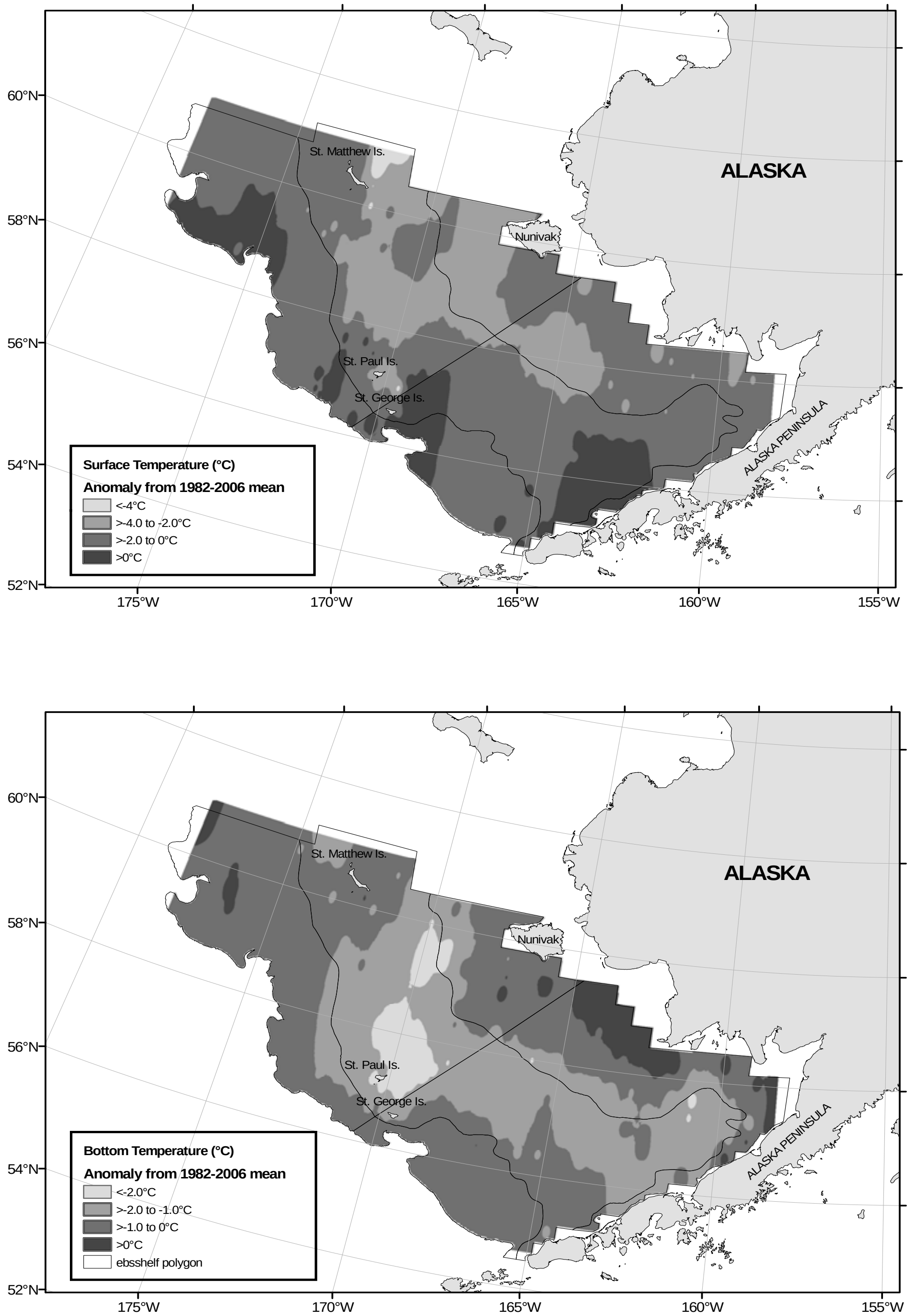

Figure 39. Summer bottom (bottom panel) and surface (top panel) temperature anomalies in 2007 from the 1982-2006 means at standard bottom trawl survey stations in the eastern Bering Sea.

Variations in water mass properties during fall 2000-2005 in the eastern Bering Sea-BASIS
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Last updated: November 2006

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

ALEUTIAN ISLANDS

Eddies in the Aleutian Islands -FOCI
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Last updated: August 2007

Eddies in the Alaskan Stream south of the Aleutian Islands have been shown to influence flow into the Bering Sea through the Aleutian Passes (Okkonen 1996). By influencing flow through the passes, eddies could impact flow in the Aleutian North Slope Current and Bering Slope Current as well as influencing the transports of heat, salt and nutrients (Mordy et al. 2005, Stabeno et al. 2005) into the Bering Sea. Eddy kinetic energy (EKE) calculated from gridded altimetry data (Ducet et al. 2000) is particularly high in the Alaskan Stream from Unimak Pass to Amukta Pass (Figure 40) indicating the occurrence of frequent, strong eddies in the region. The average EKE in the region 171°W-169°W, 51.5°-52.5°N (Figure 41) provides an index of eddy energy likely to influence the flow through Amukta Pass. Particularly strong eddies were observed south of Amukta Pass in 1997/1998, 2004, and 2006/2007.

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

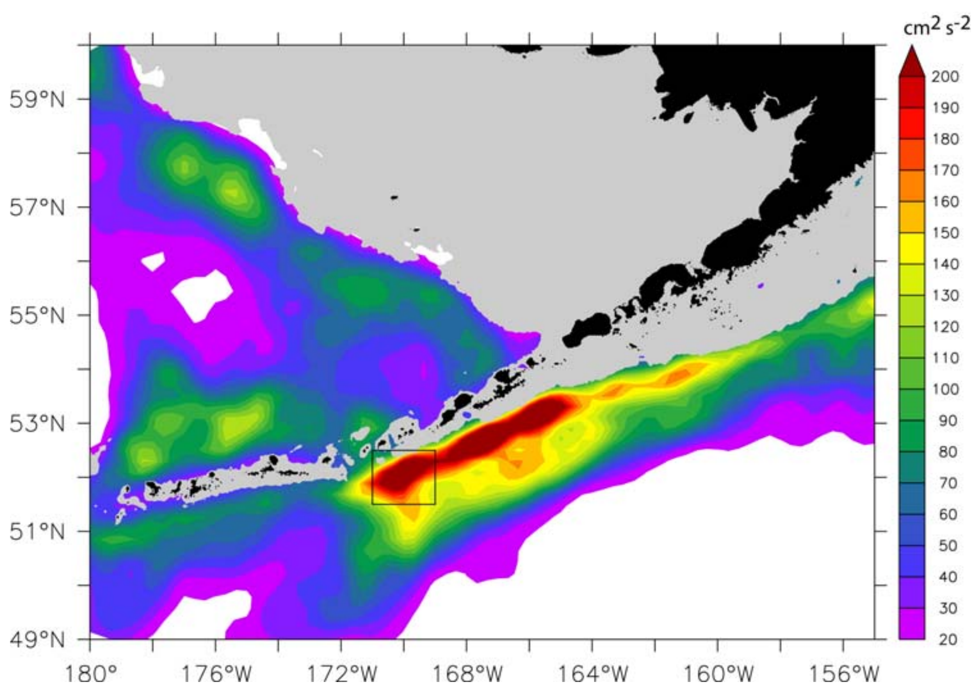

Figure 40. Eddy Kinetic Energy averaged over October 1993 – October 2006 calculated from satellite altimetry. Square denotes region over which EKE was averaged for Figure 41.

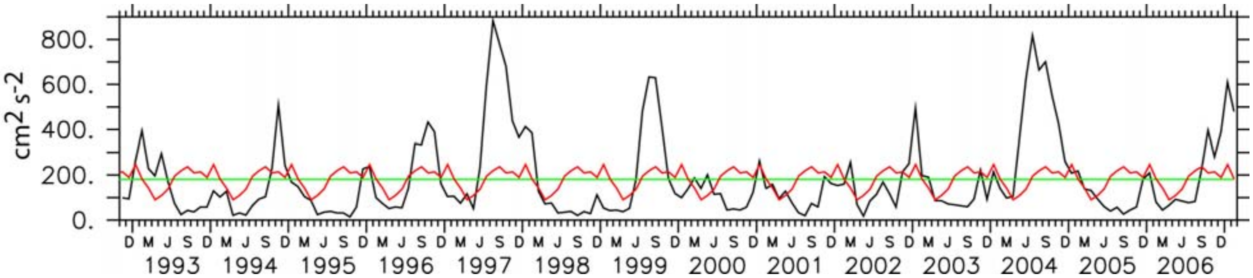

Figure 41. Eddy kinetic energy ($cm^2\ s^{-2}$) averaged over region shown in Figure 40. Black (line with highest variability): monthly EKE. Red: seasonal cycle. Green (straight line): mean over entire time series.

Water temperature data collections – Aleutian Islands Trawl Surveys
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Last updated: October 2007

The oceanography of the Aleutian Islands is shaped in large part by three major currents running along the archipelago and strong tidal forces in the passes between islands (Hunt and Stabeno 2005). The Alaska Coastal Current (Shumacher and Reed 1986, Reed 1987) flows westward along the south side of the Aleutians from the Gulf of Alaska to Samalga Pass. The Alaskan Stream also flows westward along the southern shelf break of the Aleutians to Amchitka Pass where some of the water flows northward to serve as the source water for the Aleutian North Slope Current. The remainder of the Alaskan Current continues westward in a series of meanders and eddies to bathe the western Aleutians. The Alaska Coastal Current is warmer and fresher than the Alaskan Current and these differences contribute greatly to the chemical and physical properties of the water flowing through the passes of the Aleutian Islands. The Aleutian North Slope Current flows eastward along the north side of the Aleutians from Amchitka Pass.

Water temperature data have been routinely collected on NMFS survey bottom trawl hauls since 1994 using micro-bathythermographs. Prior to that, temperature data were routinely collected near trawl haul sites using expendable bathythermographs, although these earlier data were not used in this analysis. Groundfish assessment survey periods have ranged from early May to late September, and sampling has usually progressed from east to west, but notable exceptions exist especially for the earliest three surveys involving Japanese vessels and for the 2002 and 2006 surveys. These differences in sampling patterns in time and space complicate inter-annual comparison due to the strong relationship between date of collection and water temperature at all depths throughout the survey area. In order to account for these problems and make inter-annual comparisons more meaningful, an attempt was made to remove the effect of date of collection on water temperature, in effect standardizing temperatures to an approximate median date for most AI surveys (July 10). This was achieved by using generalized additive modeling techniques to model the effects of day of year and depth on temperature with an interaction term. The model was then used to predict the temperature at the new date (July 10) at the same depth and the residuals of the original model were added to the prediction for the final estimate. All analyses use these predicted temperatures.

In order to facilitate visualization of the modeled temperatures, the data were binned into ½ degree longitude and multiple depth increments and mean temperature in each increment was calculated. Depth increments were much finer at shallower depths to capture the rapid changes in water temperatures often seen in these depths. The results are shown in Figure 42. Some common features are notable for all years including warmer surface temperatures between about 173º W and 179º W and west of 175º E. Cooler temperatures at depths greater than 100 m appear consistently around Seguam Island (~174º W), and this seems to be a particularly striking feature in colder than average years. This may result from the Alaska Coastal Current turning northward, although this is slightly further west than has previously been reported for this phenomenon (Hunt and Stabeno 2005). Cooler temperatures at depths greater than 100 m are also a predominant feature west of 175º E.

Water temperatures were warmer in 1997 than in any other year in the series. Not only were surface temperatures quite warm, but deeper waters were also consistently warmer than in other years. Temperatures in 2004 were also quite warm with a similar temperature pattern to 1997, although deeper waters in the extreme western Aleutians were cooler than in 1997. The coolest year in this series is 2000 when surface temperatures were generally cooler at the surface throughout the survey area, and waters deeper than 100 m were dominated by cooler water in the western Aleutians, particularly west of 180º. Water temperatures in 2006 appear to be intermediate to these extremes as evidenced by the warmer surface temperatures in the eastern and western ends of the survey area, cooler water around Seguam Island, and the generally warmer than normal temperatures below 100 m west of 180º. Figure 43 shows mean temperature profiles for different years, again showing 2000 to be the coolest year in the series and 1997 and 2004 the warmest.

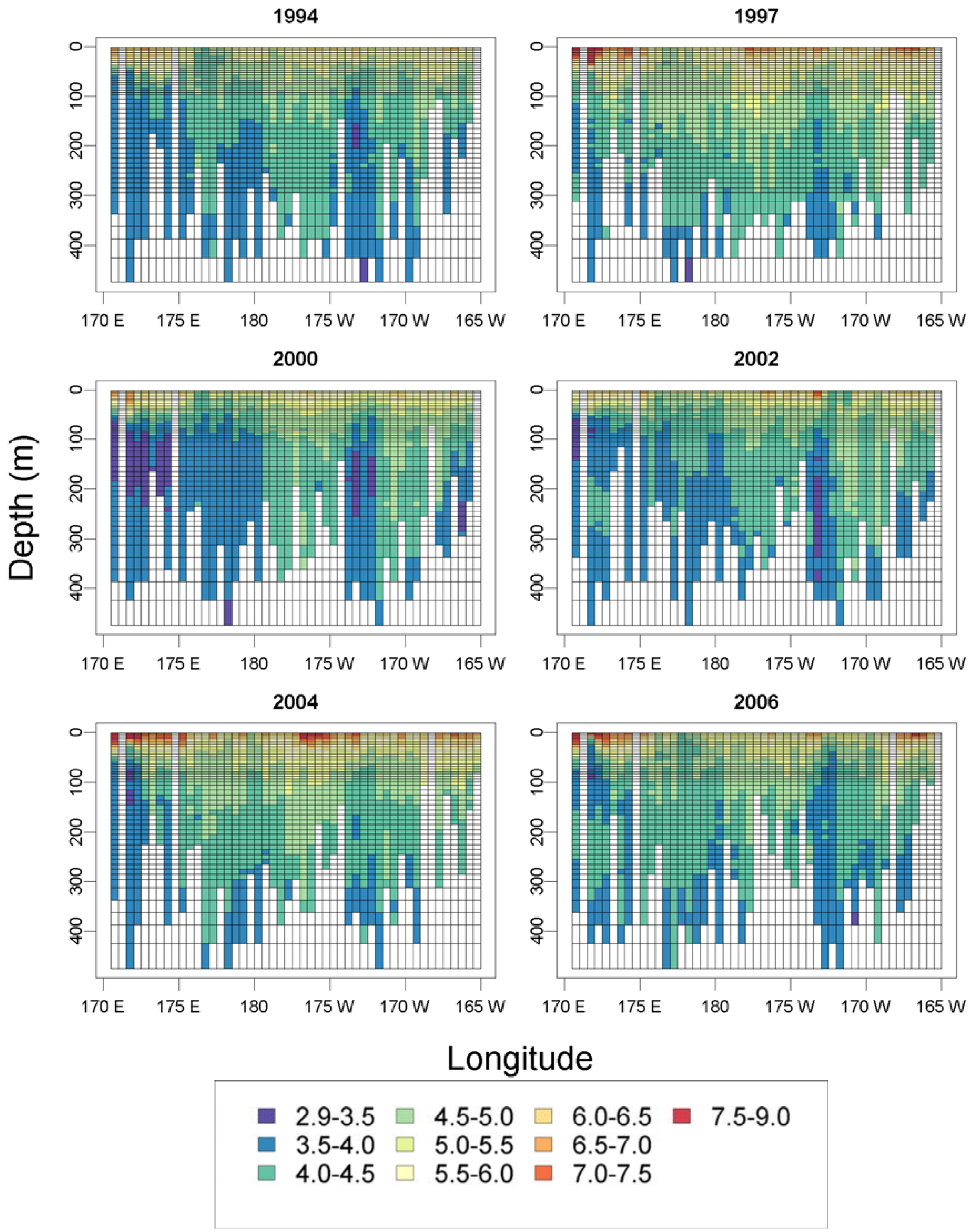

Figure 42. Date adjusted temperature profiles by ½ degree longitude intervals for years 1994-2006.

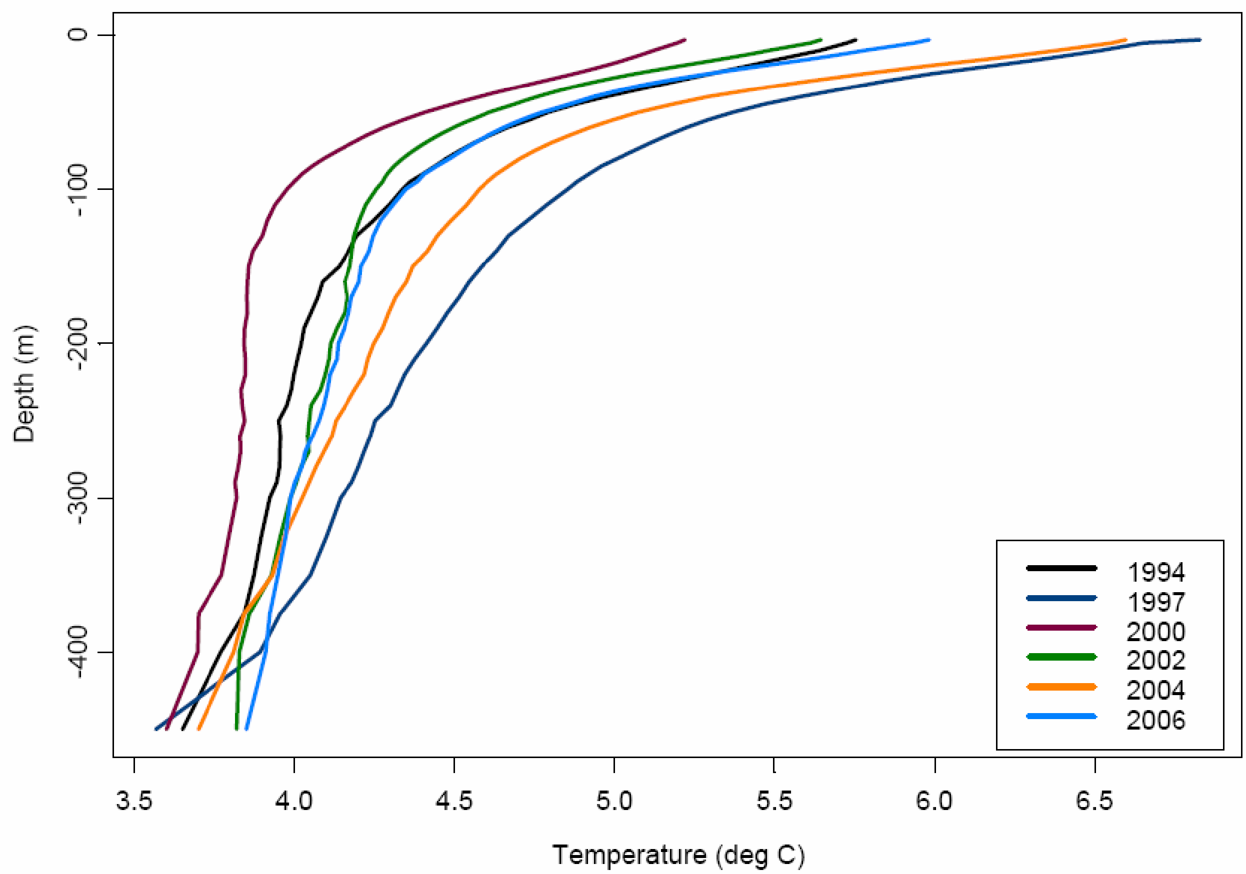

Figure 43. Date adjusted temperature mean profiles for depths to 300 m for years 1994-2006.

Habitat

HAPC Biota – Gulf of Alaska

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

Despite the caveats, a few general patterns are clearly discernible. Sponge and sea anemone abundances seem to generally decrease from west to east across the GOA (Figure 44). The frequency of occurrence for both of these groups seems to have increased over time in all areas. Gorgonians seem to be most abundant in the eastern GOA, but the frequency of occurrence is quite low and the pattern may therefore be deceiving. Sea pen and soft coral frequency of occurrence rates are also very low and no abundance trends are discernible from this limited information. Stony corals appear to be much more abundant in the areas sampled in the western GOA, and are also captured more frequently in this area.

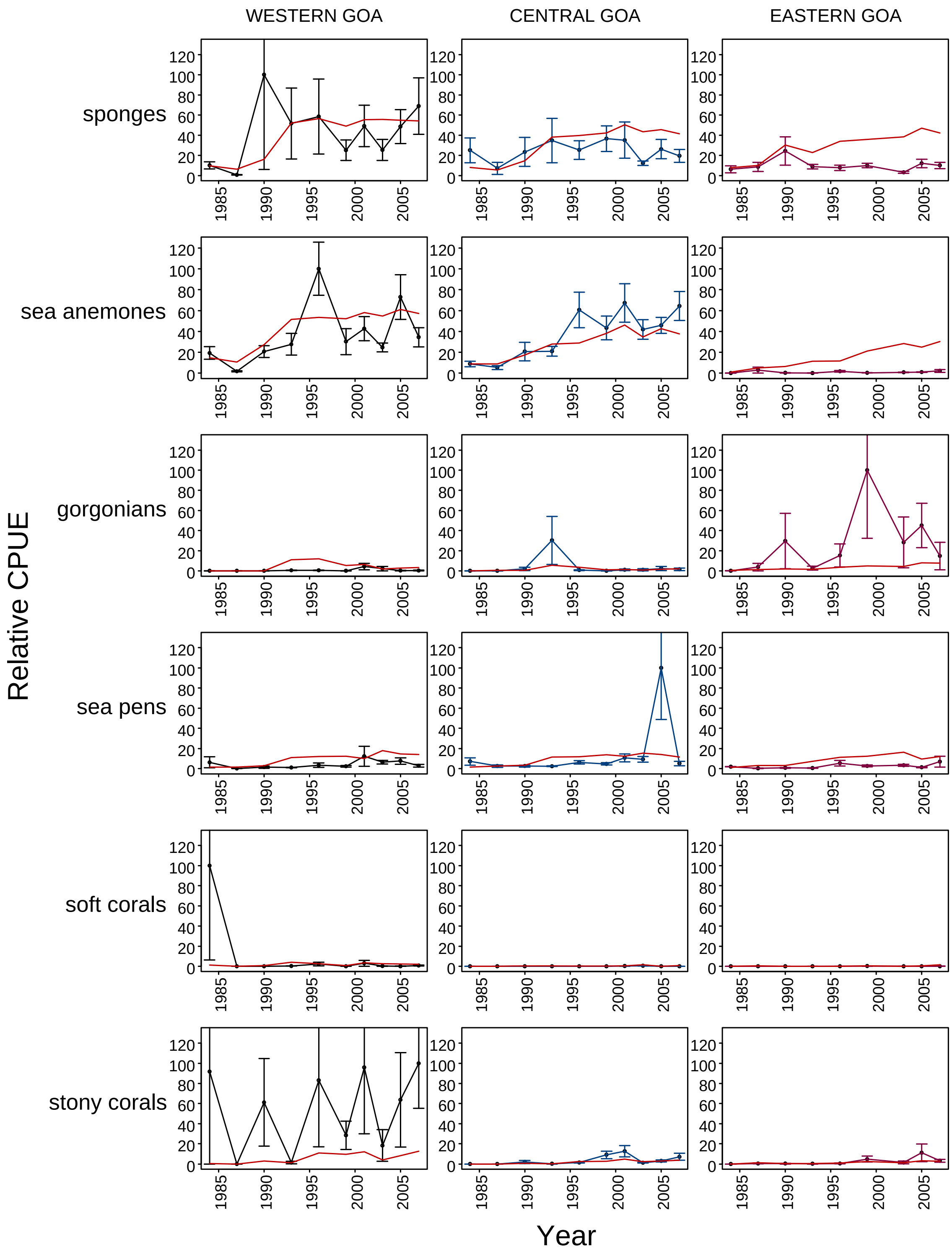

Figure 44. Mean catch per unit effort of HAPC species groups by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2007. Error bars represent standard errors. The red line shows the percentage of all hauls that contained the species group.

HAPC Biota – Bering Sea

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Last updated: November 2007

Groups considered to be HAPC biota include: seapens/whips, corals, anemones, and sponges. Corals are rarely encountered on the Bering Sea shelf so were not included here. It is difficult to detect trends of HAPC groups on the Bering Sea shelf from the RACE bottom trawl survey results from 1982 to 2007 because of the relatively large variability in relative CPUE (Figure 45). Further research on gear selectivity and the life history characteristics of these organisms is needed to interpret these trends. For each species group, the largest catch over the time series was arbitrarily scaled to a value of 1 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error.

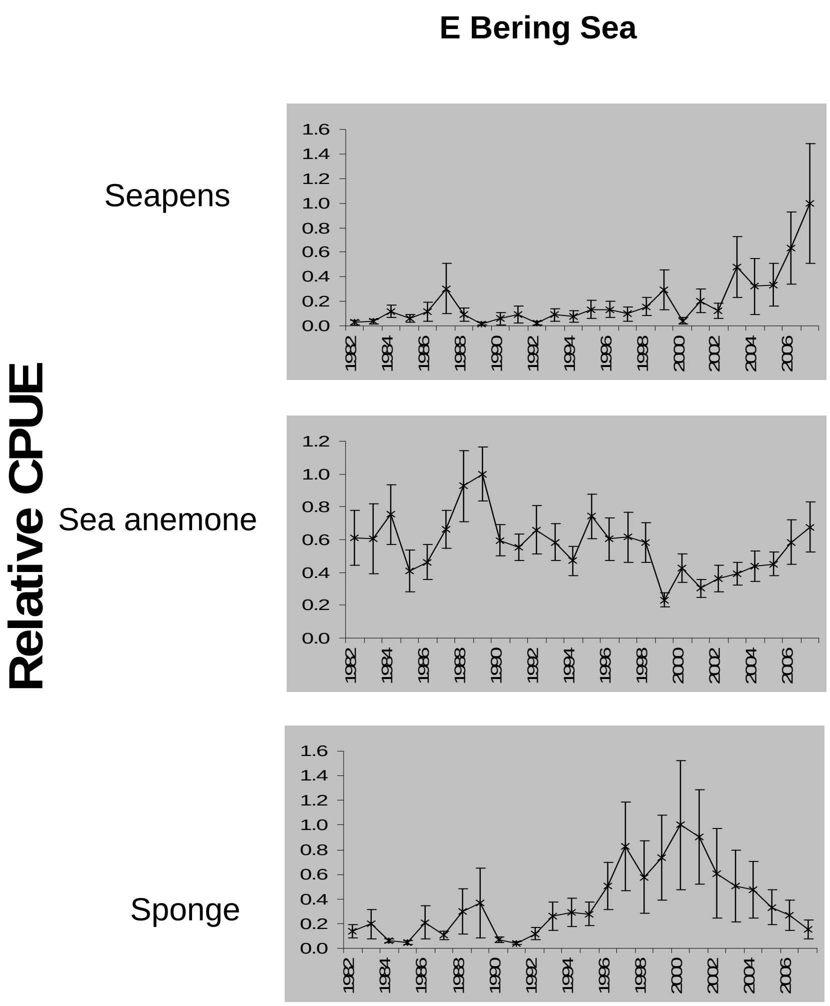

Figure 45. Relative CPUE trends of HAPC biota from the RACE bottom trawl survey of the Bering Sea shelf, 1982-2007. Data points are shown with standard error bars.

HAPC Biota – Aleutian Islands

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See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Distribution of rockfish species along environmental gradients in Gulf of Alaska and Aleutian Islands bottom trawl surveys.

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Last updated: August 2007

Environmental variability affects the distributions of most marine fish species. In an analysis of rockfish (*Sebastes* spp.) in Alaska, five species assemblages were defined based on similarities in their distributions along environmental gradients (Figure 46). Data from 14 bottom trawl surveys of the Gulf of Alaska and Aleutian Islands (n = 6767) were used. The distinct assemblages of rockfish were defined by geographical position, depth, and temperature (Rooper *in press*). The 180 m and 275 m depth contours were major divisions between assemblages inhabiting the shelf, shelf break, and lower continental slope. Another noticeable division was between species centered in southeastern Alaska and those found in the northern Gulf of Alaska and Aleutian Islands.

In this time-series, the mean-weighted distribution of six rockfish species along the three environmental gradients was calculated for the Gulf of Alaska and Aleutian Islands. The three variables examined were depth, temperature and geographical position. Position is the distance of each trawl haul from Hinchinbrook Island, Alaska. A weighted mean value for each environmental variable (depth, temperature, and position) was computed for each Aleutian Islands survey based on the formulation of Murawski and Finn (1988) as:

$$Mean = \frac{\sum (f_i x_i)}{\sum f_i} ,$$

where *fi* is the CPUE of each rockfish species group in tow *i* and *xi* is the value of the environmental variable at tow *i*. The weighted standard error (*SE*) was then computed as:

$$SE = \frac{\sqrt{\dfrac{\left(\sum (f_i x_i^2) \right) - \left(\left(\sum f_i \right) * mean^2 \right)}{\left(\sum f_i \right) - 1}}}{\sqrt{n}} ,$$

where *n* is the number of tows with positive catches. Details of the calculations and data collection and selection process can be found in Rooper (*in press*).

There were no definitive trends in distribution over the time series for position, depth or temperature in the Aleutian Islands (Figure 47). There was high variability in the mean-weighted variables in the 1991 Aleutian Islands survey, but after that the time series is remarkably stable. This is in contrast to the trends in rockfish distribution in the Gulf of Alaska.

There were no trends in distribution over the time series for depth or temperature in the Gulf of Alaska (Figure 48). However, there did appear to be some movement of the mean-weighted distribution towards the north and east (as indicated by the position variable). This may indicate a change in rockfish distribution around the Gulf of Alaska.

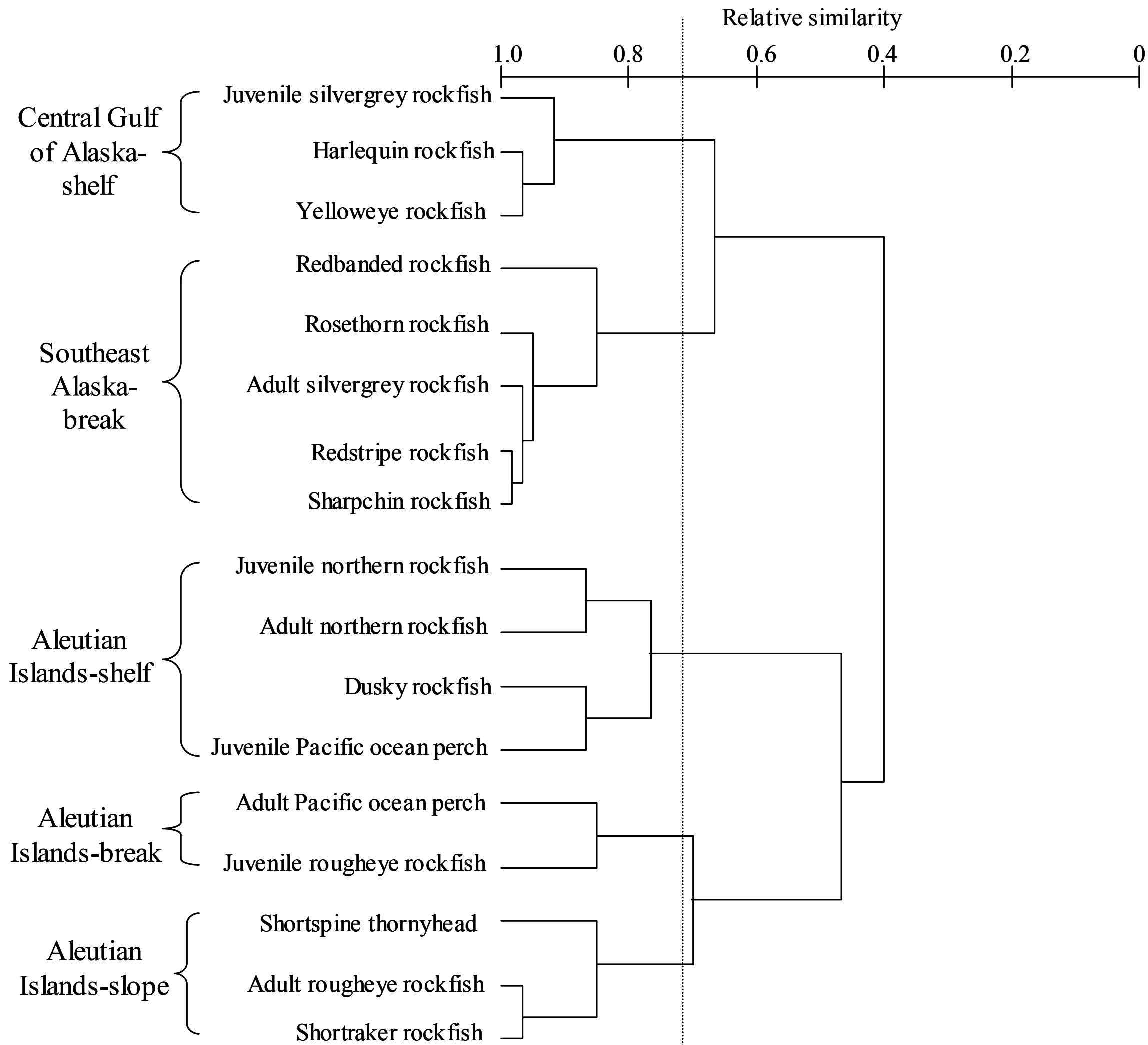

Figure 46. The results of cluster analysis of rockfish showing relative similarity amongst species-subgroups. The x-axis shows the relative similarity among species derived from the multinomial overlap indices among species-group pairs along the three environmental gradients (depth, position, and temperature). The dashed line (0.73) is where rockfish species assemblages were defined based on a similarity of 0.9 across the three environmental gradients (reprinted from Rooper (*in press*)).

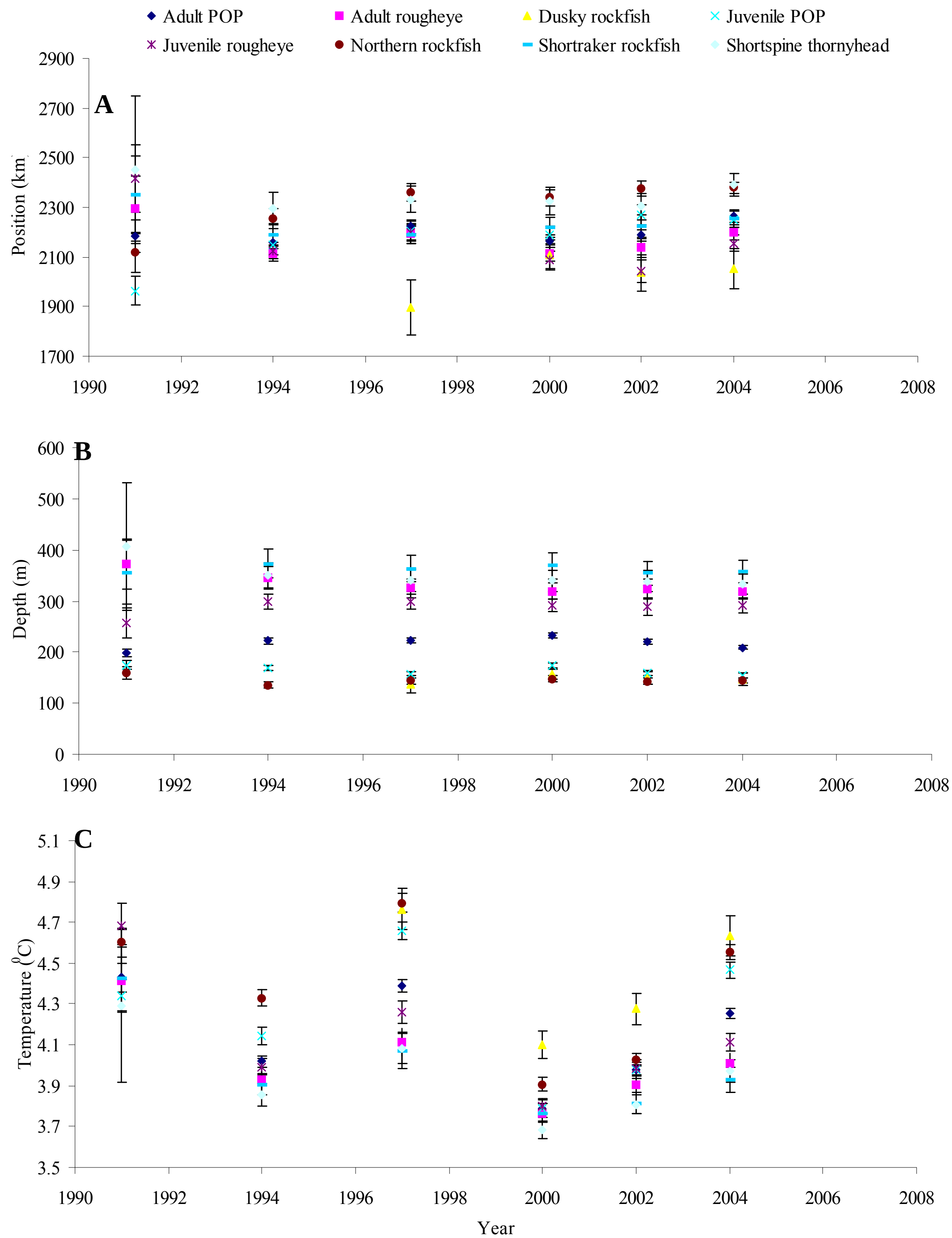

Figure 47. Plots of mean weighted (by catch per unit effort) distributions (and SEs) of six rockfish species-groups along three environmental variables in the Aleutian Islands. Mean weighted distributions of rockfish species-groups are shown for A) position, B) depth, and C) temperature. Position is the distance from Hinchinbrook Island, Alaska, with positive values west of this central point in the trawl surveys and negative values in southeastward.

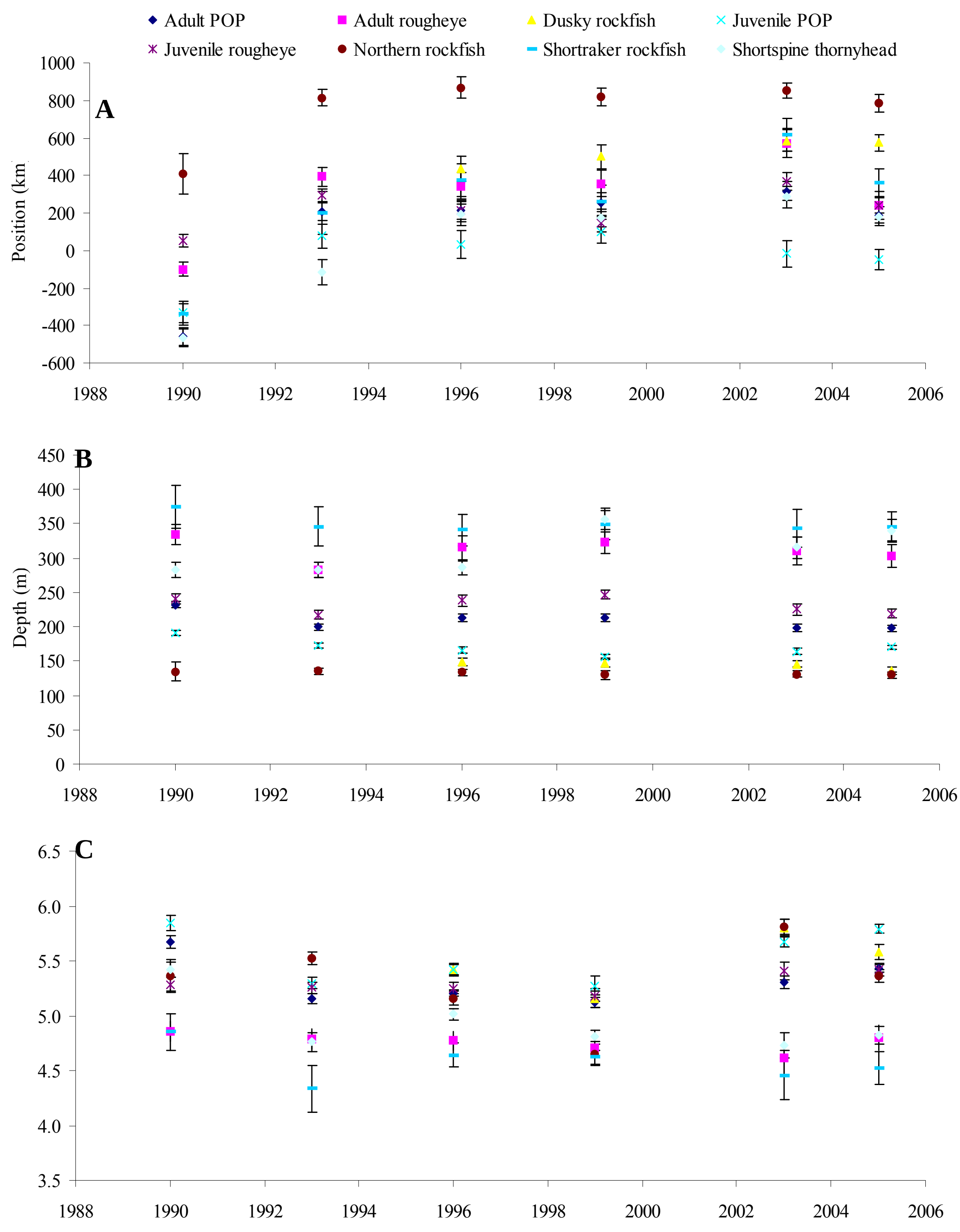

Figure 48. Plots of mean weighted (by catch per unit effort) distributions (and SEs) of six rockfish species-groups along three environmental variables in the Gulf of Alaska. Mean weighted distributions of rockfish species-groups are shown for A) position, B) depth, and C) temperature. Position is the distance from Hinchinbrook Island, Alaska.

Effects of Fishing Gear on Seafloor Habitat
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Last updated: November 2005

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm
And: http://www.afsc.noaa.gov/abl/MarFish/geareffects.htm

Nutrients and Productivity
Nutrient and Chlorophyll Processes on the Gulf of Alaska Shelf
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Nutrients and Productivity Processes in the southeastern Bering Sea
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Variations in phytoplankton and nutrients during fall 2000-2005 in the eastern Bering Sea- BASIS
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Last updated: November 2006

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Zooplankton
Gulf of Alaska Zooplankton
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See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Bering Sea Zooplankton

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See the 2006 report in the “Assessment Archives” at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Forage Fish

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

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See the 2006 report in the “Assessment Archives” at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

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

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

The distribution and abundance of age-0 walleye pollock was studied in the EBS during annual fall trawl surveys, and their energy density and diet were determined in the laboratory. The trawl surveys were conducted aboard the F/V Sea Storm from August - October, 2003-2006. Sampling stations were located between 54ºN and 68ºN and spaced 15 to 30 km apart; however, spatial coverage varied between years as a result of lost sampling opportunities due to poor weather conditions. For regional comparisons, the EBS was divided into two regions, with waters from 60° N and northward classified as northern EBS, and waters south of 60°N classified as southern EBS. Fish were captured using a surface trawl towed for 30 minutes at and average speed of 3.5 to 5 knots. All tows were made during day light hours. On board, fish were identified, counted, measured, and a sub-sample of 10 fish per station were retained for on board diet analysis. An additional 10 fish per haul were retained for laboratory analysis. Annual abundance of age-0 walleye pollock was estimated by dividing the average number of age-0 walleye pollock caught by the average volume of water swept for all trawls in the 2003-2006 survey years. In the lab, whole body energy density (J/g wet weight) was determined using bomb calorimetry of fish collected at similar locations during the 2003-2006 survey years using bomb calorimetry. Analysis of variance (ANOVA) was used to test the effects of region on energy density. Stomach content data (% wet weight of prey) were also compared among years and between regions for the 2003-2006 survey years.

Age-0 walleye pollock were distributed throughout the EBS, with the highest concentrations occurring in frontal regions and in Bristol Bay (Figure 49). Average abundance increased annually between 2003 and 2004, and declined until 2006; however, sampling areas were different among years and, therefore, no definitive abundance estimates can be made until differences in survey area are accounted for (Figure 50). In 2005 and 2006, fish appeared to be distributed further offshore relative to 2003 and 2004. Energy densities of age-0 walleye pollock varied regionally and among years (Figure 51). The energy densities were generally lowest in fish from the southern region of the EBS, while among years energy density was lowest in 2005 and highest in 2006. There was a significant difference in energy density of juvenile walleye pollock between northern and southern regions during 2003 and 2004 ($P<0.01$), but no significant differences were detected in 2005 and 2006. Stomach content analysis indicated that the diet of age-0 walleye pollock varied considerably by region and year (Figure 52). Generally, copepods were more of an important diet component in 2003-2004, while euphausiids were important in the northern EBS in 2005 and the southern EBS in 2006. Age-0 walleye pollock consistently consumed fish as a prey item in the southern region of the EBS, and this prey item was only identified in one of the four years (2005) in the northern region of the EBS.

Sea surface temperatures were warmer in 2003-2005 compared to 2006 (Moss and Feldmann, in review). Cooler spring temperatures and late ice retreat in 2006 could have resulted in the decrease of age-0 walleye abundance seen in 2006 and their extended offshore distribution compared to the other years. Additionally, cooler springtime ocean temperatures cause later than average spring bloom, which limits zooplankton production (Coyle and Pinchuk 2002) and potential foraging opportunities for age-0 walleye pollock. Energy density of age-0 walleye pollock was greatest in 2006 when sea surface temperatures were cool. This may be due to the allocation of energy from somatic tissue to lipid storage at an earlier date relative to warmer years. The proportion of pteropods increased in the diets of age-0 walleye pollock in the southern EBS in 2005, while the proportion of fish decreased. Pteropods have a much lower energy content compared to euphausiids, copepods, and fish (Davis et al. 1998, Nishiyama 1977) and therefore may have contributed to the low energy density seen on age-0 walleye pollock in 2005. Additionally, in 2005 compared to previous years, walleye pollock were distributed west of the inner front where well mixed coastal domain water meets stratified middle domain water and this may have separated them from critical foraging areas. Frontal regions are known to be areas of higher productivity (Franks 1992). In 2003 and 2004, age-0 walleye pollock were more closely associated with the productive inner front associated with the 50 meter isobath (Kachel et al. 2002). Further investigation of the zooplankton biomass and oceanographic conditions in the EBS study area is needed to understand the observed variations in distribution, abundance, energy density, and diet of age-0 walleye pollock, and to determine whether these variations have an effect on their early marine survival.

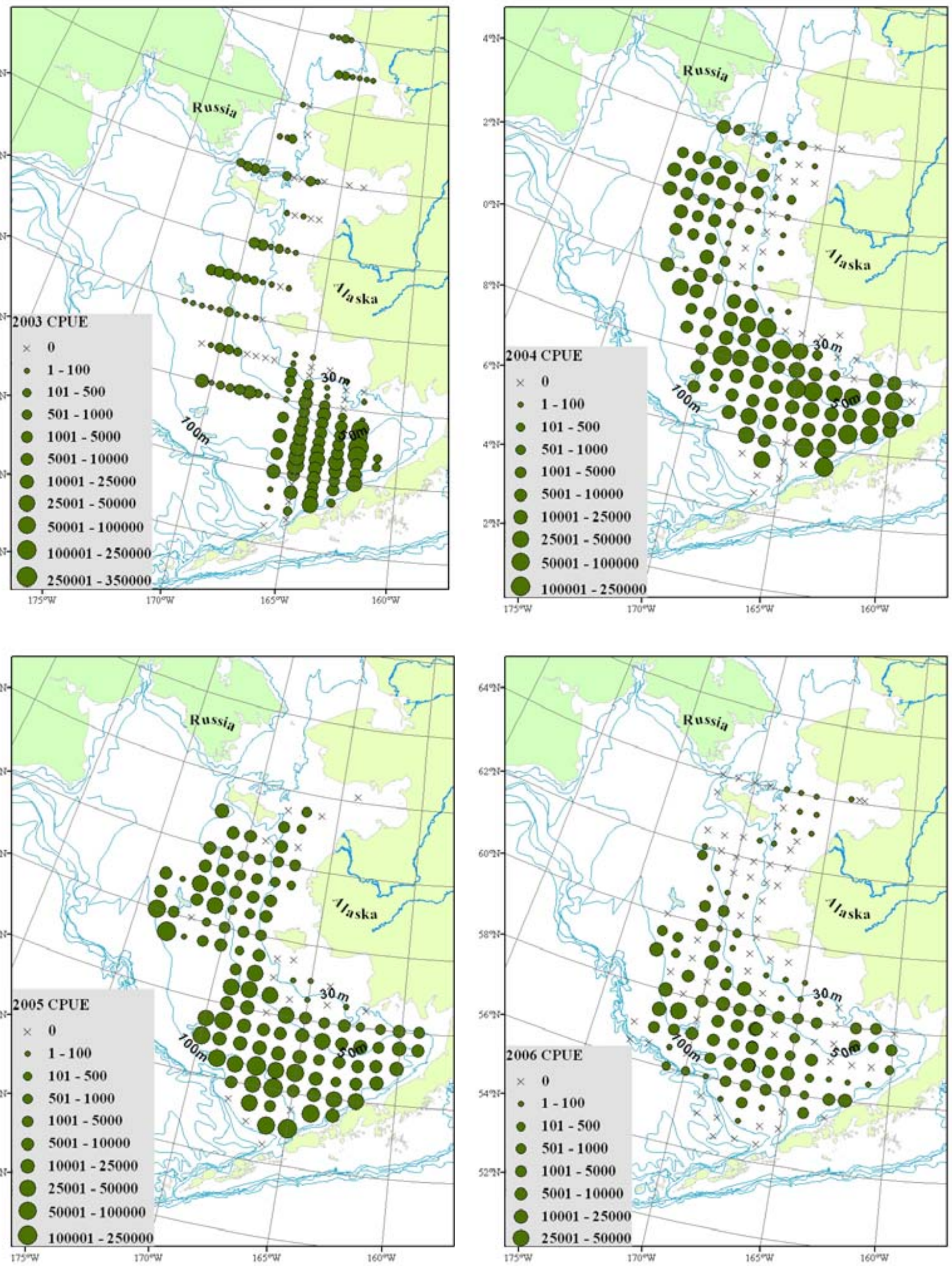

Figure 49. Catch per unit effort (CPUE, fish/km3) of age-0 walleye pollock based on 30 minute surface trawl hauls in the eastern Bering Sea from August to October, 2003-2006.

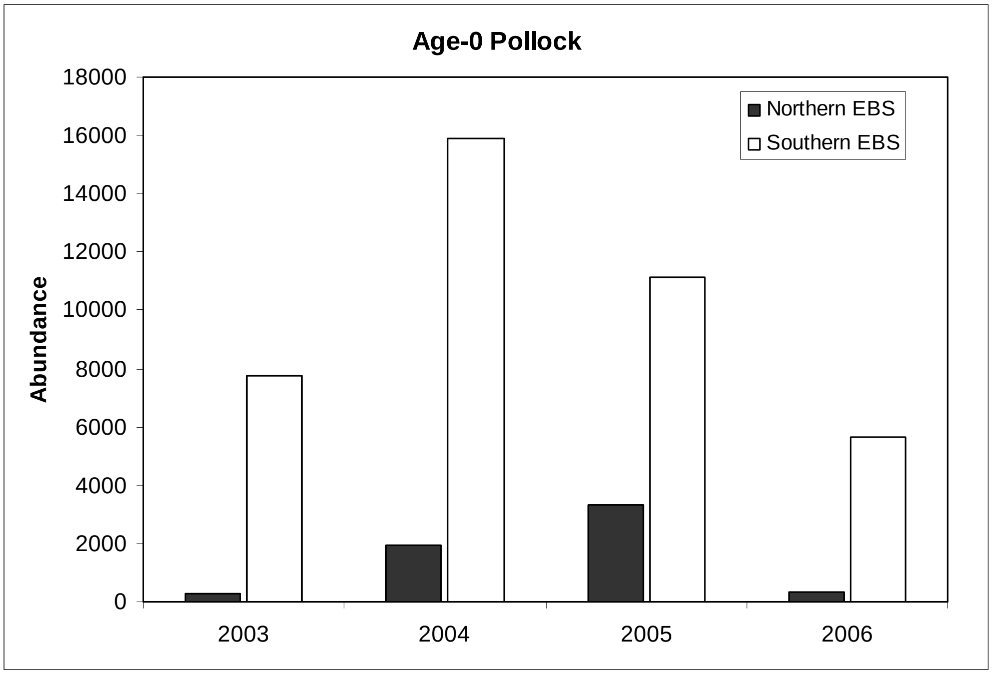

Figure 50. Average age-0 walleye pollock catch per unit effort (fish/km3) in the northern and southern regions of the eastern Bering Sea from August to October, 2003-2006.

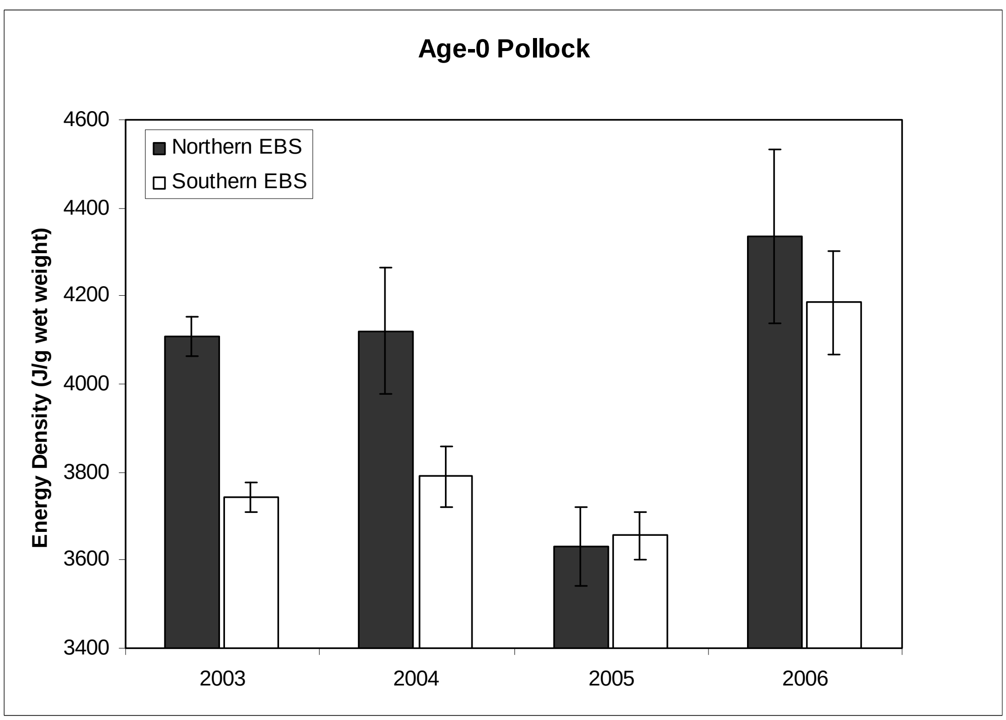

Figure 51. Average energy density (J/g wet weight) of age-0 walleye pollock in the northern and southern regions of the eastern Bering Sea from August to October, 2003-2006. Error bars represent 95% confidence intervals.

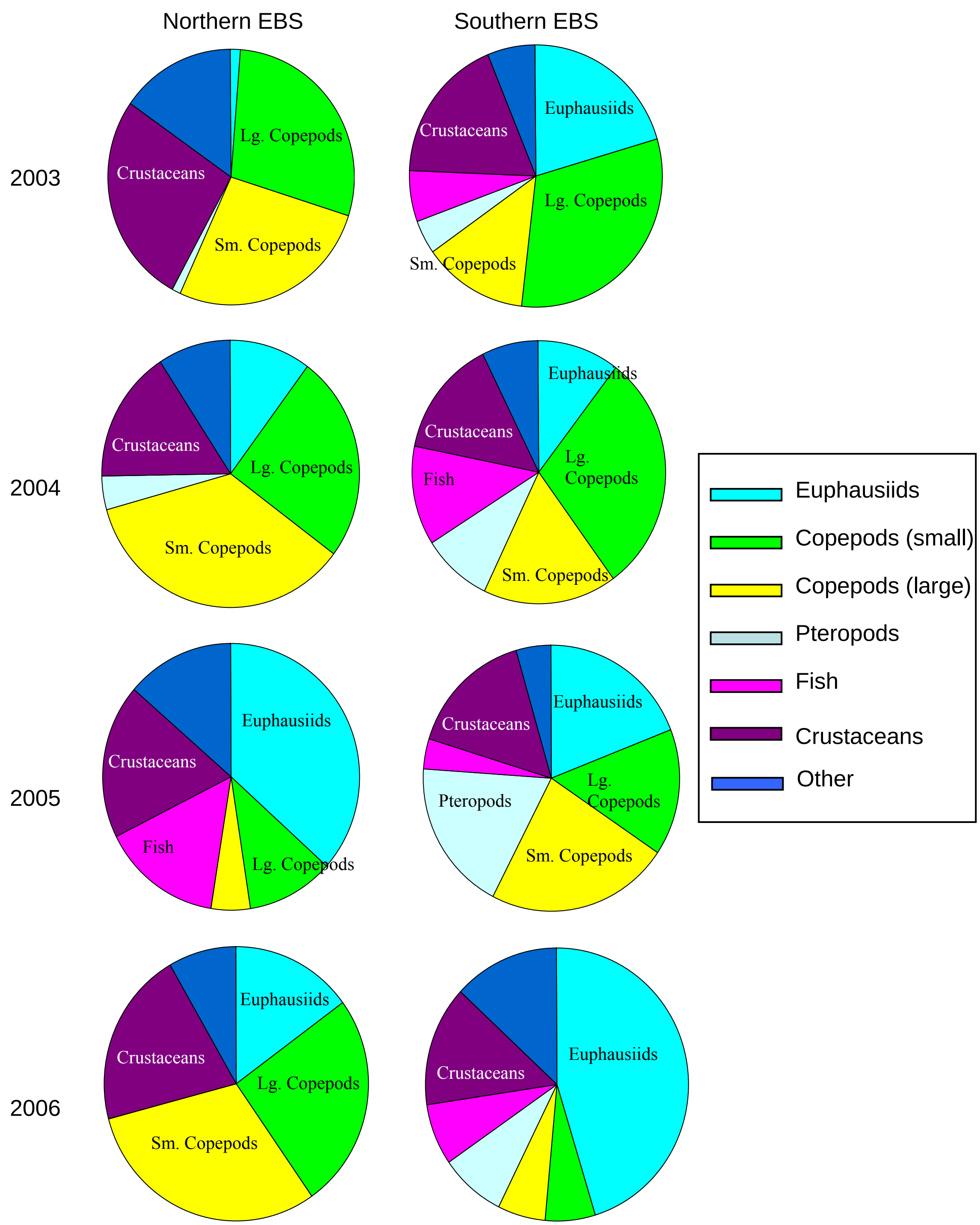

Figure 52. Diet composition by % prey weight for age-0 walleye pollock in the northern and southern regions of the eastern Bering Sea from August to October, 2003-2006. The left panel represents the proportional contribution of prey from the northern region, and the right panel represents the proportional contribution of prey from the southern region.

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

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Last updated: November 2006

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Forage Species– Gulf of Alaska

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The North Pacific Fishery Management Council has defined several groups as forage species for management purposes in the Gulf of Alaska (GOA). These groups include gunnels, lanternfish, sandfish, sandlance, smelts, stichaeids, and euphausiids. Several of these groups are captured incidentally in the Gulf of Alaska biennial RACE bottom trawl survey. Since all of these species are quite small relative to the size of the mesh used in the survey gear, the capture efficiency for these species is quite low. Many of these species are rarely encountered during the survey and therefore trends in abundance are difficult to discern, due to the high variability of the resulting estimates. A possible exception to this generalization would appear to be eulachon (*Thaleichthys 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 peaked in 2003, before returning to lower levels in the past two surveys (Figure 53). It is also interesting to note that the frequency of occurrence generally increases from west to east, although the biomass seems to be highest in the central GOA. For each species group, the largest catch over the time series was arbitrarily scaled to a value of 100 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error.

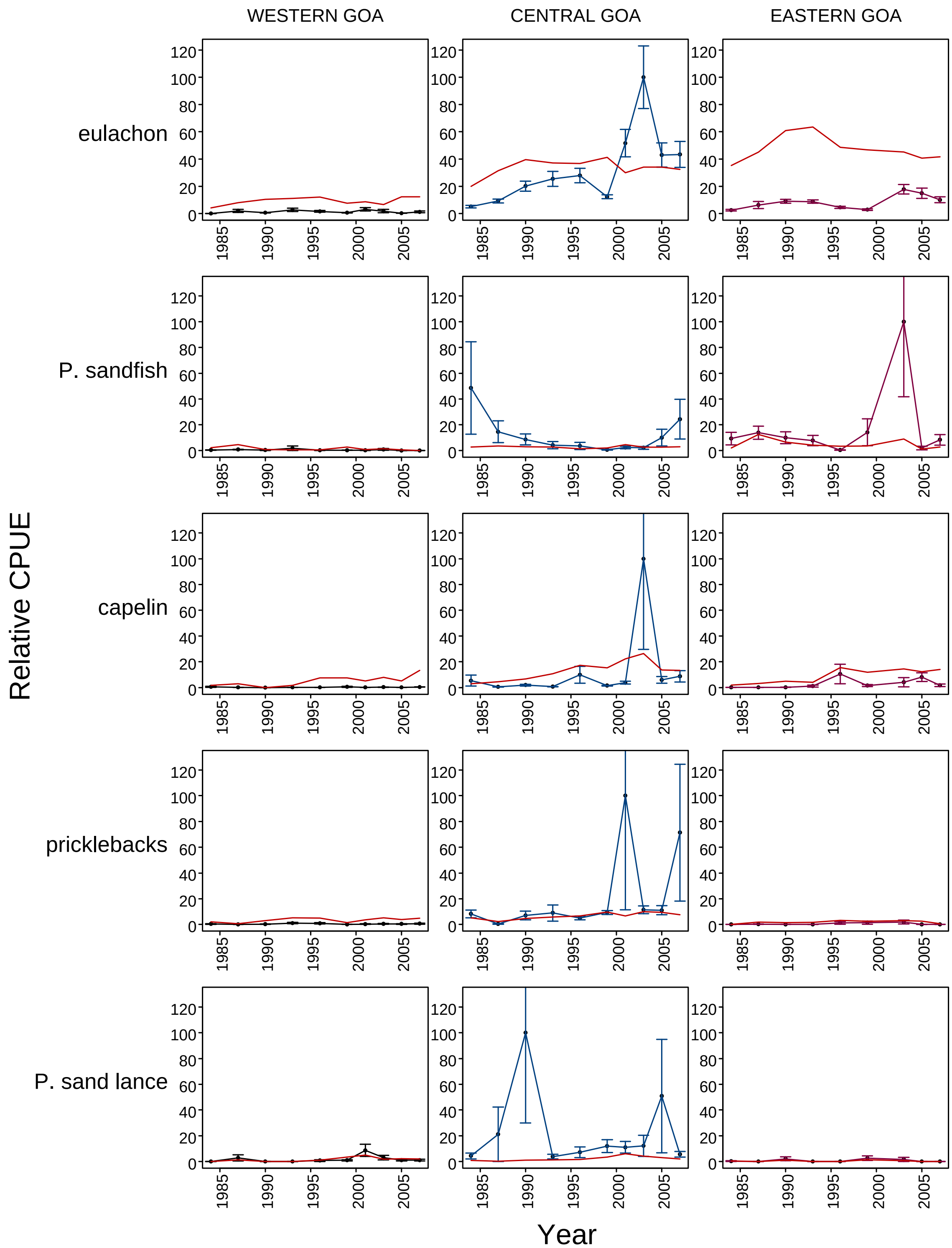

Figure 53. Relative mean CPUE of forage fish species by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2007. Error bars represent standard errors. The red lines represent the percentage of non-zero catches.

Forage – Eastern Bering Sea

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Last updated: October 2007

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 eastern Bering Sea shelf, which may provide an index of abundance (Figure 54). For each species group, the largest catch over the time series was arbitrarily scaled to a value of 1 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error. Sandfish are generally in low abundance in the trawl surveys and are usually caught in high abundance in only a few hauls in the shallower stations (Figure 54). Stichaeids, which include the longsnout prickleback (*Lumpenella longirostris*), daubed shanny (*Lumpenus maculatus*) and snake prickleback (*Lumpenus sagitta*), are small benthic-dwelling fish. Their relative abundance in trawl survey catches was generally higher in trawl survey catches prior to 1999. Similar to stichaeids, the relative CPUEs of sandlance were generally higher prior to 1999. Eulachon relative CPUE was higher than the past four years. Capelin catches in the survey have been relatively low, with the exception of one year (1993) when CPUE was very high (Figure 54).

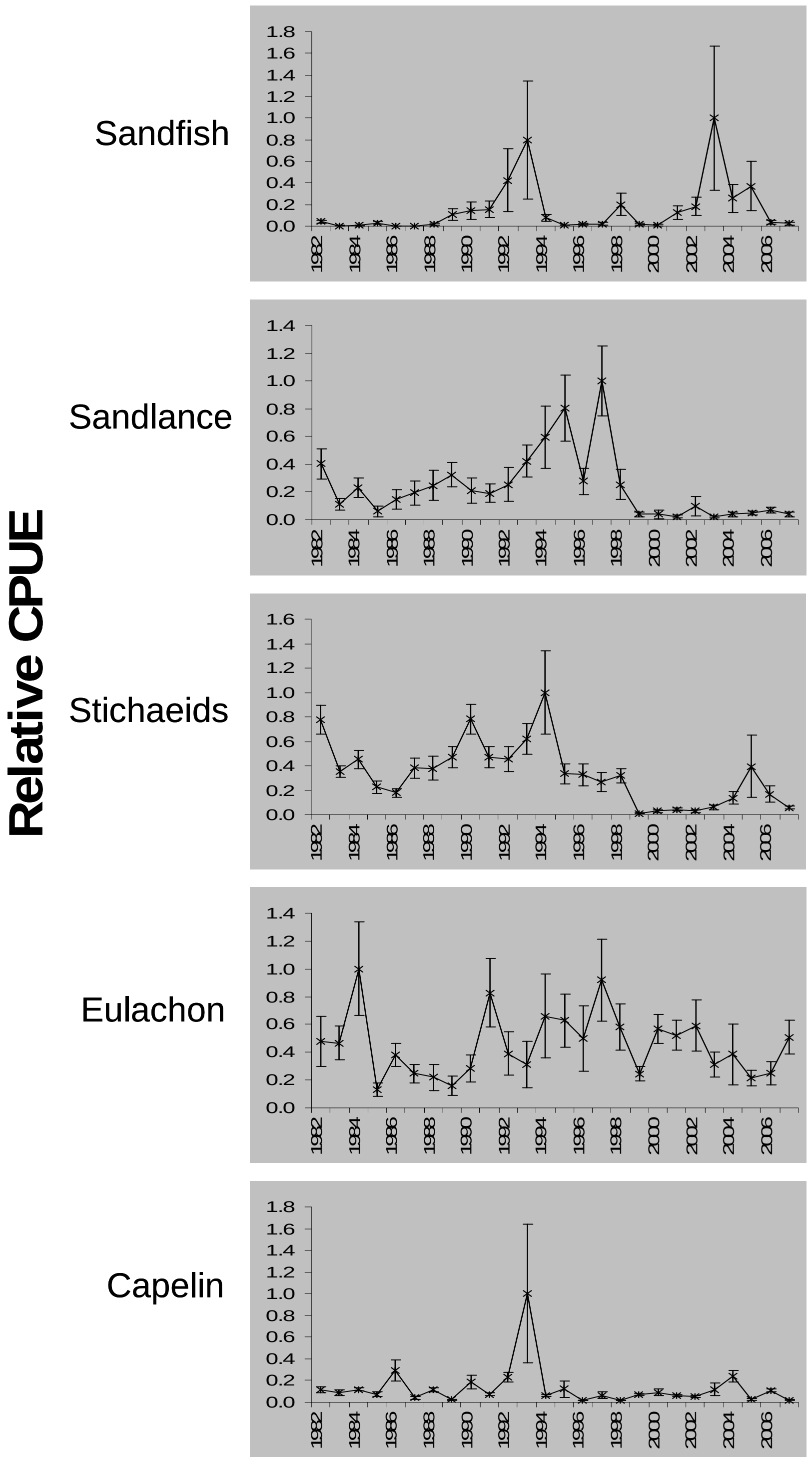

Figure 54. Relative CPUE of several forage fish groups from the eastern Bering Sea summer bottom trawl survey, 1982-2007. Data points are shown with standard error bars.

Forage – Aleutian Islands

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Last updated: November 2006

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Herring

Prince William Sound Pacific herring

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Southeastern Alaska herring

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Togiak Herring Population Trends

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Last updated: October 2007

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 1980s with approximately 1.6 billion fish when herring from the 1977 and 1978 year classes recruited into the fishery as age-4 fish in 1981 and 1982 (Figure 55). Beginning in 1983, total abundance steadily declined until modest recruitment events occurred in 1991 and 1992 from the 1987 and 1988 year classes. Temporal trends in Togiak herring abundance show that total abundance in the 1980s to the mid-1990s was above the 1978 - 2006 average, with the exception of 1989 and 1990. Total abundance fell below the long term average in 1995 and has remained below average until 2006 (with the exception of 2001) (Figure 55).

The high abundance estimates in the early 1980s may be a result of projecting backwards from the ASA model which was used beginning in 1993. The model has a tendency to over hindcast biomass estimates from the 1980s and early 1990s since it was not initially designed to hindcast. In 2006, age-4 and age-5 herring made a larger than expected contribution to the commercial fishery by weight, comprising a larger portion of the commercial purse seine harvest as the season progressed. The larger than expected return of age-4 and age-5 fish observed in the fishery may suggest strong recruitment in the future.

Pacific herring recruitment trends are highly variable, with large year classes occurring occasionally at regular intervals of approximately every 9-10 years, with the most recent events occurring from the 1996 and 1997 yearclasses (Figure 55). These large recruitment events drive the Togiak herring population. Environmental conditions may be the critical factor that influences strength of herring recruitment. Williams and Quinn (2000) have demonstrated that Pacific herring populations in the North Pacific are closely linked to environmental conditions with temperature having the strongest correlation. A general consensus in fisheries points towards the larval stage of herring life history as being the most important factor for determining year class strength (Cushing 1975, Iles and Sinclair 1982). Ocean conditions relative to spawn run timing would greatly influence the strength of each year class. Closer examination of trends in sea surface temperature, air temperature, and Bering Sea ice cover specific to the Bristol Bay area may find a specific correlate for Togiak herring recruitment.

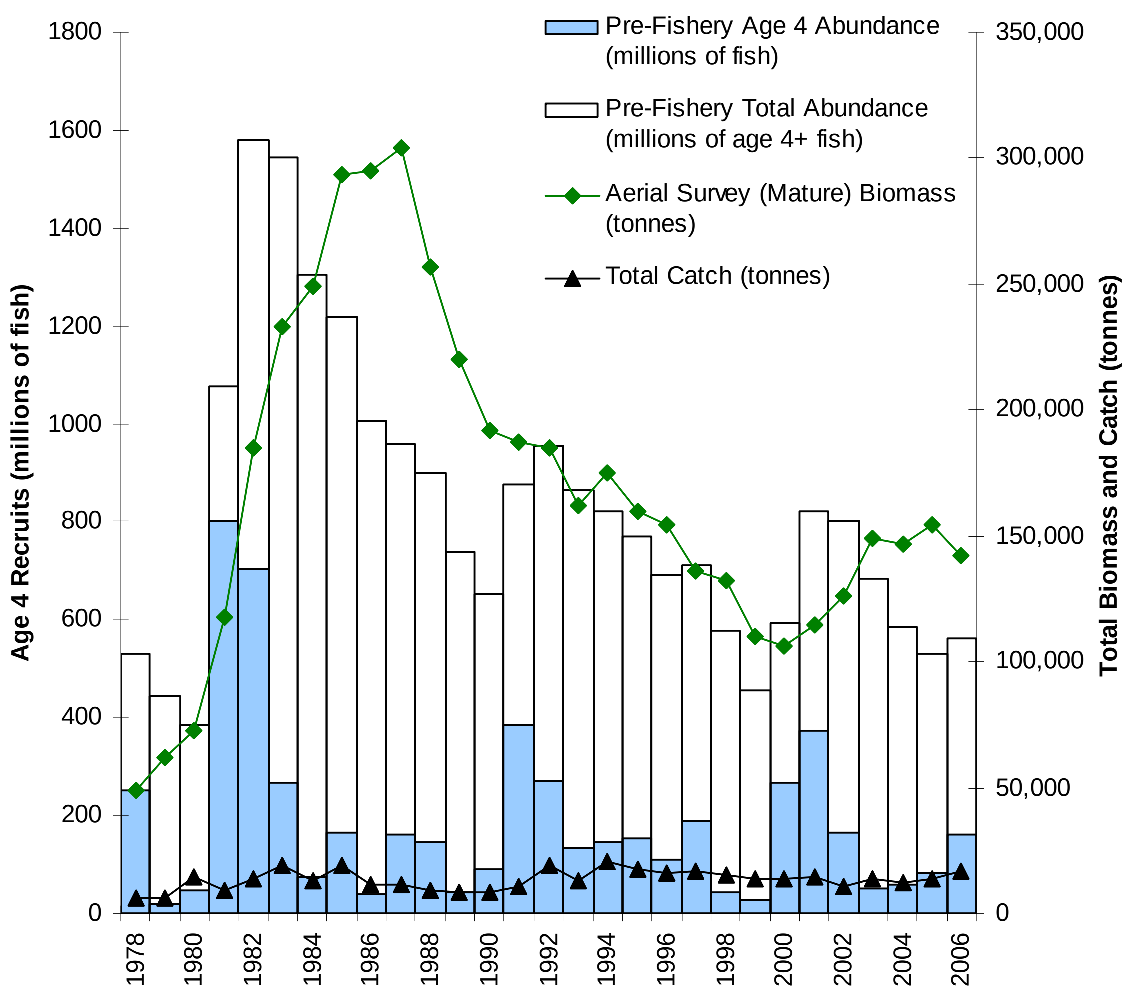

Figure 55. Total age-4+ abundance, abundance of age-4 recruits, mature biomass, and total harvest of Pacific herring in the Togiak District of Bristol Bay, 1978 – 2006.

Salmon

Historical trends in Alaskan salmon

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Last updated: November 2006

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Western Alaska juvenile ecology along the eastern Bering Sea shelf.

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Last updated: April 2005

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Groundfish

Trends in Groundfish Biomass and Recruits per Spawning Biomass

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Last updated: October 2007

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

Methods

Median recruit per spawning biomass (log(R/S)) anomalies were calculated for each species to provide an index of survival. In stocks that are abundant, the relationship between recruits and spawners will not be linear and density dependent factors may limit recruitment. Under these circumstances, the pattern of recruits per spawner will appear as an inverse of the pattern of spawning biomass as annual rates of production have leveled off. For this reason, it is important to also consider recruitment, as well as recruits per spawning biomass. Abundance of recruits for each species was lagged by the appropriate number of years to match the spawning biomass that produced them. For graphical display, the median of each time series was subtracted from the log-transformed recruit per spawning biomass ratios and expressed as a proportion of the median. 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. At least two variables are needed for the STARS method: the cutoff value (minimum length of regimes) and the p-value (probability level). For this analysis, a cutoff value of 10 years and a p-value of 0.10 were chosen. A description of STARS and software is available at: http://www.beringclimate.noaa.gov/index.html. An analysis of recruitment is not included in this section; however, Mueter (see contribution in this report and Mueter et al. 2007) examined combined standardized indices of groundfish recruitment and survival rate. Mueter's indices of survival rate are calculated as residuals from stock-recruit relationships, thereby, accounting for density dependence and providing an alternative examination of groundfish survival.

Results

BIOMASS

Total biomass of BSAI groundfish was apparently low in the late 1970s but increased in the early 1980s to around 20 million metric tons. Some fluctuations in the total biomass have occurred, with biomass below the 1978-to-present average occurring in 1978-82, 1990-91, and 2006 (Figure 56). 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 56) are different from those in the BSAI. Although biomass increased in the early 1980s, as also seen in the BSAI, GOA biomass declined after peaking in 1982 at over 6 million metric tons. Total biomass has been fairly stable since 1985, however the species composition has changed. Pollock were the dominant groundfish species prior to 1986 but arrowtooth flounder has increased in biomass and is now dominant. The 2007 IPHC stock assessment of halibut, ages 6 and older, for the GOA (areas 2C and 3A) indicates halibut biomass increased from 1978 to 1996, declined slightly during 2001-2004, and has been relatively stable since. Biomass levels in 2007 were still above the 1978-present average.

RECRUIT PER SPAWNING BIOMASS

Several stocks experienced step-changes in survival, as indicated by log(R/S), in the late 1970s and 1980s; however, in general, there was no indication of uniform step changes in all stocks in either time period for the GOA or BSAI (Figures 57-59 and Table 7).

Most roundfish (gadids, sablefish, and Atka mackerel) typically did not show a shift in survival in 1976-77 or 1988-89 in the BSAI or GOA (Figures 57 and 58). Instead, shifts were observed in the early 1970s and early 1980s. Sablefish showed significant negative shifts in 1969 and 1985 and a positive shift in 1977.

Several BSAI flatfish had high survival prior to the late 1980s and lower survival in the 1990s, including arrowtooth flounder, yellowfin sole, northern rock sole and flathead sole (Figure 57 and Table 7). This was not the case for most GOA flatfish, which tended to show shifts in the mid- late 1990s. GOA arrowtooth flounder had negative step-changes in survival in 1980 and 1988; however the total biomass of arrowtooth flounder has been increasing since the mid-1970s.

Pacific ocean perch showed positive shifts in the mid- 1970s in both the BSAI and GOA (Table 7). After the mid-1980s, there was a decreasing trend in log(R/S) anomalies (Figures 57 and 58). BS POP also showed a negative shift in 1989, whereas, GOA POP showed a negative shift in 1996 (Figures 57 and 58 and Table 7). Other rockfish showed shifts in other years or no shifts at all.

Conclusions

Several stocks experienced step-changes in survival in the late 1970s and 1980s; however, in general, there was no indication of uniform step changes in all stocks in either time period for the GOA or BSAI. Mueter et al. (2007) found, however, that when groundfish time series are combined, there does appear to be a system-wide shift in groundfish survival and recruitment within the BSAI and GOA in the late 1970s with mixed results in the late 1980s. This indicates that there may be some overall response to changes resulting from environmental forcing.

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 and between ecosystems. For example, pollock and cod have similar recruit per spawner trends within both the BSAI and GOA. Barbeaux et al. (2003) found that Aleutian Island pollock (not included in this analysis) and Atka mackerel show similar patterns in recruitment. This may be an indication that roundfish respond in similar ways to large-scale climate changes.

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

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

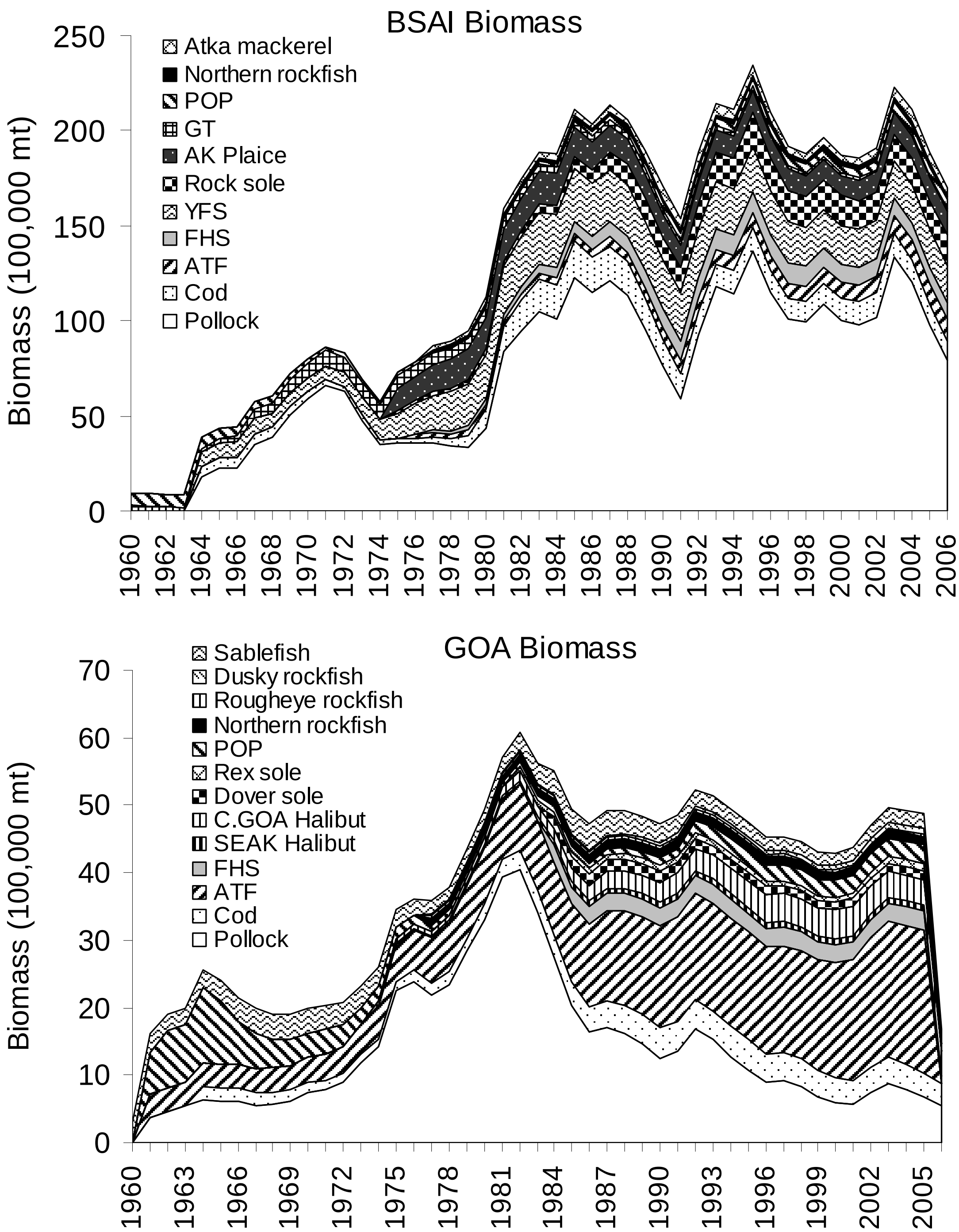

Figure 56. Groundfish biomass trends (100,000 metric tons) in the BSAI (1960-2006) and GOA (1960-2005), as determined from age-structured models of the Alaska Fisheries Science Center reported by NPFMC (2006 a, b). Halibut data provided by the IPHC (S. Hare, personal communication).

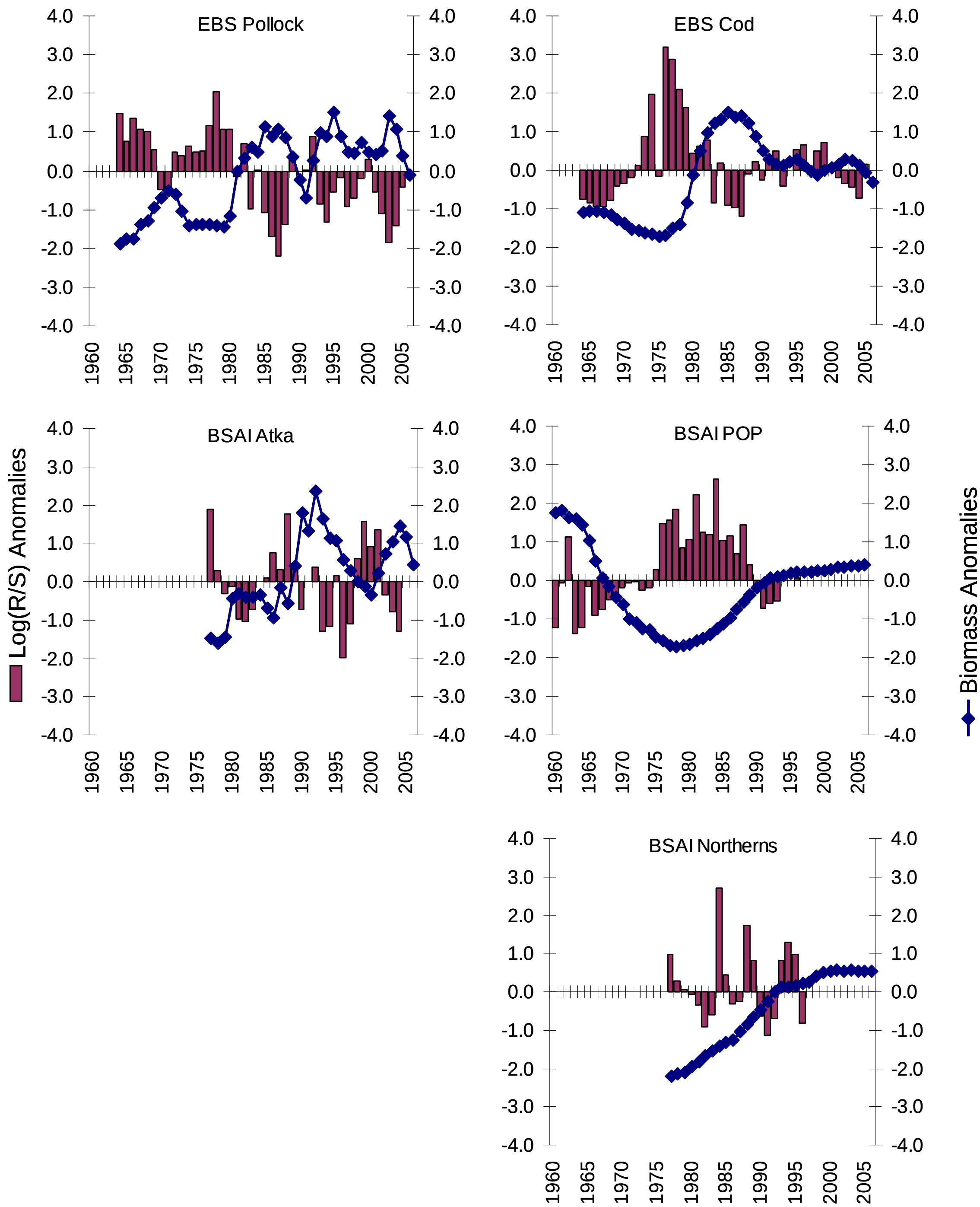

Figure 57. Median log recruit per spawning biomass anomalies and biomass anomalies for BSAI groundfish species assessed with age- or size-structured models, 1960-2006. EBS = Eastern Bering Sea, BS = Bering Sea, AI = Aleutian Islands, POP = Pacific ocean perch, Northerns = Northern rockfish, Atka = Atka mackerel.

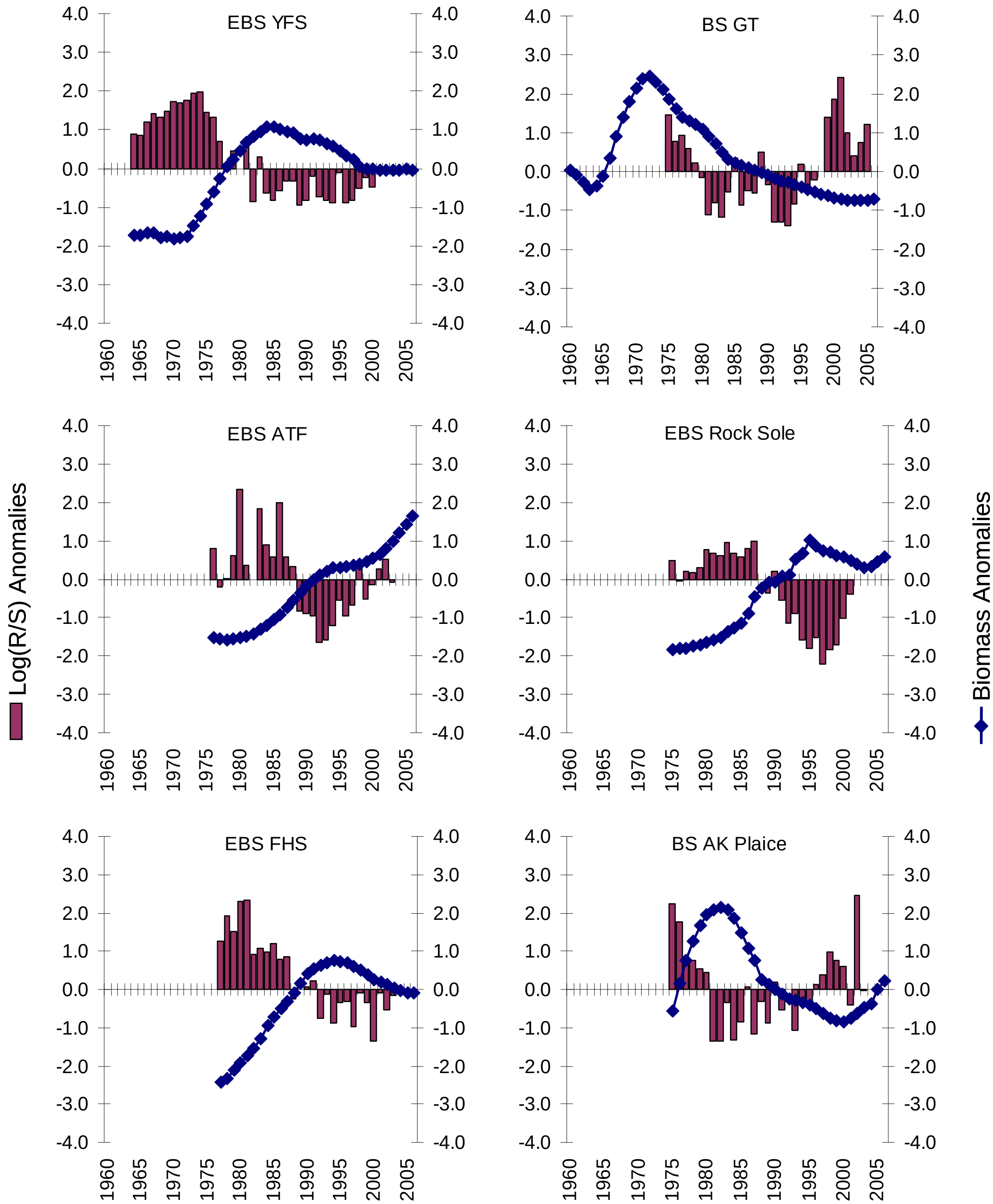

Figure 57 continued. Median log recruit per spawning biomass anomalies and biomass anomalies for BSAI groundfish species assessed with age- or size-structured models, 1960-2006. EBS = Eastern Bering Sea, BS = Bering Sea, AI = Aleutian Islands, YFS = yellowfin sole, ATF = arrowtooth flounder, FHS = flathead sole, GT = Greenland turbot.

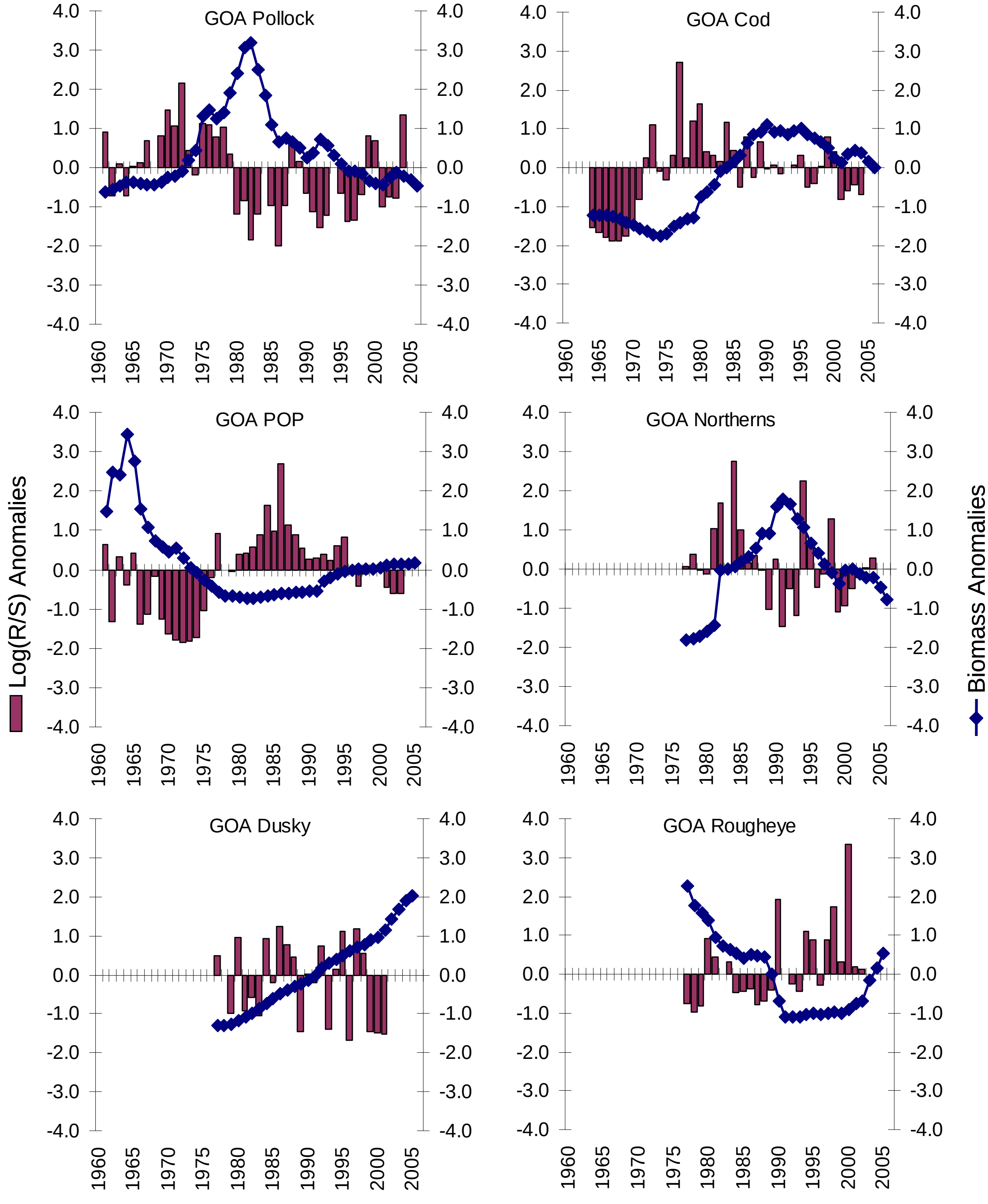

Figure 58. Median log recruit per spawning biomass anomalies and biomass anomalies for GOA groundfish species assessed with age- or size-structured models, 1960-2005. GOA = Gulf of Alaska, POP = Pacific ocean perch, Northerns = Northern rockfish, Dusky = Dusky rockfish, Rougheye = Rougheye rockfish.

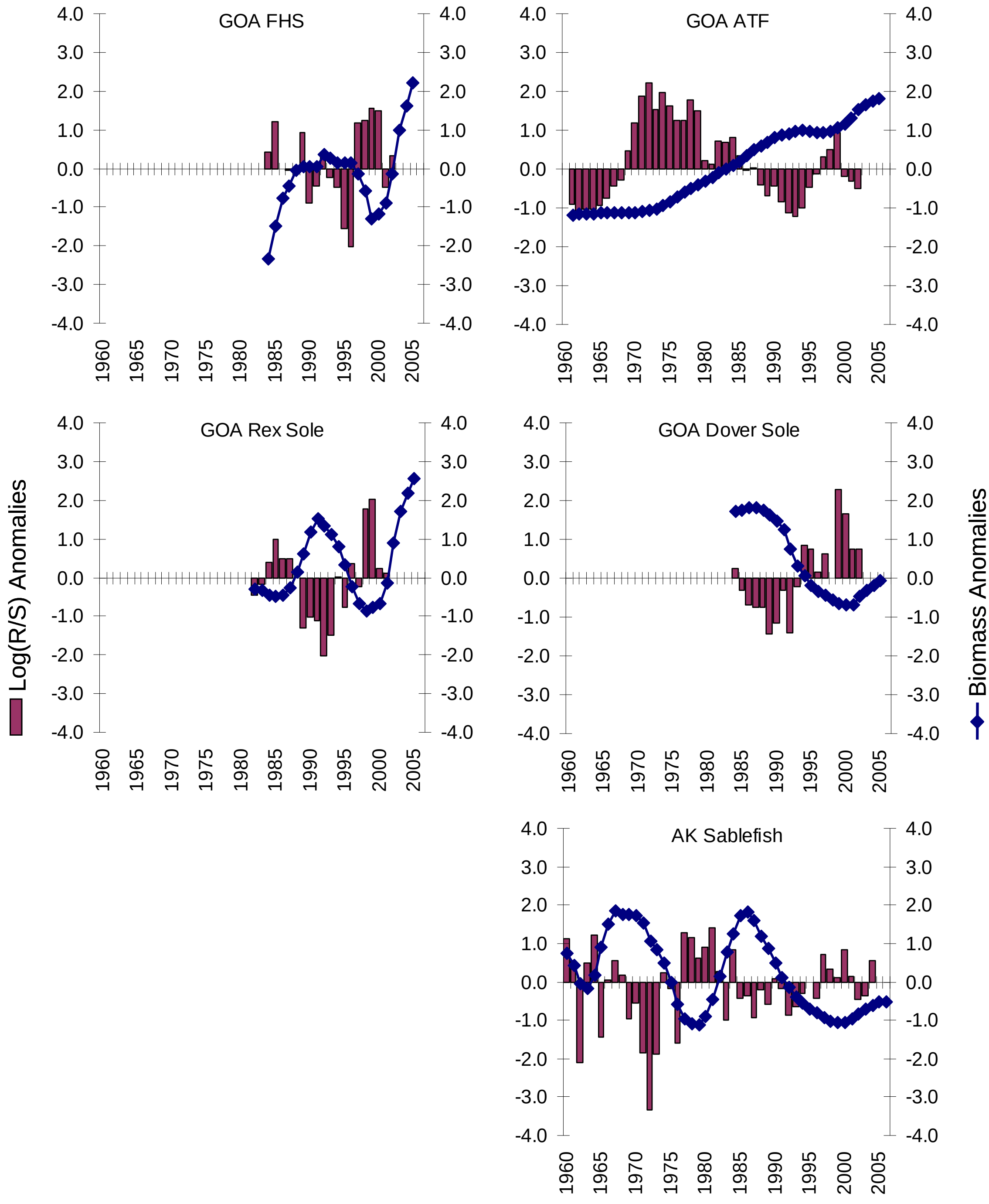

Figure 58 continued. Median recruit per spawning biomass anomalies and biomass anomalies for GOA groundfish species assessed with age- or size-structured models, 1960-2005. GOA = Gulf of Alaska, FHS = flathead sole, ATF = arrowtooth flounder, Rex = Rex sole.

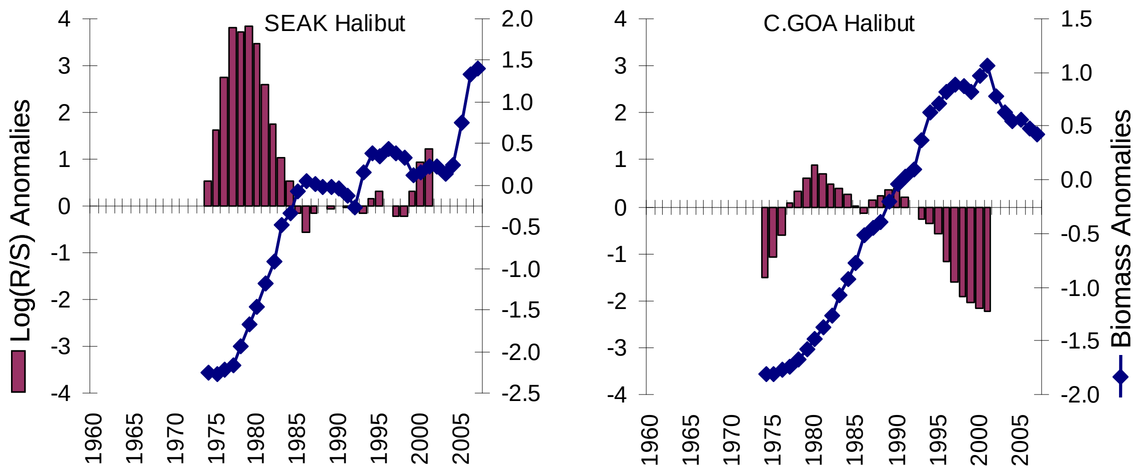

Figure 58 continued. Median log recruit per spawning biomass anomalies and biomass anomalies for halibut, 1974-2007. C.GOA = central Gulf of Alaska, SEAK = southeast Alaska.

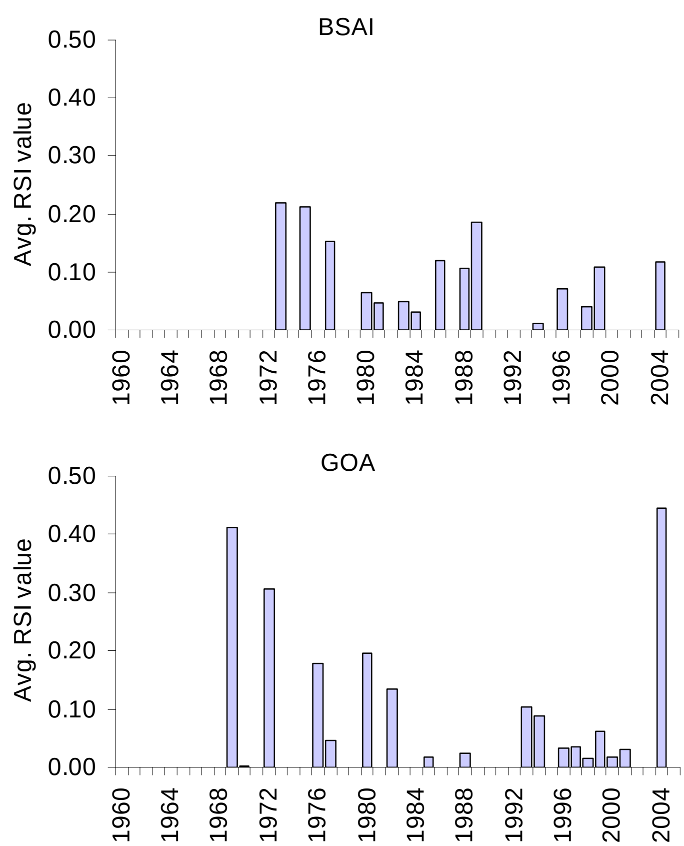

Figure 59. Average regime shift indices (RSI) values from the STARS (Rodionov 2005, Rodionov and Overland 2005) analysis (absolute values that indicate strength of step change) on log recruit per spawning biomass anomalies in each year for the BSAI and GOA.

Table 7. Years of significant step-changes in log-recruit per spawning biomass anomalies in the Bering Sea/Aleutian Islands (BSAI) and the Gulf of Alaska (GOA). Regular font represent years of positive changes, parentheses represent years of negative changes, and italics represent a significant step-change in the final year of the time series (i.e., likely to change with the addition of newer data).

BSAI	Years	GOA	Years
Pollock	(1983)	Pollock	1970, (1980), *2004*
Cod	1973, (1980)	Cod	1972, (2001)
FHS	(1986)	FHS	1997
ATF	(1989), 1998	ATF	1969, (1980), (1988), 1997
POP	1975, (1989)	POP	1976, (1996)
Northern rockfish	*(1996)*	Northern rockfish	
YFS	(1977), (1984)	Dusky rockfish	(1999)
GT	1999	Rougheye rockfish	1994
Rock sole	(1988), (1994)	Rex sole	1998
AK Plaice	(1981), 1996	Dover sole	1994
Atka mackerel	*(2005)*	SEAK Halibut	(1982), 2000
		CGOA Halibut	(1993)
		AK Sablefish	(1969), 1977, (1985)

Update on EBS winter spawning flatfish recruitment and wind forcing

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Last updated: August 2007

Wilderbuer et al. (2002) summarized a study examining the recruitment of winter-spawning flatfish in relation to decadal atmospheric forcing, linking favorable recruitment to the direction of wind forcing during spring. OSCURS model time series runs indicated in-shore advection to favorable nursery grounds in Bristol Bay during the 1980s. The pattern change to off-shore in the 1990- 97 time series coincided with below-average recruitment for northern rock sole, arrowtooth flounder and flathead sole, relative to the 1980s. The time series is updated (2001-2007; Figure 60) for the last 7 years.

Five out of seven OSCURS runs for 2001-2007 were consistent with those which produced above-average recruitment in the original analysis, 2005 and 2007 being the exceptions. The north-northeast drift pattern suggests that larvae may have been advected to favorable, near-shore areas of Bristol Bay by the time of their metamorphosis to a benthic form of juvenile flatfish. Preliminary estimates of rock sole recruitment in recent years are consistent with this larval drift hypothesis (Figure 60). For arrowtooth flounder and flathead sole, the correspondence between the springtime drift pattern from OSCURS and estimates of year class strength have weakened since the 1990s. Arrowtooth flounder produced year classes of average strength during some off-shore drift years, suggesting that this species may have different settlement preferences than northern rock role. In the case of flathead sole, weak recruitment has persisted since the 1990s with no apparent response to the surface wind advection pattern.

The end point of the drift trajectory in 2007 was offshore; therefore, recruitment strength for the 2007 year class of northern rock sole may be weak.

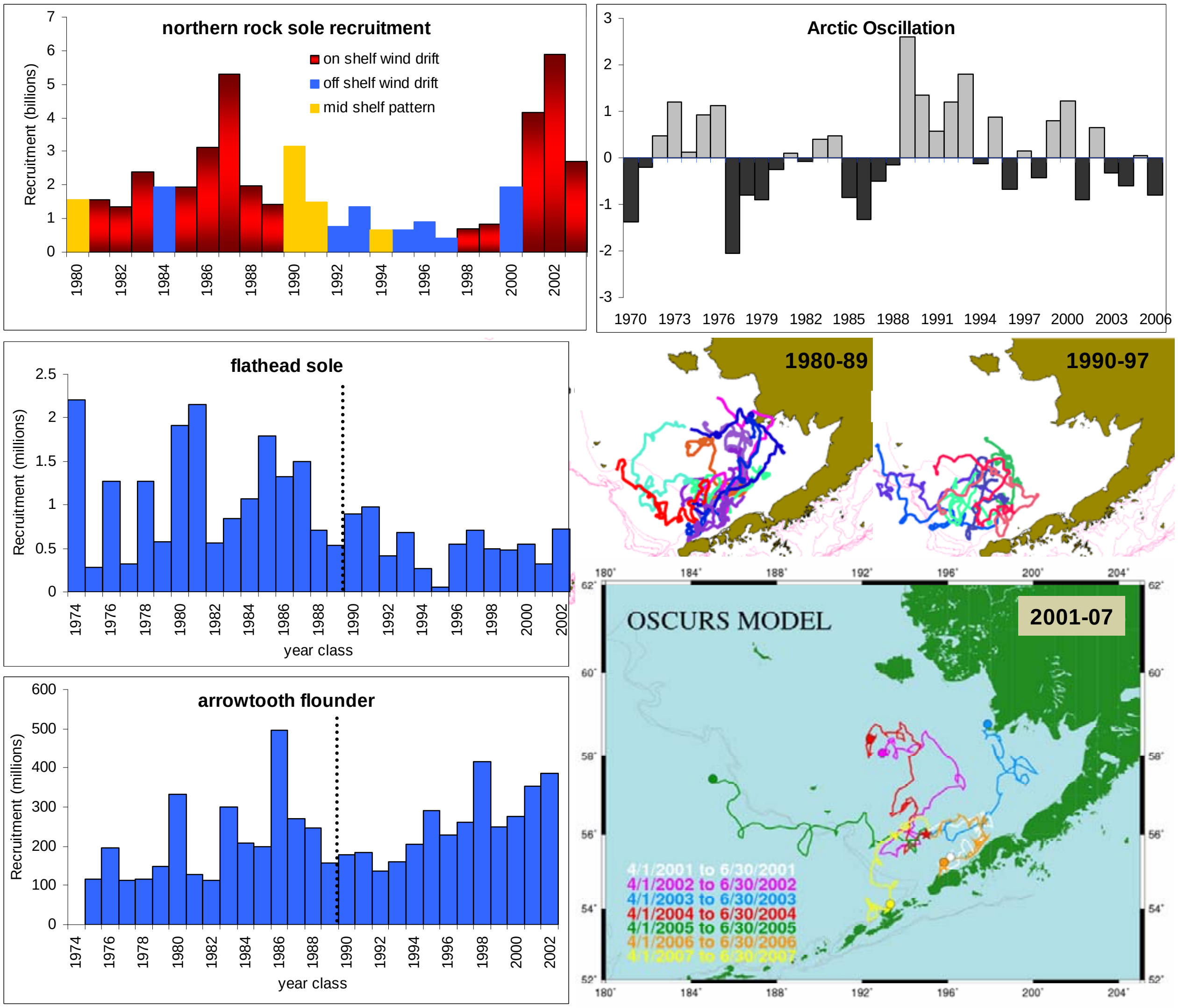

Figure 60. The left column shows recruitment of northern rock sole (1974-2003), flathead sole (1974-2002), and arrowtooth flounder (1974-2002) in the Bering Sea. The right column shows the Arctic Oscillation index (1970-2006), along with OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56° N, 164° W from April 1-June 30 for three periods: 1980-89, 1990-97, and 2001-2007.

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

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Last updated: September 2005

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Benthic Communities and Non-target Fish Species

ADF&G Gulf of Alaska Trawl Survey

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Last updated: November 2006

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Gulf of Alaska Small Mesh Trawl Survey Trends

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Last updated: November 2006

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Bering Sea Crabs

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Last updated: October 2006

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Stock-recruitment relationships for Bristol Bay red king crabs

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Last updated: October 2007

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

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

and an autocorrelated Ricker curve:

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

where

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

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

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

Generally, strong recruitment occurred with intermediate levels of effective spawning biomass, and very weak recruitment was associated with extremely low levels of effective spawning biomass (Figure 61). 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=0.48, *df*=29) was used to describe the density-dependent relationship, and the autocorrelated Ricker curve (R^2=0.47, *df*=29) was used to depict the autocorrelation effects. Because the autocorrelated curve regards the strong recruitment during the late 1960s and early 1970s as a result of autocorrelation, the recruitment associated with intermediate effective spawning biomass is much lower for the autocorrelated curve than for the general curve. Likewise, because the autocorrelated curve is less density-dependent, it has much higher recruitment than the general curve when effective spawning biomass is very high. The autocorrelation parameter fit the residuals well only before the 1982 year class and then fit the residuals poorly. As expected, recruitment levels as a function of the spawning stock are lower from the S–R curve estimated with the data after 1976 than those estimated with all data.

The S–R curves estimated with mature male biomass on February 15 have overall lower recruitment levels than those estimated with effective spawning biomass (Figure 61). The S–R curves fit the data better with effective spawning biomass than with mature male biomass (R^2=0.37, *df*=29 for the general curve and R^2=0.44, *df*=29 for the autocorrelated curve).

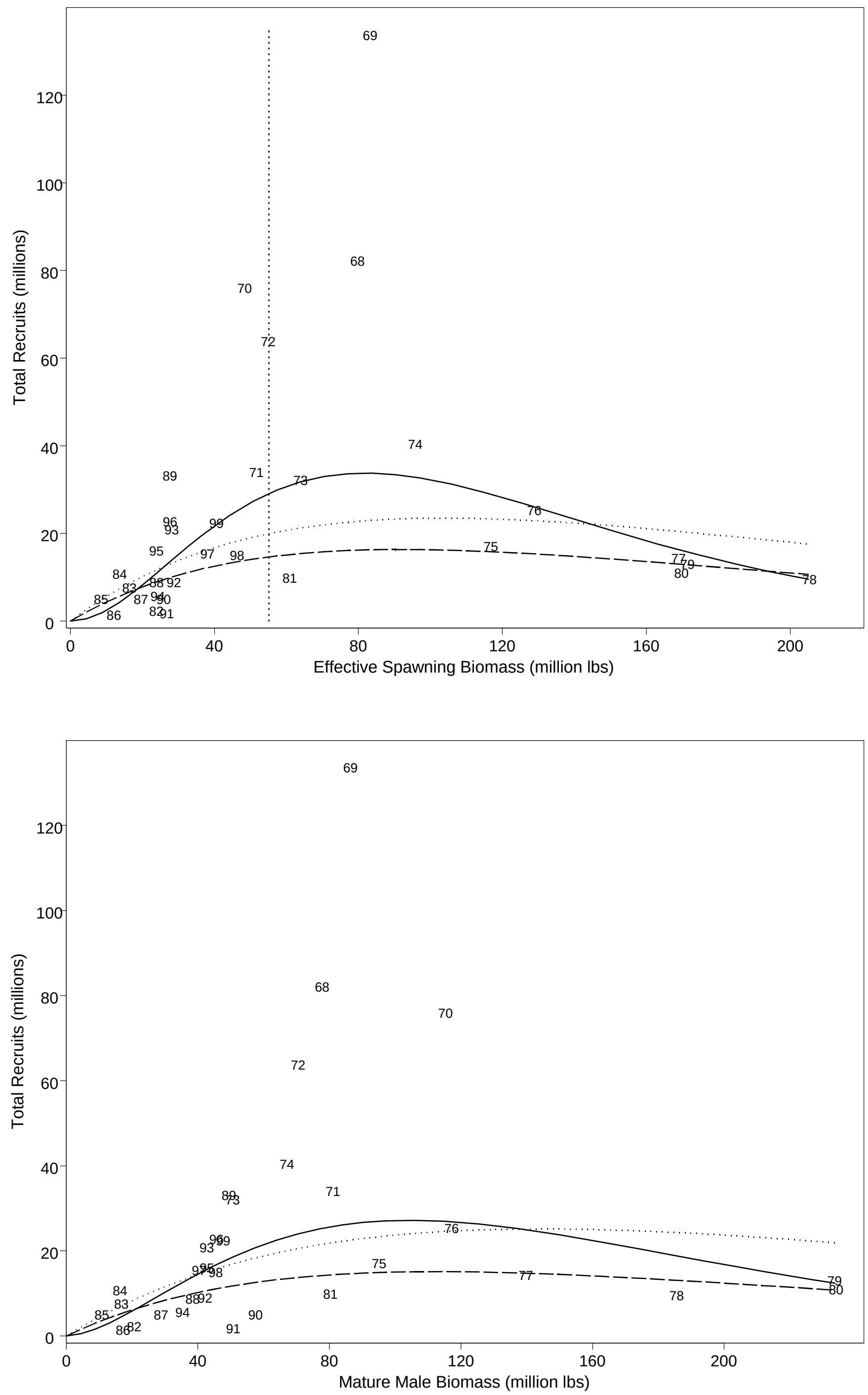

Figure 61. Relationships between effective spawning biomass and total recruits (upper panel) and between mature male biomass on Feb. 15 and total recruits at age 7 (i.e., 8-year time lag) (lower panel) for Bristol Bay red king crabs. Numerical labels are years of mating, the solid line is a general Ricker curve, the dotted line is an autocorrelated Ricker curve without υ_t values (equation 2), and the dashed line is a Ricker curve fit to recruitment data after 1976 brood year. The vertical dotted line is the targeted rebuilding level of 55 million lbs effective spawning biomass.

Miscellaneous Species – Gulf of Alaska

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Last updated: October 2007

RACE bottom trawl surveys in the Gulf of Alaska (GOA) are designed primarily to assess populations of commercially important fish and invertebrates. However many other species are identified, weighed and counted during the course of these surveys and these data may provide a measure of relative abundance for some of these species. Many of these species are not sampled well by the gear or occur in areas that are not well sampled by the survey (hard, rough areas, mid-water etc.) and are therefore encountered in small numbers which may or may not reflect their true abundance in the GOA. The fishing gear used aboard the Japanese vessels that participated in all GOA surveys prior to 1990 was very different from the gear used by all vessels since. This gear difference almost certainly affected the catch rates for some of these species groups. Apparent abundance trends for a few of these groups are shown in Figure 62. For each species group, the largest catch over the time series was arbitrarily scaled to a value of 100 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error.

Despite the numerous caveats, a few general patterns of abundance are discernible from the data (Figure 62). Echinoderm abundances have generally been highest in the central GOA and their mean catch per unit effort (CPUE) has increased dramatically in this area since 1987. The percentage of hauls with echinoderms has also increased over time, leveling off in recent years at a very high percentage of tows in all areas, in a pattern remarkably similar to that found in the Aleutian Islands.

The abundance of jellyfish has generally been higher in the central and eastern GOA than in the western GOA, although jellyfish abundance was quite low in 2007 compared to previous survey years. The highest jellyfish abundance seen in the GOA time series was in 1990. Eelpout mean CPUE has consistently increased over time, particularly in the eastern GOA. Both poacher mean CPUE and rates of capture seems to consistently increase from east to west.

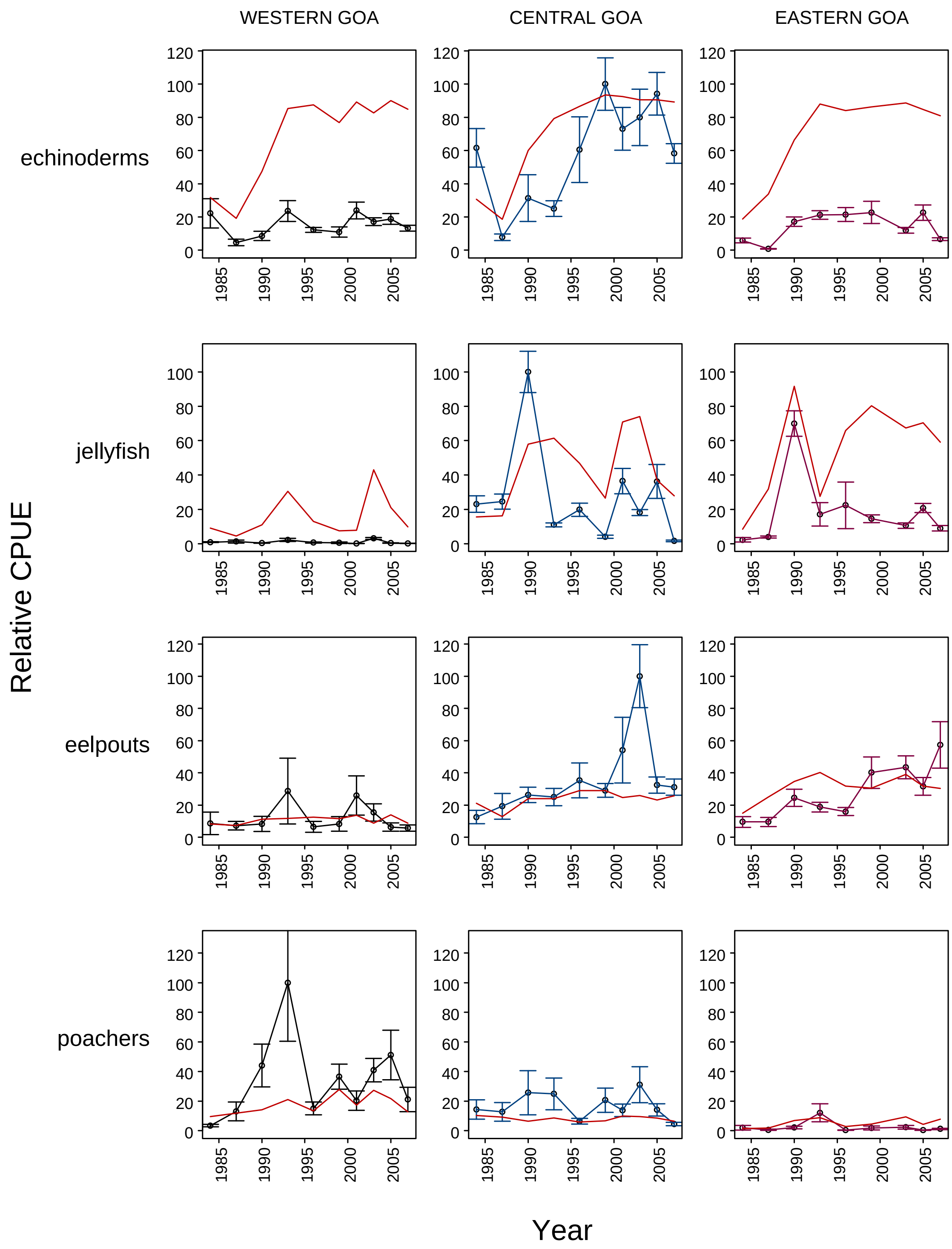

Figure 62. Relative mean CPUE of miscellaneous species by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2007. Error bars represent standard errors. The red lines represent the percentage of non-zero catches.

Jellyfish – Eastern Bering Sea

Contributed by Robert Lauth, Alaska Fisheries Science Center
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Last updated: November 2007

The time series of jellyfish caught as bycatch in the annual Bering Sea bottom trawl survey was updated for 2007 (Figure 63). The largest catch over the time series was arbitrarily scaled to a value of 1 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error. The trend for increasing relative CPUE that began around 1989 reported by Brodeur et al. (1999) did not continue in 2001-2007. The relative CPUE of jellyfish decreased dramatically in 2001 and the relative CPUE has since remained close to levels seen in the 1980s and early 1990s. It should be noted, however, that jellyfish were often thrown out and not quantified in the early part of the time series. Outbursts in jellyfish populations, such as the one in 2000, may be related to shifts in the physical or biological conditions on the eastern Bering Sea shelf such as climate change.

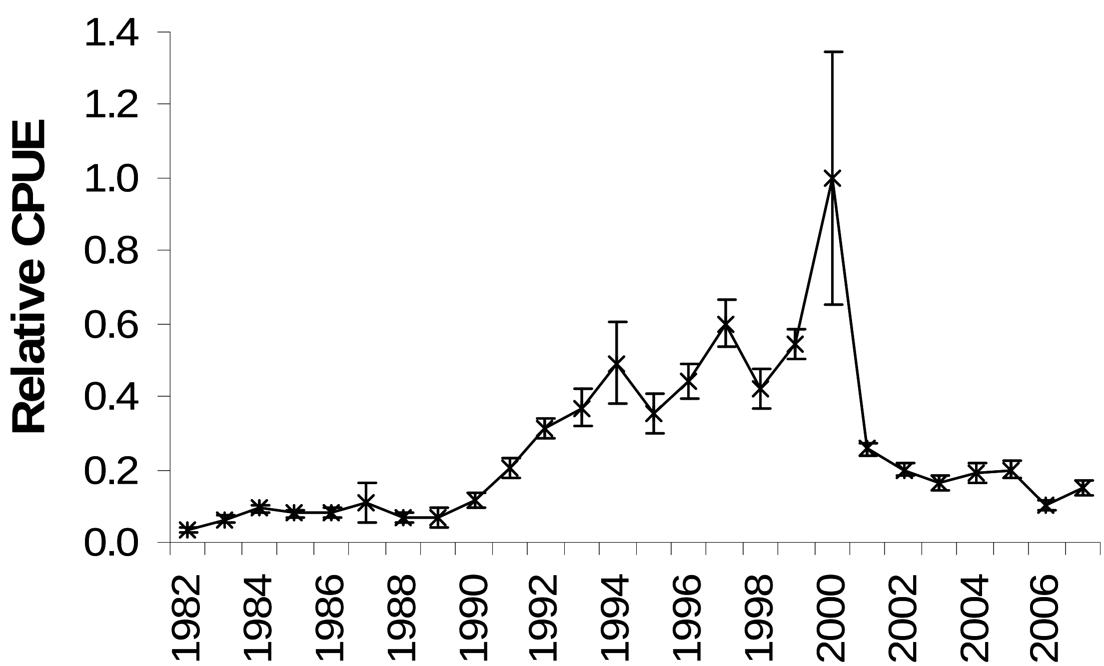

Figure 63. Relative CPUE of large medusae during the summer in the eastern Bering Sea from the NMFS bottom trawl survey, 1982-2007. Data points are shown with standard error bars.

Trends in Jellyfish Bycatch from the Bering Aleutian Salmon International Survey (BASIS)

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Last updated: August 2007

Jellyfish sampling was incorporated aboard the US BASIS (Bering Aleutian Salmon International Surveys) vessels beginning in 2004 and continued through 2007. All jellyfish medusae caught in the surface trawl (top 18 m of water column) are sorted by species and subsampled for bell diameter and wet weight. Six species are commonly caught with the surface trawl: *Aequorea sp., Chrysaora melanaster, Cyanea capillata, Aurelia labiata, Phacellocephora camtschatica,* and *Staurophora mertensi*. Distributions have been patchy for all species in the sampling grid for each year. Highest concentrations of all species combined, were found to occur in the Middle Shelf Domain, although distributions throughout the domain were uneven for all years (Figure 64). Of the six species sampled, *Chrysaora melanaster* had the highest density for all years, followed by *Aequorea sp., Cy. capillata, S. mertensi, A. labiata, and P. camtschatica* (Figure 65). Notable declines in jellyfish biomass for five of the species were observed in 2006 compared to 2004 and 2005. Only *P. camtschatica* had a recorded increase in biomass in 2006.

As 2006 has been described as a cold year, the decline in jellyfish biomass may be partially attributed to a decline in zooplankton and other prey availability, as suggested by Hunt's Oscillating Control Hypothesis (Hunt et al. 2002). Physical ocean factors (temperature and salinity) alone do not seem to be causing shifts in biomass distributions but environmental forcing earlier in the growing season or during an earlier life history stage (polyp) may influence large medusae biomass and abundances.

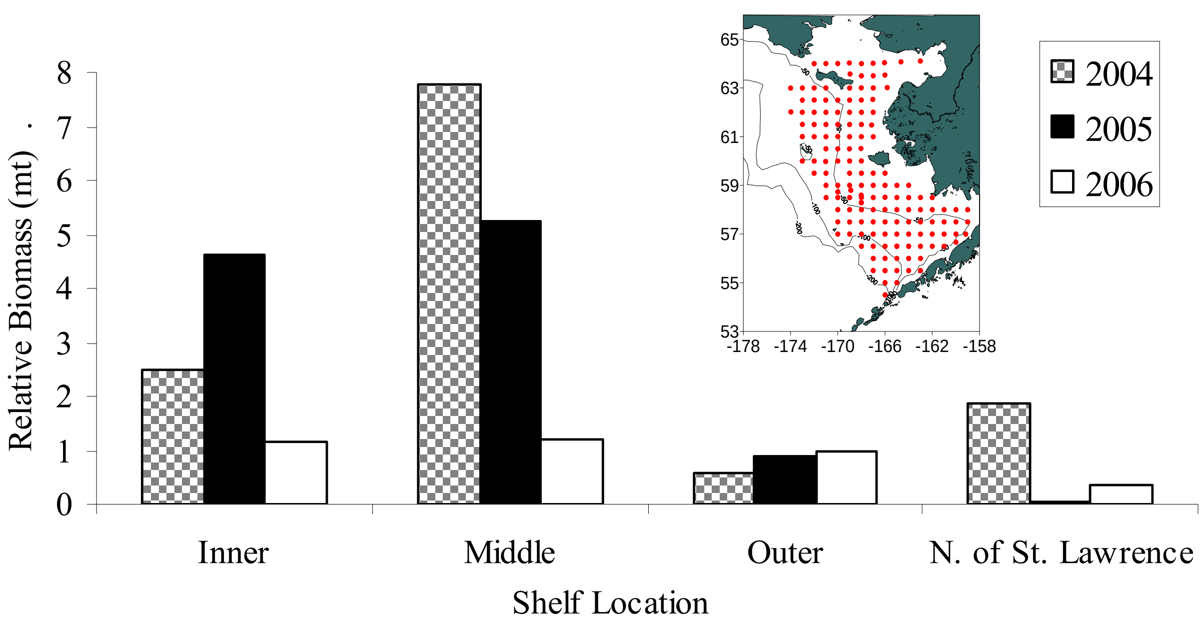

Figure 64. Relative biomass by year for each shelf location in the Eastern Bering Sea. Relative biomass is defined as the total weight of a particular species in a 30 minute trawl. Shelf locations (domains) are by depth, Inner 0-50m, Middle 50-100m, and Outer >100m. North of St. Lawrence is all stations sampled above 64° N latitude. Numbers above bars indicate sample size.

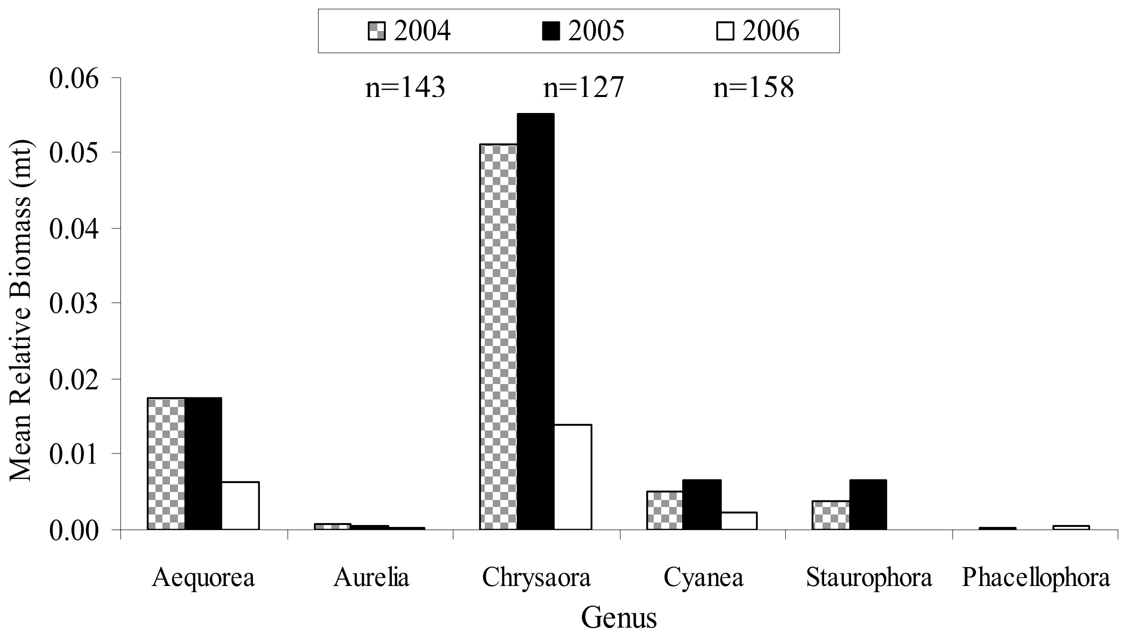

Figure 65. Mean relative biomass (mt) by genus for 2004-2006 in the Eastern Bering Sea. Relative biomass is defined as the total weight of a particular species in a 30 minute trawl. Sample size (n) is indicated below figure key.

Miscellaneous species - Eastern Bering Sea

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Last updated: November 2007

Three species of eelpouts are predominant on the eastern Bering Sea shelf: marbled eelpout (*Lycodes raridens*), wattled eelpout (*L. palearis*) and shortfin eelpout (*L. brevipes*). For each species group, the largest catch over the time series was arbitrarily scaled to a value of 1 and all other values were similarly scaled. The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error. The relative CPUE of this group appeared higher in the early 1980s than in the late 1980s to present (Figure 66), and there was a significant drop in relative CPUE from 2006 to 2007 to the lowest level since 2002. More detailed analyses are underway to investigate the distribution patterns of marbled eelpout in relation to habitat, oceanography, and climate. The relative CPUE of poachers is dominated by the sturgeon poacher (*Podothecus acipenserinus*) and was low in the early 1980s but increased in the late 1980s to the mid-1990s. The relative CPUE appeared to be on the rise since 2000 but took a sharp turn downward in 2006 and remained at a similar level in 2007 (Figure 66). The composition of echinoderms in trawl catches on the shelf are dominated by the purple-orange seastar (*Asterias amurensis*), which is found primarily in the inner/middle shelf regions, and the common mud star (*Ctenodiscus crispatus*), which is primarily an inhabitant of the outer shelf. The relative CPUE values for the echinoderm group have remained fairly level since 2001 but were lowest in 1985, 1986, and 1999, and highest in 1997. Fully understanding relative CPUE trends of eelpouts, poachers, and echinoderms will require more specific research on survey trawl gear selectivity and on the life history characteristics of each species.

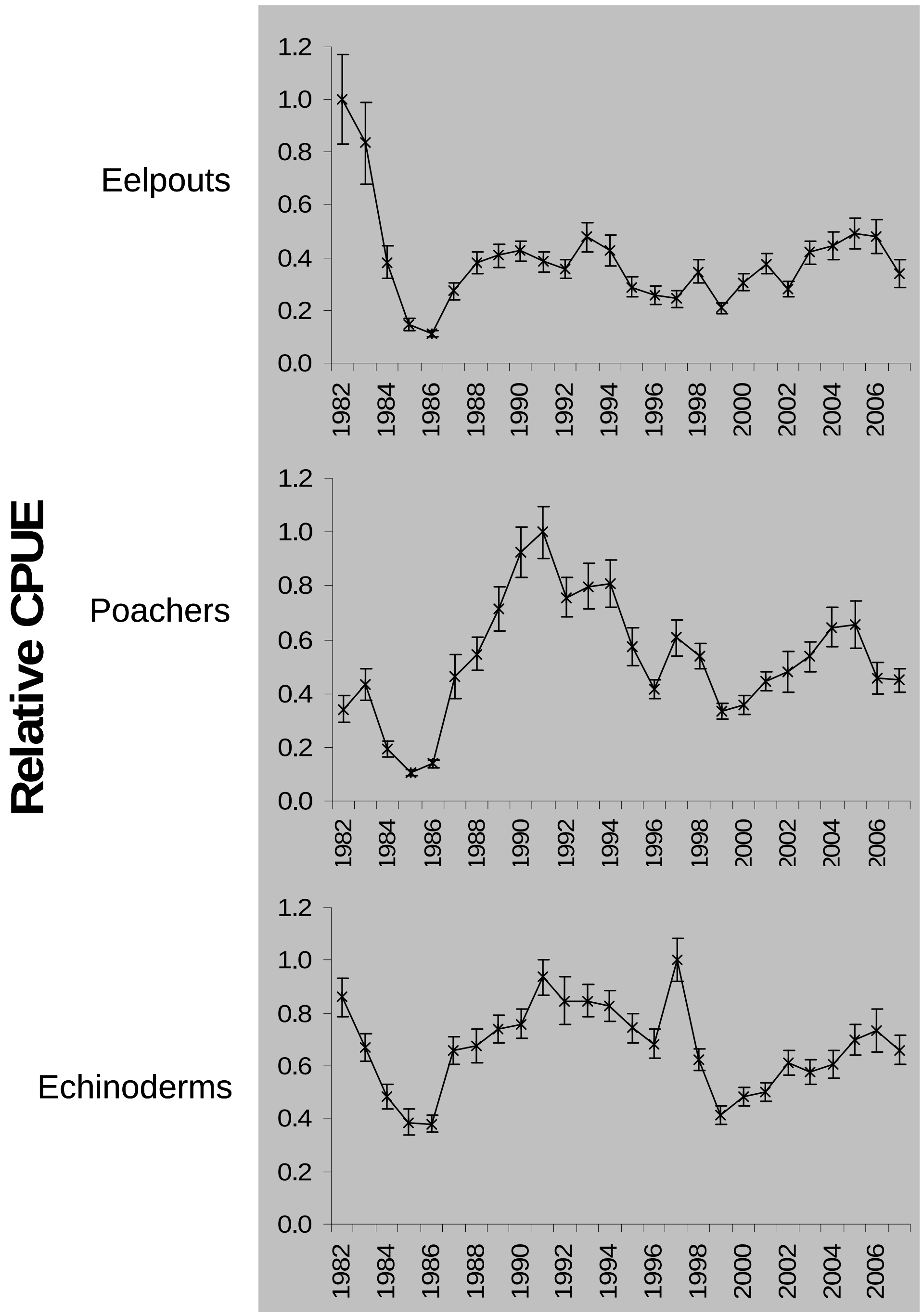

Figure 66. Relative CPUE of miscellaneous species caught in the eastern Bering Sea summer bottom trawl survey, 1982-2007. Data points are shown with standard error bars.

Miscellaneous Species– Aleutian Islands

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Last updated: November 2006

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Marine Mammals

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Last updated: October 2007

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 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.

Pinnipeds

Steller sea lion (*Eumetopias jubatus*) **Last updated: October 2007**

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In November 1990, the NMFS listed Steller sea lions as "threatened" range-wide under the U.S. Endangered Species Act (55 Federal Register 49204, November 26, 1990) in response to a population decrease of 75% during the previous 15-year period in the core of their range in the Aleutian Islands and Gulf of Alaska. By 1997, two population stocks were identified, based largely on differences in genetic identity, but also on regional differences in morphology and population trends (Bickham et al. 1996, Loughlin 1997). The western stock, which occurs from 144°W (approximately at Cape Suckling, just east of Prince William Sound, Alaska) westward to Russia and Japan, was listed as "endangered" in June 1997 (62 Federal Register 24345, May 5, 1997). The eastern stock, which occurs from Southeast Alaska southward to California, remained classified as threatened. Population assessment for Steller sea lions is currently achieved by aerial photographic surveys of non-pups (adults and juveniles at least 1 year-old) and pups, supplemented by on-land pup counts at selected rookeries each year (Figure 67). Trends in the non-pup western stock in Alaska are monitored by surveys at groups of 'trend sites' (all rookeries and major haul-outs) that have been surveyed consistently since the mid-1970s (N=87 sites) or 1991 (N-161 sites). To investigate spatial differences in population trends, counts at trend sites within sub-areas of Alaska are monitored (Figure 68).

A. Adult and Juvenile (Non-Pup) Steller sea lions

The last complete aerial survey of non-pups in the endangered western Steller sea lion population in Alaska (from Cape St. Elias, 144°W to Attu Island, 172°E) was conducted by NMFS in June 2004. This was the first survey to use medium format (MF), vertical photogrammetric techniques. In previous years, counts of non-pups 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. Non-pup surveys were conducted in both 2006 (MF) and 2007 (MF and vertical digital photography), but neither was complete across the entire range of the western stock in Alaska (sub-areas 2-7 in Figure 68). In 2007, NMFS surveyed all or all but one of the 1990s trend sites in four of the six Alaskan sub-areas:

- All in the eastern Gulf of Alaska (E GULF: 145°-150°W; N=13)
- Missing one (Long Island) in the central Gulf of Alaska (C GULF: 150°-157°W; N=32 of 33)
- Missing one (Kak Island) in the western Gulf of Alaska (W GULF: 157°-163°W; N=19 of 20) and
- Missing one (Umnak/Cape Aslik) in the eastern Aleutian Islands (E ALEU: 163°-169°W; N=26 of 27) (Tables 1 and 3).

There was no survey effort in the western Aleutian Islands (W ALEU: 172°-177°E) in 2007, while in the central Aleutian Islands (C ALEU: 169°W – 177°E), survey effort was limited to the eastern portion between Yunaska and Tanaga Islands (170.5°-178°W), with very little effort occurring west of Amchitka Pass. This enabled the creation of an eastern portion of the C ALEU sub-area for comparison of 2004 and 2007 counts at all 1990s trend sites except Chagulak. In addition, trends within eastern and western portions of the C ALEU were compared.

NMFS estimated that the western Steller sea lion population increased approximately 11-12% from 2000 to 2004 (Fritz and Stinchcomb 2005). Although counts at some trend sites are missing for both 2006 and 2007, available data indicate that the size of the adult and juvenile portion of the western Steller sea lion population throughout much of its range (E GULF through the eastern portion of the C ALEU; Cape St. Elias to Tanaga Island, 145°-178° W) in Alaska has remained largely unchanged between 2004 (N=23,107) and 2007 (N=23,118; Figure 67A and 67B and Table 8A). This was the same general conclusion reached following the incomplete survey of 2006. However, there are significant regional differences in recent trends: increases between 2004 and 2007 in the E ALEU, W GULF and C GULF have largely been offset by decreases in the eastern C ALEU and E GULF. Winship and Trites (2006) also noted that significant differences in regional trends could affect the species' ability to occupy its present range in the future.

Counts in the eastern C ALEU increased 49% between 1996 and 2004 (Figure 67C). Because counts in the western portion of the C ALEU declined steadily between 1991 and 2002, increasing counts in the eastern C ALEU were responsible for the relatively stable counts observed in the C ALEU as a whole since the mid-1990s (Figure 67B). Counts in 2004 and 2006 in the western C ALEU and the W ALEU suggest that the western Steller sea lion population between Amchitka Pass and Attu Island continues to decline (Table 8B). Declining trends in Alaska west of Amchitka Pass combined with largely stable numbers from Cape St. Elias through Amchitka Pass indicate that the overall trend for the wDPS in Alaska (through 2007) is either stable or declining slightly. This is the same conclusion reached by Holmes et al (2007) based on age-structured modeling of the C GULF Steller sea lion population.

B. Steller sea lion pup production

The most recent complete Steller sea lion pup production survey in Alaska was conducted in June-July 2005. During 2005, pups were counted (1) from medium format photographs taken vertically during an aerial survey conducted from Dixon Entrance at 133°W to Attu Island at 172°E) and (2) during visits to selected rookeries from the eastern Aleutian Islands (169°W) to Prince William Sound (147°W) during a pup branding and assessment cruise; both survey efforts were conducted by NMFS. In cases where both aerial and ground counts were available, the maximum pup count at the site was used to assess trends. Based on the surveys in 2005, a total of 9,951 pups were counted within the range of the western stock in Alaska. This number is thought to represent a nearly complete census of pups in 2005. Holmes and York (2003) and Holmes et al (in press) estimated that 95% of all pups in the C GULF region were born (and counted) on rookeries, and the 2005 survey included all rookeries and major haulouts in Alaska where at least 10 pups had been counted in the past.

Steller sea lion pup production at western stock trend rookeries in the Kenai to Kiska area (C GULF west through C ALEU; Figure 68) declined 40% in the 1990s (Figure 69). However, from 2001 to 2005, there were small increases in pup numbers of 4% (+265 pups) at trend rookeries in the Kenai to Kiska area and 3% (+239 pups) across the range of the western stock in Alaska. These recent trends in pup counts, while encouraging, were less than those observed in non-pup counts from 2000 to 2004, which increased 11-12% (Fritz and Stinchcomb 2005). The ratio of pups to non-pups (at trend sites) has declined steadily since the early 1990s, and may reflect a decline in the reproductive rates of adult females (Holmes and York 2003; Holmes et al., in press).

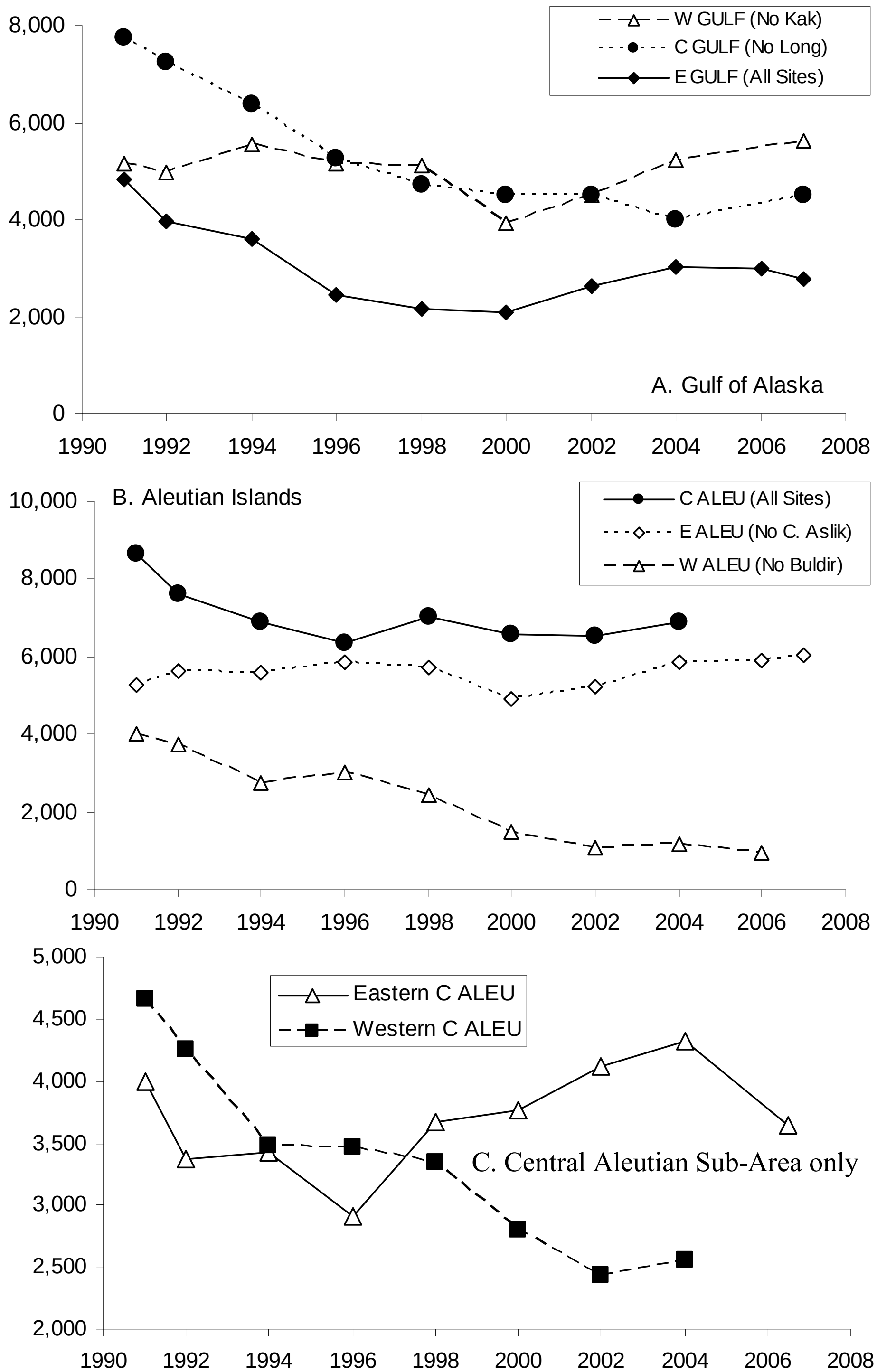

Figure 67. Counts of non-pup (adult and juvenile) Steller sea lions on rookery and haulout trend sites in the range of the western population from 1991-2007. Counts are aggregated by sub-area in the A.Gulf of Alaska and B. Aleutian Islands. Counts in the central Aleutian subarea are divided between eastern and western portions in C. Surveys in 1991-2002 used 35 mm oblique slides, while the 2004 and 2006 surveys used medium format vertical photographs. Counts in 2004, 2006, and 2007 displayed above have been reduced 3.64% from the actual count to account for the format differences.

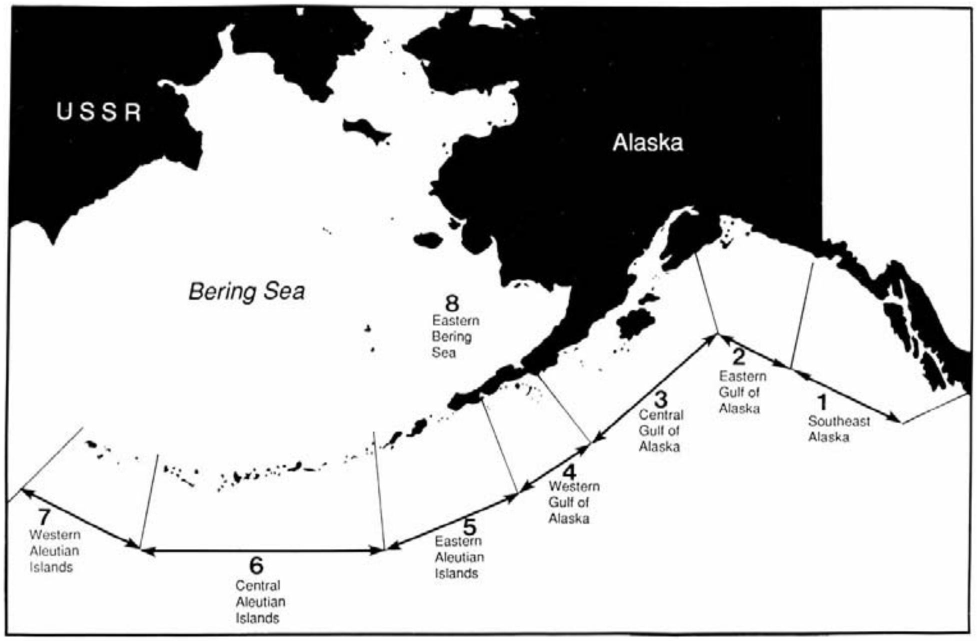

Figure 68. Map of Alaska showing areas within the range of the western Steller sea lion (subareas 2-7) surveyed in 2004.

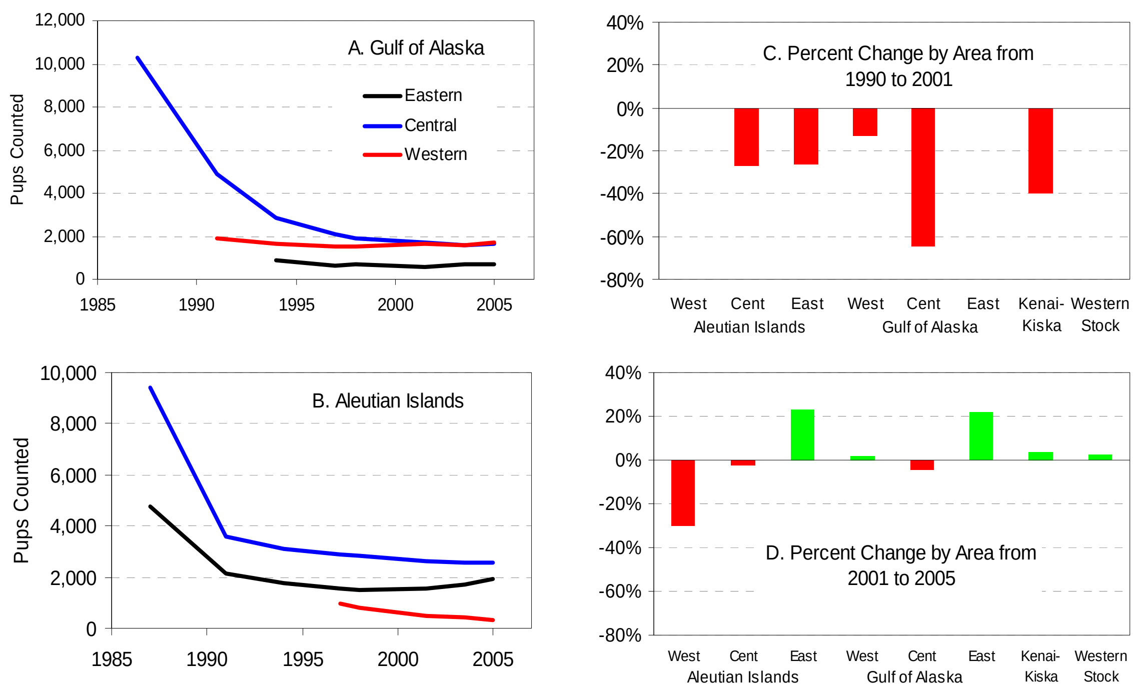

Figure 69. Steller sea lion pup counts at trend rookeries in the range of the western stock in Alaska by region from the late 1980s to 2005 in the Gulf of Alaska (A) and Aleutian Islands (B). Percent change in counts between 1990/92 and 2001/02 (C) and 2001/02 and 2005 (D) are also shown.

Table 8A. Counts of adult and juvenile (non-pup) Steller sea lions observed at rookery and haulout trend sites surveyed consistently since 1991 (N=161) in six sub-areas of the Alaskan range of the western stock during June and July aerial surveys from 1991 to 2007. Counts through 2002 were made visually or from 35 mm slides shot obliquely out the side windows of aircraft. Counts in 2004-2007 were made from medium format or digital photographs shot vertically over rookery and haulout sites. Comparison studies suggest that counts from vertical medium format/digital photographs are approximately 3-4% greater than from 35 mm photographs; adjusted sub-area counts in 2004-2007 are listed.

	Gulf of Alaska				Aleutian Islands			
Year	Eastern	Central	Western	Total	Eastern	Central	Western	Total
1991	4,812	7,872	5,338	18,022	5,283	8,656	4,601	18,540
1992	3,981	7,358	5,112	16,451	5,707	7,633	4,199	17,539
1994	3,612	6,505	5,718	15,835	5,664	6,909	3,114	15,687
1996	2,450	5,400	5,356	13,206	5,967	6,368	3,334	15,669
1998	2,158	4,806	5,367	12,331	5,774	7,017	2,786	15,577
2000	2,102	4,555	3,996	10,653	4,990	6,560	1,633	13,183
2002	2,615	4,594	4,617	11,825	5,261	6,547	1,196	13,004
2004	3,015	4,028	5,233	12,276	5,991	6,885	1,286	14,162
2006	3,101				5,973			
2007	2,760							

Table 8B. Counts of adult and juvenile (non-pup) Steller sea lions observed at rookery and haulout trend sites surveyed in 2004, 2006, and 2007 in six sub-areas of the Alaskan range of the western stock. Counts are un-adjusted counts from medium-format or digital vertical photographs.

Sub-Area	2004	2006	2007	Comments
E GULF	3,129	3,218	2,865	
C GULF	4,148		4,688	Missing Long Island
W GULF	5,414		5,845	Missing Kak Island
E ALEU	6,098	6,186	6,261	Missing Umnak/Cape Aslik
Eastern C ALEU	4,318		3,460	Yunaska-Tanaga only; No Chagulak Island
Total	**23,107**		**23,118**	
W ALEU	1,227	997		Missing Buldir Island

Northern fur seal (*Callorhinus ursinus*) **Last updated: October 2007**

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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.

NMFS estimated that 127,008 pups were born on the Pribilof Islands in 2006: 109,937 (SE = 1,521) pups were born on St. Paul Island and 17,070 (SE = 144) pups were born on St. George Island. Pup production on St Paul Island has been declining since the mid-1990s (Figure 70; Towell et al. 2006), and was 43% less in 2006 than in 1994. Pup production on St George was relatively stable between 2002 and 2006, but declined 23% between 1994 and 2006. Estimated pup production on both Pribilof Islands in 2006 was similar to the level observed in 1916; however the population trend at the beginning of the 20th century was much different than at beginning of the 21st. In 1916, the northern fur seal population was increasing at approximately 8% per year following the cessation of extensive pelagic sealing, while currently (1998 through 2006), pup production on both Pribilof Islands is estimated to be decreasing at approximately 6% per year. The trend in pup production on Bogoslof Island in the 1990s has been opposite those observed on the Pribilofs (Figure 70). Pup production increased at approximately 20% per year on Bogoslof Island between 1995 and 2007. This rate is faster than what could be expected from a completely closed population of fur seals, indicating that at least some of it is due to females moving from the Pribilof Islands (presumably) to Bogoslof to give birth and breed. However, declines observed on the Pribilof Islands are much greater than the increase in numbers on Bogoslof, indicating that the decline on the Pribilofs cannot be due entirely to emigration. Differences in trends between the predominately shelf-foraging Pribilof fur seals and the predominately pelagic-foraging Bogoslof fur seals are unlikely related to large-scale spatio-temporal changes in the North Pacific Ocean (e.g., regime shifts, Pacific Decadal Oscillation), since these populations are almost entirely sympatric.

The observed pup mortality rates of 4.5% on St. Paul Island and 4.2% on St. George Island in 2006 were relatively low, but 1-2% higher than estimates obtained in 2004.

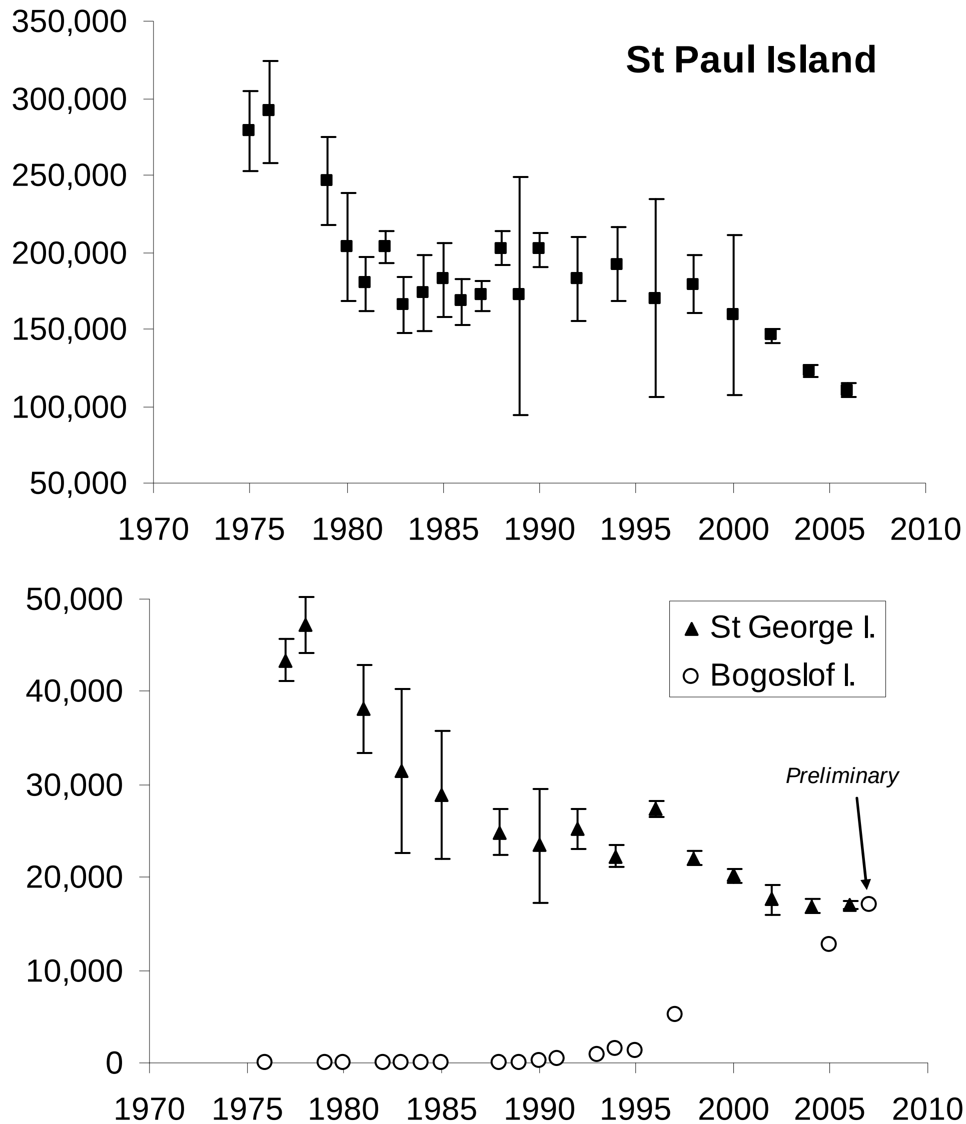

Figure 70. Northern fur seal pups born on the Pribilof Islands (St Paul and St George Islands) and Bogoslof Island, 1975-2007. Error bars are approximate 95% confidence intervals.

Harbor Seals (*Phoca vitulina*) **Last updated: October 2007**

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Geographic Range and Stocks

Harbor seals inhabit coastal and estuarine waters off Baja California, north along the western coasts of the United States, British Columbia, and Southeast Alaska, west through the Gulf of Alaska and Aleutian Islands, and in the Bering Sea north to Cape Newenham and the Pribilof Islands. They haul out on rocks, reefs, beaches, and drifting glacial ice, and feed in marine, estuarine, and occasionally fresh waters. Harbor seals generally are non-migratory, with local movements associated with such factors as tides, weather, season, food availability, and reproduction (Scheffer and Slipp 1944, Fisher 1952, Bigg 1969, Bigg 1981). The results of recent satellite tagging studies in Southeast Alaska, Prince William Sound, and Kodiak are also consistent with the conclusion that harbor seals are non-migratory (Swain et al. 1996, Lowry et al. 2001, Small et al. 2001). However, some long-distance movements of tagged animals in Alaska have been recorded (Pitcher and McAllister 1981, Lowry et al. 2001, Small et al. 2001). Strong fidelity of individuals for haulout sites in June and August also has been reported, although these studies considered only limited areas during a relatively short period of time (Pitcher and Calkins 1979, Pitcher and McAllister 1981).

Westlake and O'Corry-Crowe's (2002) analysis of genetic information revealed population subdivisions on a scale of 600-820 km. These results suggest that genetic differences within Alaska, and most likely over their entire North Pacific range, increase with increasing geographic distance. New information revealed substantial genetic differences indicating that female dispersal occurs at region specific spatial scales of 150-540 km. This research identified 12 demographically independent clusters within the range of Alaskan harbor seals; however additional research is required as un-sampled areas within the Alaskan harbor seal range remain (O'Corry-Crowe et al. 2003).

Three separate stocks are currently recognized in Alaska waters: 1) the Southeast Alaska stock - occurring from the Alaska/British Columbia border to Cape Suckling, Alaska (144EW), 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. The data presented here on statewide abundance and stock trends refers to these three stocks. However, further genetic information continues to provide evidence of greater population structure. NMFS is currently working with Native Alaskan co-managers to develop new stock definitions. Until these stocks are defined, any formal stock assessment is on hold. Once the stocks have been defined and assessments completed, information will be available through the NMFS Stock Assessment Reports.

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 1998 and 2002, with one region surveyed per year. The current statewide population estimate for Alaskan harbor seals is 156,418 (Table 9). This estimate includes counts at both terrestrial and glacial ice sites and also inflates the estimate to account for seals in the water at the time of survey. The estimates presented in Table 9 are updated values from those reported in the latest stock assessment report. Publication of these estimates is currently in preparation (Boveng et al., in prep.)

Table 9. Provisional regional and statewide population estimates for Alaskan harbor seals (subject to revision as part of analyses that are currently underway).

Stock	Region	No. of Seals	SE(No. of Seals)
SE Alaska	Southern Southeast (1998)	47,051	6,227.7
Gulf of Alaska	Aleutians (1999)	9,113	1,743.1
Bering Sea	Bristol Bay (2000)	31,315	12,614.9
Gulf of Alaska	Gulf of Alaska (2001)	31,648	1,354.2
SE Alaska	Northern Southeast (2002)	21,995	2,171.1
SE Alaska, Gulf of Alaska	Glacial Sites	15,296	747.9
	Total	156,418	14,424.47

Southeast Alaska Stock Trends

Population trend data have been collected in the vicinity of Sitka and Ketchikan since 1983. Based on counts near Ketchikan, abundance has increased 7.4% annually (95% CI: 6.1-8.7) from 1983 to 1998, but at a lower rate of 5.6% during the latter portion between 1994 and 1998 (Small et al. 2003). Counts near Sitka failed to show a significant trend either between 1984 and 2001 or 1995 and 2001 (Small et al. 2003). It should be emphasized that these data are from selected 'trend' sites and not complete census surveys. Further, both of these trend routes are for terrestrial haul-out locations, which may not be representative of animals that use glacial haul-out sites. Alaska Natives who hunt for seals in Yakutat Bay believe the local harbor seal population has declined over the past 10-15 years, as determined by less successful hunting trips over time (Yakutat Tlingit Tribe, pers. comm., cited in Jansen et al. 2006).

Additional information concerning trend counts in Southeast Alaska come from Glacier Bay. The number of harbor seals in Johns Hopkins Inlet (a tidewater glacial fjord in Glacier Bay) increased steeply (30.7% annually) between 1975 and 1978, and then at a slower rate (2.6% annually) for the period from 1983 to 1996 (Mathews and Pendleton 1997). Immigration and reduced mortality may have contributed to the steep growth between 1975 and 1978. During 1992-96, the number of seals in Johns Hopkins Inlet (glacial ice haul out) increased 7.1% annually (95% CI: 1.7%-12.4%), whereas the number of seals using terrestrial haul outs decreased 8.6% annually (95% CI: 5.6%-11.7%) over the same period. New information from Glacier Bay indicates a sharp overall decline of 63-75% in harbor seal abundance from 1992 to 2002; the cause of the decline is unknown (Mathews and Pendleton 2006). Results from the Sitka (stable), Ketchikan (increasing), and Glacier Bay (decreasing) trend analyses, and observations about a possibly declining local population in Yakutat Bay provide an uncertain basis for inferring trends in the Southeast Alaska stock as a whole.

Bering Sea Stock Trends

The number of harbor seals in the Bering Sea stock is thought to have declined between the 1980s and 1990s (Alaska SRG, see DeMaster 1996); however, published data to support this conclusion are unavailable. Specifically, in 1974 there were 1,175 seals reported on Otter Island. The maximum count in 1995 (202 seals) represents an 83% decline (Withrow and Loughlin 1996a). However, as noted by the Alaska SRG (DeMaster 1996), the reason(s) for this decline is(are) confounded by the recolonization of Otter Island by northern fur seals since 1974, which has caused a loss of available habitat for harbor seals. Further, counts of harbor seals on the north side of the Alaska Peninsula in 1995 were less than 42% of the 1975 counts, representing a decline of 3.5% per year. The number of harbor seals in northern Bristol Bay are also lower, but have remained stable since 1990 (Withrow and Loughlin 1996a). Trend counts have been conducted in Bristol Bay only between 1998 and 2001. 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.

Gulf of Alaska Stock Trends

There are trend counts available from two areas within the Gulf of Alaska stock of harbor seals: Kodiak and Prince William Sound. In Prince William Sound, harbor seal numbers declined by 57% from 1984 to 1992 (Pitcher 1989, Frost and Lowry 1993). Frost et al. (1999) reported a 63% decline in Prince William Sound from 1984-97; more recent information on trends in this area is not available. The decline began before the 1989 Exxon Valdez oil spill, was greatest in the year of the spill, and may have lessened thereafter. Between 1989 and 1995, aerial survey counts of 25 haulout sites in Prince William Sound (trend route A) showed significant declines in the number of seals during the molt (19%) and during pupping (31%) (Frost et al. 1996). Adjusted molt period counts for 1996 were 15% lower than the 1995 counts, indicating that harbor seal numbers in Prince William Sound have not yet recovered from the spill or whatever was causing the decline and that the long-term decline has not ended (Frost et al. 1997).

A steady decrease in numbers of harbor seals has been reported throughout the Kodiak Archipelago from the mid-1970s to the 1990s. Trend counts from Kodiak documented a significant increase of 6.6%/year (95% CI: NOAA-TM-AFSC-168 Angliss, R. P., and R. B. Outlaw Alaska Marine Mammal Stock Assessments, 2006 32 5.3-8.0; Small et al. 2003) over the period 1993-2001, which was the first documented increase in harbor seals in the Gulf of Alaska. On southwestern Tugidak Island, formally one of the largest concentrations of harbor seals in the world, counts declined 85% from 1976 (6,919) to 1988 (1,014) (Pitcher 1990). More recently, the Tugidak Island mean count has increased from 769 in 1992 to 2,090 in 2001 (Small 1996, Withrow et al. 2002), although this still only represents a fraction of its historical size. Despite some positive signs of growth in certain areas, the overall Gulf of Alaska stock size likely remains small compared to its size in the 1970s and 1980s.

Recent analysis of harbor seal counts in the Aleutian Islands has also showed a marked decline (Small et al, in review). By comparing counts from 108 islands surveyed in 1977-1982 (8,602 seals) with counts from the same islands during a 1999 aerial survey (2,872 seals), we estimated the abundance of harbor seals decreased at least 66.6% in the Aleutian Islands over the ~20 year period. Regionally, the largest decline of 86.2% was in the western Aleutians (n=7 islands), followed by 66.3% in the central Aleutians (n=65 islands), and 45.0% in the eastern Aleutians (n=36 islands).

Arctic ice seals: Bearded seal, ribbon seal, ringed seal, spotted seal **Last updated: October 2007**

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Stock definitions and geographic ranges

The four species of ice associated seals (i.e., bearded, spotted, ribbon, and ringed seals), often referred to collectively as “ice seals”, are important resources for northern coastal Alaska Native communities, and are likely to be key ecological components of arctic marine ecosystems.

Bearded seals (*Erignathus barbatus*) have a circumpolar distribution from approximately 45°N to 85°N. In Alaskan waters they are distributed over the shallow (less than 200 m) continental shelf of the Bering, Chukchi, and Beaufort Seas. Recent spring surveys indicated that in many areas bearded seals may be more abundant 20-100 nmi offshore than within 20 nmi of shore (Bengtson et al. 2000). Some seals migrate through the Bering Strait from April to June and spend the summer along the ice edge in the Chukchi; while others appear to remain in the open ocean during this time.

Ribbon seals (*Histriophoca fasciata*) inhabit the North Pacific Ocean and southern parts of the Arctic Ocean. In Alaska waters, they range northward from Bristol Bay, in the Bering Sea, into the Chukchi and Western Beaufort Seas. Ribbon seals are usually found on or near pack ice in the open sea, and rarely along the coast or on fast ice. From March to May they inhabit the Bering Sea ice front and are most abundant in the central and western Bering Sea. As the ice recedes in summer they move north with the ice edge. Little is known about ribbon seal distribution the rest of the year. Some migrate north through the Bering Strait while others may remain pelagic in the central Bering Sea.

Ringed seals (*Phoca hispida*) have a circumpolar distribution in the arctic and sub-arctic. In Alaska waters, and depending on ice cover, they are found as far south as the southern Bering Sea. Ringed seals have an affinity for ice-covered waters and tend to prefer areas within 20 nmi of shore (Bengtson et al. 2005). Recent spring surveys suggest that the density of ringed seals is higher in the eastern part of the Alaskan Beaufort Sea than in the west. Ringed seals are believed to follow the ice edge north as it melts in summer, but the details of this migration are unknown.

Spotted seals (*Phoca largha*) are distributed along the continental shelf of the Beaufort, Chukchi, Bering, and Okhotsk Seas, and south into the northern Yellow and western Sea of Japan. In Alaskan waters, they are known to occur as far south at the Pribilof Islands, Bristol Bay, and the eastern Aleutian Islands. Spotted seals are easily mistaken for harbor seals. There is little morphological difference between the two species and their geographic ranges overlap in the southern Bering Sea. However, only the spotted seal is regularly associated with pack ice.

A lack of significant genetic, phenotypic and population response data does not warrant subdividing the bearded, ribbon, ringed or spotted seals stocks. As such, in U.S. waters, only the Alaska stocks are recognized.

Population sizes, status and trends

Reliable estimates for the current minimum population size, abundance and trend of the Alaska stocks of bearded, ribbon, ringed or spotted seals are considered unavailable. However, there are crude estimates available in the historical literature. For example, early estimates of the Bering- Chukchi Sea population of bearded seals range from 250,000 to 300,000 (Popov 1976, Burns 1981a). Burns (1981b) estimated the worldwide population of ribbon seals at 240,000 in the mid 1970s, with an estimate for the Bering Sea at 90,000-100,000. Similarly rough estimates for the numbers of ringed seals in Alaska include 1-1.5 million (Frost 1985) or 3.3-3.6 million (Frost et al. 1988); about 230,000 are estimated to inhabit the Alaska coastal regions of the Chukchi Sea (Bengtson et al. 2005). The worldwide population of spotted seals was estimated by Burns (1973) to be in the range of 335,000-450,000, with an estimate for the Bering Sea of 200,000-450,000.

Bearded, ribbon, ringed or spotted seals are not listed as “depleted” under the MMPA or listed as “threatened” or “endangered” under the Endangered Species Act. Current and reliable estimates of the minimum population size, total abundance, PBR (potential biological removal) and human-caused injury or mortality are not available. There is also a lack of information suggesting that subsistence hunting is adversely affecting these stocks and because of minimal evidence of interactions with U.S. fisheries the Alaska stocks of bearded, ribbon, ringed or spotted seals are not classified as strategic stocks.

Issues

The distributions and densities of ice-dwelling seals are highly sensitive to suitable sea ice conditions, and as such, these seals may be particularly vulnerable to climatic change. Changes in sea ice extent have been non-uniform; therefore, the effects on seals are likely to occur on regional scales, emphasizing the need for quality data throughout their range.

Abundance, population discreteness, annual survival and reproductive rates (together with information on food habits, seasonal movements and distribution), are essential to making sound management and conservation decisions. Unfortunately, current knowledge and monitoring programs are insufficient to allow for the timely detection of changes in population trend.

Ecological data is also important and future studies should focus on assessing the natural causes of fluctuations in the numbers and distribution of ice seals. For example, it is unknown how many ribbon seals remain in the Bering Sea and to what extent they compete with the pollock fishery in summer. Information on the specific habitat requirements for breeding, molting, feeding, etc. of these species is also lacking. This is particularly important with regards to the future effects of global warming. A reduction or change in ice cover would likely directly affect the survival of these species, particularly ringed seals which are so well adapted to occupying seasonal and permanent ice.

Finally, the extent to which these populations are affected by human caused mortality is also poorly known. Their interactions with commercial fisheries (e.g., entanglement in nets) are not well described as these data are collected voluntarily and are self-reported by each vessel. In addition, the physical similarities between spotted and harbor seals makes interpreting any data from these species problematic. Bearded and ringed seals are actively targeted in the Alaska Native subsistence harvest, with an average of 6,788 and 9,567 taken each year (ADF&G 2000a, b). There is significant annual variation in these numbers however, and without reliable estimates of the minimum population of these species PBRs can not be calculated and the resulting effects on the populations can not be estimated or managed for.

Recent projects by the National Marine Mammal Laboratory are beginning to address some of these knowledge gaps. Current satellite-tagging studies are providing some of the first information on the seasonal movements, habitat use, and foraging ecology of bearded, ribbon and spotted seals (Cameron 2005, Cameron 2006, Cameron 2007, Boveng et al. 2007). Similarly, recent abundance surveys will provide estimates of the different ice seal populations inhabiting U.S. waters (Bengtson et al. 2000, Cameron 2006, Cameron and Boveng, 2007).

Cetaceans

Bowhead whale (*Balaena mysticetus*)

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Last updated: October 2007

All stocks of bowhead whales (*Balaena mysticetus*) were severely depleted by commercial whaling (Woodby and Botkin 1993) and were classified as protected by the International Whaling Commission (IWC) under the 1946 International Convention for the Regulation of Whaling. The IWC currently recognizes the Okhotsk Sea, Spitsbergen, Eastern Canada-West Greenland, and Western Arctic stocks of bowhead whales (IWC 2007a). The Western Arctic stock, also known as the Bering Sea (Burns et al. 1993) or Bering-Chukchi-Beaufort (Rugh et al. 2003) stock, is the only stock of bowheads in U.S. waters (Angliss and Outlaw 2007, George et al. 2007, IWC 2007a). In the U.S., this stock is classified as endangered under the Endangered Species Act (ESA) of 1973 and depleted under the Marine Mammal Protection Act of 1972; thus, it is also considered a strategic stock. However, the Western Arctic stock has been increasing in recent years (George et al. 2004) and may be approaching its carrying capacity (Brandon and Wade 2004).

Western Arctic bowheads generally migrate between wintering areas in the Bering Sea and summering areas in the eastern Beaufort Sea (Braham et al. 1980, Moore and Reeves 1993). Systematic ice-based visual counts during this migration have been conducted since 1978 (Krogman et al. 1989). A summary of the resulting abundance estimates, corrected for whales missed during the census (Zeh et al. 1993, Clark et al. 1996), is provided in Table 10 (Angliss and Outlaw 2007) and Figure 71 (George et al. 2004); however, these estimates have not been corrected for a small, unknown, portion of the population that may not migrate past Point Barrow during the survey (Angliss and Outlaw 2007). The most recent population abundance estimate in 2001 of 10,545 (CV=0.128) whales in the Western Arctic stock was calculated from ice-based census counts (George et al. 2004, Zeh and Punt 2004). The rate of increase and the record high count of 121 calves in 2001 suggest a steady recovery of the stock (George et al. 2004).

Alaskan Natives living in villages along the migration route of the Western Arctic stock of bowheads have hunted these whales for at least 2,000 years (Marquette and Bockstoce 1980, Stoker and Krupnik 1993), and the IWC has regulated subsistence takes since 1977 (IWC 1978). Alaskan Natives landed 832 whales between 1974 and 2003 (Suydam and George 2004), 36 whales in 2004 (Suydam et al. 2005), 55 in 2005 (Suydam et al. 2006), and 31 in 2006 (Suydam et al. 2007). Russian subsistence hunters harvested one whale in 1999 and one in 2000 (IWC 2002), three in 2003 (Borodin 2004), and one in 2004 (Borodin 2005). Canadian Natives also harvested one whale in 1991 and one in 1996 (Angliss and Outlaw 2007). At its annual meeting in 2007, the IWC renewed the existing 5-year bowhead quota for the 5-year period from 2008 to 2012 (IWC 2007b); the quota currently includes up to 280 whales landed, with no more than 67 whales struck in any year and up to 15 unused strikes carried over each year.

Oil and gas development in the Arctic has the potential to impact bowheads through increased risks of exposure to pollution and to the sound produced by exploration, drilling operations, and increased vessel traffic in the area (Angliss and Outlaw 2007). Past studies have indicated that bowheads are sensitive to sounds from seismic surveys and drilling operations (Richardson and Malme 1993, Richardson 1995, Davies 1997) and will avoid the vicinity of active seismic operations (Miller et al. 1999), active drilling operations (Schick and Urban 2000), and the resulting vessel traffic (Richardson et al. 2004). To facilitate mitigation of future oil and gas development along the migration route of the Western Arctic stock of bowheads, a multi-year study (2007-2010) administered by NMFS and funded by the U.S. Department of the Interior's Minerals Management Service will estimate relationships among bowhead whale prey, oceanographic conditions, and bowhead whale feeding behavior in the western Beaufort Sea (NMML 2007).

Table 10 (Angliss and Outlaw 2007). Summary of population abundance estimates for the Western Arctic stock of bowhead whales. The historical estimates were made by back-projecting using a simple recruitment model. All other estimates were developed by corrected ice-based census counts. Historical estimates are from Woodby and Botkin (1993); 1978-2001 estimates are from George et al. (2004) and Zeh and Punt (2004).

Year	**Abundance Estimate (CV)**	**Year**	**Abundance Estimate (CV)**
Historical estimate	10,400-23,000	1985	5,762 (0.253)
End of commercial whaling	1000-3000	1986	8,917 (0215)
1978	4,765 (0.305)	1987	5,298 (0.327)
1980	3,885 (0.343)	1988	6,928 (0.120)
1981	4,467 (0.273)	1993	8,167 (0.017)
1982	7,395 (0.281)	2001	10,545 (0.128)
1983	6,573 (0.345)		

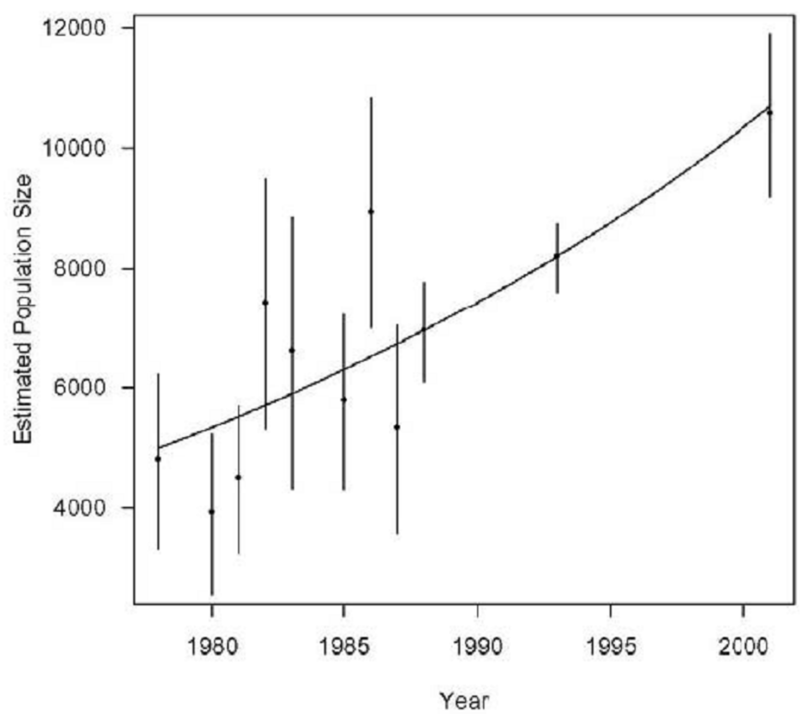

Figure 71 (George et al. 2004). Population abundance estimates for the Western Arctic stock of bowhead whales, 1977-2001, as computed from ice-based counts, acoustic locations, and aerial transect data collected during bowhead whale spring migrations past Barrow, AK. Error bars show +/- 1 standard error.

Potential Causes of Declines in Marine Mammals
Last updated November 2006

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Seabirds
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Last updated: November 2006

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Ecosystem or Community Indicators
Alaska Native Traditional Environmental Knowledge of Climate Regimes
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Last updated: November 2005

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Combined Standardized Indices of recruitment and survival rate
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Last updated: August 2007

Description of indices: 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) are provided. Time series of recruitment and spawning biomass for demersal fish stocks were obtained from the 2006 SAFE reports (NPFMC 2006a; 2005 SAFE reports for flatfish & rockfish in the GoA, NPFMC 2005b) to update the results of Mueter et al. (2007). Only recruitment estimates for age classes that are largely or fully recruited to the fishery were included. Survival rate (SR) indices for each stock were computed as residuals from a spawner-recruit model. Both a Ricker and Beverton-Holt model (with or without first-order autocorrelated errors) were fit to each stock's recruitment and female spawning biomass data and the model with the best fit (based on the small-sample Akaike Information Criterion) was used to compute the SR index. Each time series of log-transformed recruitment (logR) or SR indices was standardized to have a mean of 0 and a standard deviation of 1 (hence giving equal weight to each stock in the combined index, see below). Time series were lined up by year-class for the period 1970-2003, resulting in matrices of logR or SR indices by year with missing values at the beginning and end of many series. A combined standardized index of recruitment (CSI_R) and survival (CSI_{SR}) was computed by simply averaging indices within a given year across stocks. Prior to standardizing the series, missing values at the ends of several series were estimated by imputation using additive regression, bootstrapping, and predictive mean matching as implemented in the "hmisc" package for S-Plus and R (Frank Harrell, Univ. of Virginia, available at StatLib at http://lib.stat.cmu.edu/). Multiple imputations were obtained through bootstrap resampling to estimate the variability in the averaged index that results from filling in missing values. Because missing values are not missing at random, it is assumed that correlations between time series did not change over the period 1970-2003. Uncertainty in the stock-specific estimates of logR and SR indices was not accounted for; therefore the most recent estimates of the combined indices should be interpreted with caution.

Status and trends: The CSI_R suggests that recruitment of demersal species in the GoA and BSAI followed a similar pattern with mostly above-average recruitments from the mid- or late 1970s to the late 1980s, followed by below-average recruitments during the early 1990s (GoA) or most of the 1990s (BSAI; Figure 72). Because estimates at the end of the series were based on only a few stocks and are highly uncertain, we show the index through 2003 only, the last year for which data for at least 6 stocks was available in each region. There is strong indication for above-average recruitment in the GoA from 1994-2000 (with the exception of 1996, which had a very low recruitment index). A similar trend was evident in the Bering Sea, but was much less pronounced (Figure 72). In the Gulf of Alaska, recruitment has been below average across stocks since 2001 (below-average logR and SR indices for 9 of 11 stocks in 2001, relative to the 1970-2003 period). The CSI_{SR} indices showed very similar patterns.

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: $r = 0.52$; CSI_{SR}: $r = 0.40$). These variations in productivity are correlated with and may in part be driven by variations in large-scale climate patterns such as the PDO or more regional measures such as ocean temperatures. The Nov-Mar PDO index for the preceding winter was positively correlated with all of the indices, but none of the correlations were significant at the 95% level. The CSI_R index for the GoA was positively correlated with bottom temperatures at the GAK1 station at 59° 50.7' N, 149° 28.0' W ($r = 0.46$, $p = 0.007$).

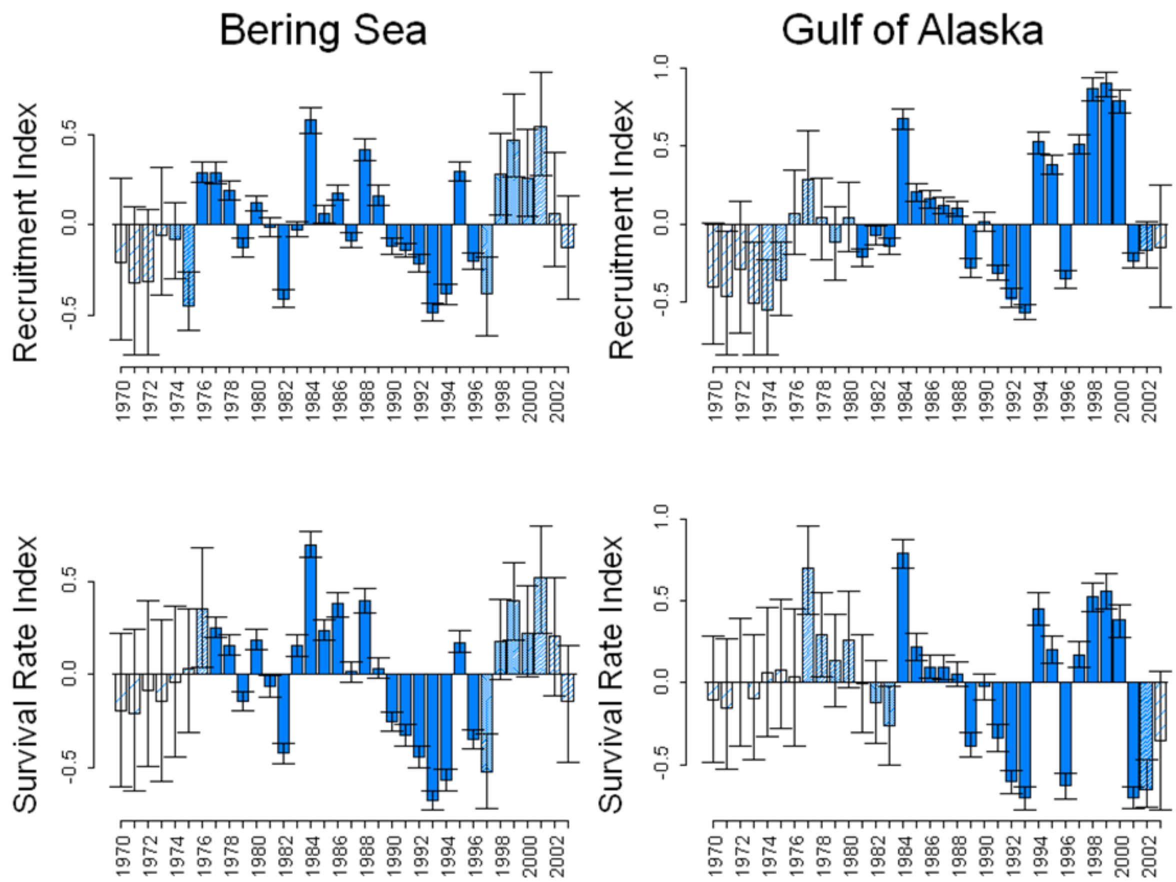

Figure 72. Combined Standardized Indices of recruitment (top) and survival rate (stock-recruit residuals, bottom) by year class across demersal stocks in the Bering Sea / Aleutian Island region (11 stocks) and in the Gulf of Alaska (11 stocks). Solid blue bars represent years with data for all stocks 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 6 stocks were included. Bootstrap confidence intervals (95%) depict uncertainty resulting from filling in missing values, but assume that survival and recruitment are estimated without error.

Average local species richness and diversity of the groundfish community

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Last updated: August 2007

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 and major invertebrate taxa per haul and the average Shannon index of diversity (Magurran 1988) by haul were computed. The latter was based on CPUE (by weight) of each species (or taxon). Indices were based on a total of 53 taxa in the GoA (contact author for list of species) and 46 taxa in the EBS (Table 1 in Mueter & Litzow, in press). 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 between 1999 and 2001 (Figure 73). Species richness and diversity on the Eastern Bering Sea shelf have undergone significant variations from 1982 to 2006 (Figure 74). The average number of species per haul has increased by one to two species since 1995, while the Shannon Index increased from 1985 through 1998 and decreased sharply in 1999.

Factors 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 how many species are caught in a hauls and how evenly CPUE is distributed among the species. In the GoA both average species diversity and local richness showed very similar trends, suggesting that relative species composition (evenness) was relatively stable. In contrast, trends in species diversity in the EBS differed markedly 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 increase in species richness, which was particularly pronounced on the middle shelf, has been attributed to subarctic species spreading into the former cold pool area as the extent of the cold pool has decreased over recent decades (Mueter & Litzow, in press). However, species diversity has been low in recent years, compared to the 1990s, which suggests that species remain patchily distributed such that a given haul may be dominated by one or a few species.

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.

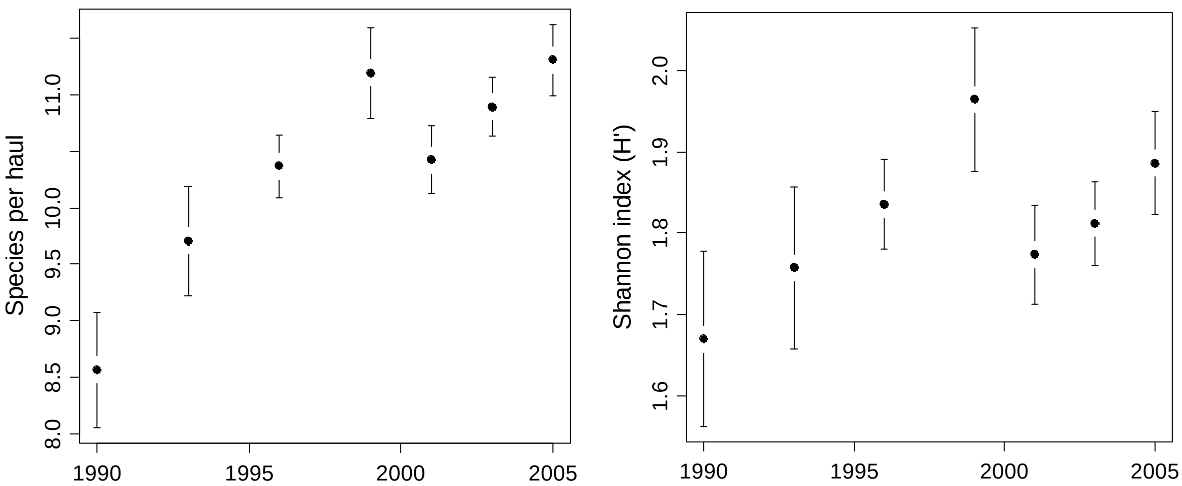

Figure 73. Model-based annual averages of species richness (average number of species per haul), and species diversity (Shannon-Wiener index) in the western Gulf of Alaska, 1990-2005, based on 55 fish taxa collected by standard bottom trawl surveys with 95% confidence intervals. Model means were adjusted for differences in area swept, depth, date and time of sampling, and geographic location among years.

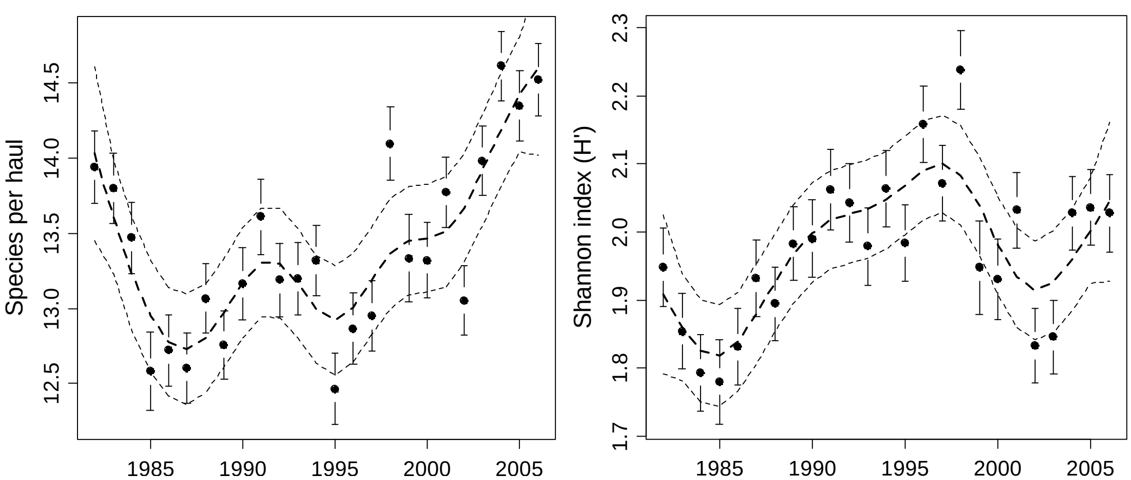

Figure 74. Model-based annual averages of species richness (average number of species per haul), and species diversity (Shannon-Wiener index) in the Eastern Bering Sea, 1982-2006, based on 47 fish taxa collected by standard bottom trawl surveys with 95% confidence intervals. Model means were adjusted for differences in area swept, depth, date of sampling, bottom temperature, and geographic location among years.

Total catch-per-unit-effort of all fish and invertebrate taxa in bottom trawl surveys
Contributed by Franz Mueter, Sigma Plus, Fairbanks, Alaska
Contact: fmueter@alaska.net
Last updated: August 2007

Description of index: The index provides a measure of overall abundance of demersal and benthic species. Average catch-per-unit-effort of selected fish and invertebrate taxa captured by standardized bottom trawl surveys in the Eastern Bering Sea (EBS) and western Gulf of Alaska (GoA) was estimated. Only major taxa that were identified and measured throughout the survey period from 1982-2006 (EBS) or 1984-2005 (GoA) were included. 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 net width following Mueter & Norcross (2002). Although catches were standardized to account for the area swept by each haul we included net width in the model because of differences in catchability of certain taxa with changes in net width (von Szalay & Somerton 2005) and because there was strong evidence that total CPUE tends to decrease with net width, all other factors being constant. The index did not account for gear differences in the Bering Sea, which are strongly confounded with interannual differences and may affect results prior to 1988. CPUE in the western GoA for the 1984 and 1987 surveys were not estimated because a large portion of these surveys used non-standard gear types.

Status and trends: Total survey CPUE in the western GoA increased from 1990 to 1996 and decreased significantly between 1996 and 1999 (Figure 75). CPUE increased again from 2001 to 2003 and remained high in 2005. Total survey CPUE in the EBS has undergone substantial variations with a pronounced minimum in 1985 and a peak in 1993/94 (Figure 76). There was an apparent long-term increase in log(CPUE) from 1982-2006 (Generalized least squares regression with first-order auto-correlated errors: $t = 1.87$, $P = 0.074$). However, estimated means prior to 1988 may be biased due to unknown gear effects. The overall increasing trend in CPUE in the EBS was particularly pronounced in the portion of the middle-shelf area that is typically occupied by the cold pool and appears to be related to the increasing colonization of this area by subarctic demersal species as the cold pool has retreated over recent decades (Mueter & Litzow, in press).

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, growth, and distribution. The increase in survey CPUE in the EBS in the 2000s 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. In addition, models including bottom temperature suggest that, in the EBS, CPUEs are greatly reduced at low temperatures (< 1˚C). This is evident in reduced CPUEs in 1999 and 2006, when the cold pool covered a substantial portion of the shelf. At present, it is not clear whether this effect is primarily due to actual changes in abundance or temperature-dependent changes in catchability of certain species. We did not include a temperature effect in the models because of missing temperature values in the early years.

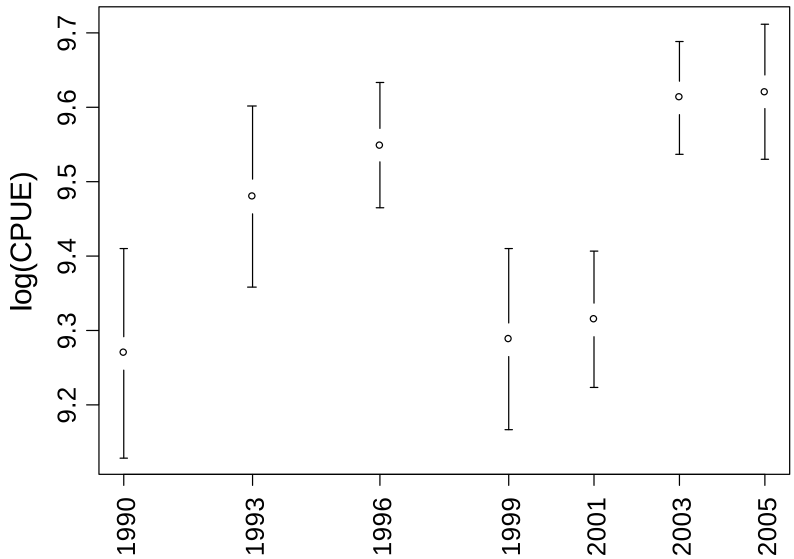

Figure 75. Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from in the western Gulf of Alaska (west of 147˚ W) by survey year with approximate 95% confidence intervals. Estimates were adjusted for differences in depth, net width and sampling locations among years.

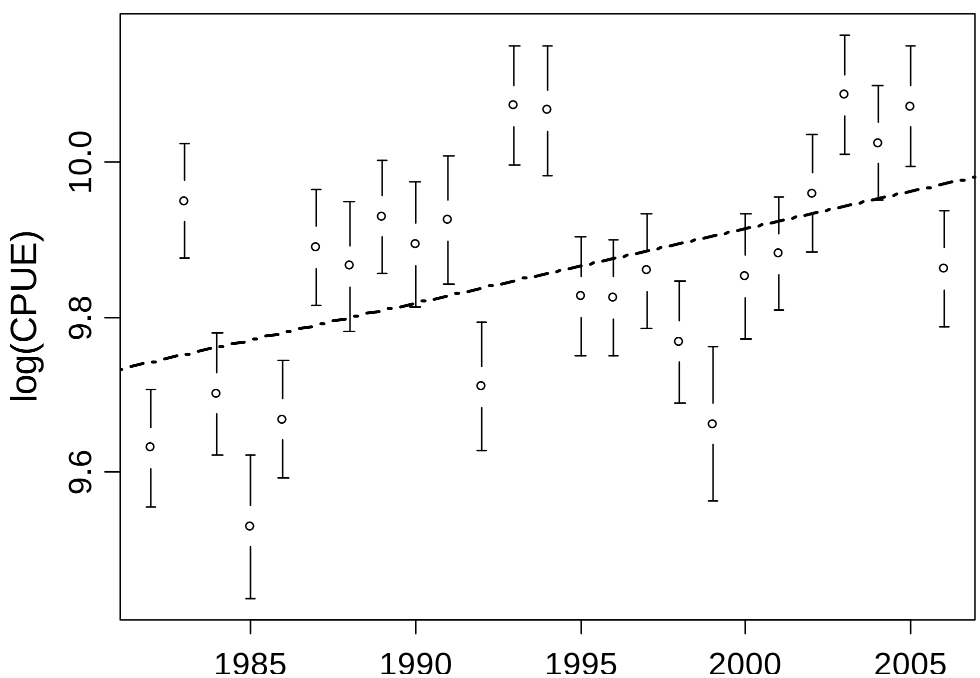

Figure 76. Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from 1982 to 2004 in the Bering Sea with approximate pointwise 95% confidence intervals and long-term linear trend. Estimates were adjusted for differences in depth, day of sampling, net width 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

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Contact: Terry.Hiatt@noaa.gov
Last updated: October 2007

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 catch (PSC). A variety of management measures have been used to control the bycatch of these species, and data from the groundfish observer program have been used to estimate the bycatch of these species and the bycatch mortality of halibut. Most of the groundfish catch and prohibited species bycatch is taken with trawl gear. The implementation of the halibut and sablefish IFQ programs in 1995 allowed for the retention of halibut in the hook and line groundfish fishery and effectively addressed an important part of the halibut bycatch problem in that fishery, but it also made it very difficult to differentiate between halibut catch and bycatch for part of the hook and line groundfish fishery. Therefore, the estimates of halibut bycatch mortality for the hook and line fishery and for the groundfish fishery as a whole are not comparable before and after 1995.

Estimates of the bycatch of prohibited species other than halibut and estimates of halibut bycatch mortality are presented in Figure 77. 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.

The Bering Sea pollock fleet (since 2001) and flatfish fleet (since the mid-1990s) have contracted with Sea State, Inc. (Sea State) to share and aggregate information about bycatch. Sea State receives information from the North Pacific Groundfish Observer Program about the bycatch rates of participating vessels, and then identifies “hotspots”, which depending upon the fishery and time of year designate either voluntary recommendations or mandatory exclusions from high-bycatch areas. Sea State also sends regular “Dirty 20” lists of vessels with high salmon bycatch to the participating fleets and communicates other information about bycatch trends and rates. Beginning in 1994, in a related attempt to control salmon bycatch in the BSAI trawl fisheries, which account for most of the salmon bycatch (averaging 71% for Chinook salmon and 93% for other salmon over the years 1994-2006), the North Pacific Fisheries Management Council (NPFMC) and NMFS established Chum and Chinook Salmon Savings Areas (SSA), which were closed by regulation in parts of the Bering Sea and at times when salmon bycatch had been highest according to historical observer data.

The key problem with the SSA closures is that in recent years they did not prove to be consistently effective. The highest chum salmon bycatch rates in 2003-05 occurred outside of the Chum SSA and after its closure. Similar problems occurred in the same years with Chinook salmon bycatch outside of the

Chinook SSA—the highest bycatch rates were encountered by the pollock trawl fleet outside of the SSA after regulations had forced its closure. The resulting Chinook salmon bycatch was about 28% higher in 2003, 46% higher in 2004, and 96% higher in 2005 than the long-term average over the period 1994-2002. Chinook salmon bycatch for all of Alaska was essentially unchanged in 2006 compared to 2005, as shown in Figure 77, but it increased by about 18% in the BSAI where, in 2006 for the first time ever, the Chinook SSA was closed to fishing during the pollock 'A' season. The closure resulted in a large economic impact on the pollock fishery during the winter roe season.

Like the Chinook salmon bycatch described above, the "other salmon" (OS) bycatch (primarily chum) has also increased dramatically in recent years. The OS bycatch more than doubled in both 2003 and 2004 compared to the previous years and increased again by about 57% in 2005. After starting at high levels early in the 'B' season, the OS bycatch decreased by about 54% in 2006 compared to the 2005 bycatch. The increases in 2003 and 2005 and the decrease in 2006 are in line with changes in salmon abundance, which is reflected by the change in the overall catch of OS, which increased by about one-third in both 2003 and 2005 and decreased by about 28% in 2006. However, the OS bycatch also more than doubled in 2004, despite an almost 6% reduction in the overall catch. Recent meetings of the NPFMC SSC have suggested that the link between salmon stock and bycatch is currently uncertain. More research is being conducted in this area so this relationship should be better understood in coming years.

To address these problems, the NPFMC passed Amedment 84 which established a new regulatory salmon-savings system, the Voluntary Rolling Hot Spot (VRHS) system. Under the VRHS system, high bycatch vessels are prohibited from fishing in high-bycatch areas for a certain time period, which provides an individual incentive for vessels to avoid bycatch. Final implementation of Amendment 84 by NMFS has been delayed, but an experimental fishing permit (EFP) is in place which allows for the testing of the VRHS system and vessels participating in the VRHS system have been exempted from Salmon Savings Area closures since August 2006. The NPFMC is also currently considering new fixed-area closures (both automatic and triggered by exceeding certain catch levels) as well as a potential fishery closure, and will in the future consider the development of some form of individual-vessel, salmon-bycatch accountability program. The latter could take the form of tradable individual bycatch quotas (IBQ) or a system of financial incentives that would reward vessels for minimizing bycatch and/or penalize vessels with high bycatch rates. A "Salmon Bycatch Work Group," composed of representatives of the pollock and salmon fishing industries/communities, has met several times since May 2007 to help shape NPFMC proposed alternatives and analysis which occur over the coming year.

Annual estimates of bycatch for the years 1994-2002 come from NMFS Alaska Region's blend data; 2003-06 estimates are from the Alaska Region's Catch-Accounting System.

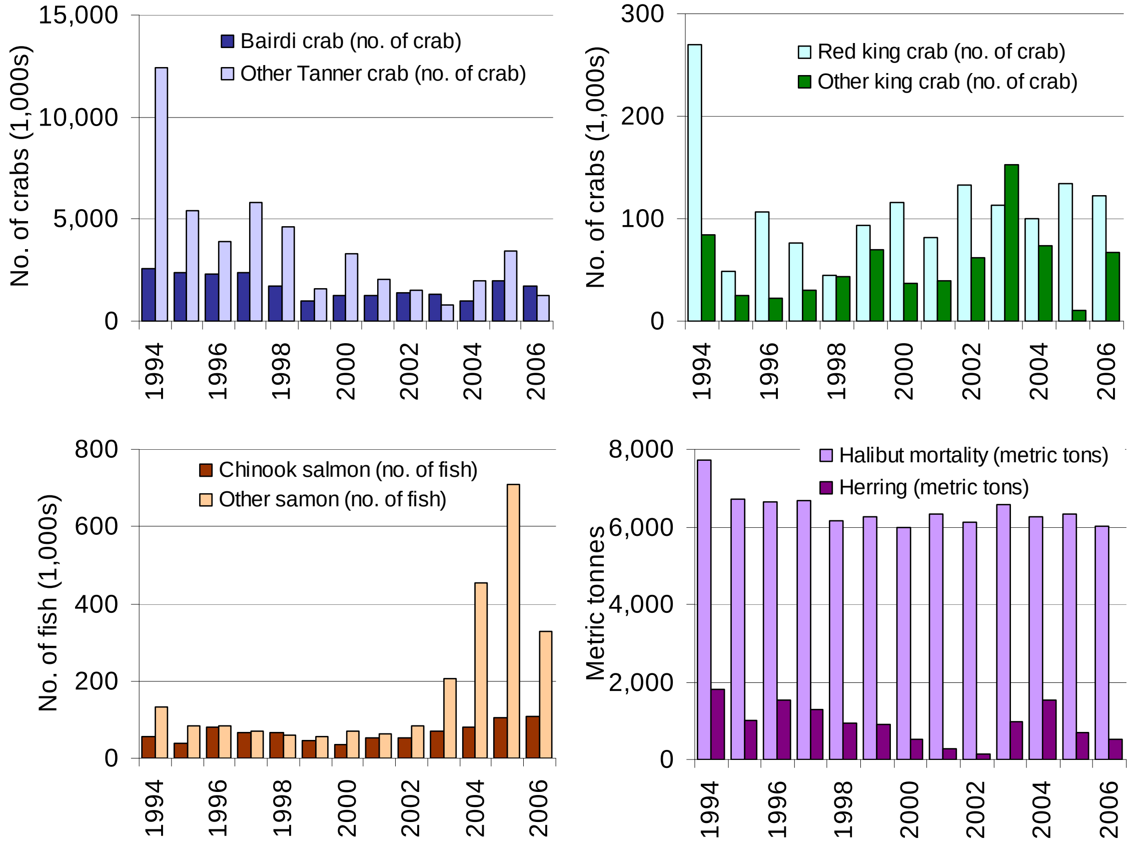

Figure 77. Bycatch of tanner and king crab, salmon, halibut, and herring in groundfish fisheries off Alaska, 1994-2006.

Time trends in groundfish discards
Contributed by Terry Hiatt, Alaska Fisheries Science Center
Contact: Terry.Hiatt@noaa.gov
Last updated: August 2007

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 78). These decreases are explained by reductions in the discard rates of pollock and Pacific cod that resulted from regulations implemented in 1998 prohibiting discards of these two species. Discards in the Gulf of Alaska increased somewhat between 1998 and 2003, but have declined again in recent years. Discards in both regions are much lower than the amounts observed in 1997, before implementation of improved-retention regulations. Estimates of discards for 1994-2002 come from NMFS Alaska Region's blend data; estimates for 2003-06 come from the Alaska Region's catch-accounting system. It should be noted that although these sources provide the best available estimates of discards, the estimates are not necessarily accurate because they are based on visual observations by observers rather than data from direct sampling.

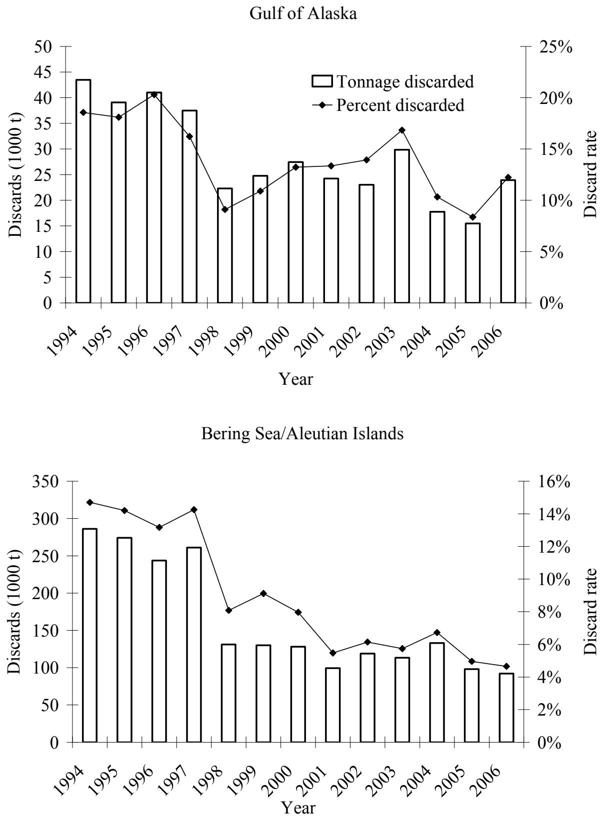

Figure 78. Total biomass and percent of total catch biomass of managed groundfish discarded in the GOA and BSAI areas, 1994-2006. (Includes only catch counted against federal TACs).

Time Trends in Non-Target Species Catch

Contributed by Sarah Gaichas and Jennifer Boldt, Alaska Fisheries Science Center

Last updated: November 2007

In addition to prohibited and target species catches, groundfish fisheries also catch non-target species (Figure 79). There are four categories of non-target species: 1.) forage species (gunnels, sticheids, sandfish, smelts, lanternfish, sandlance), 2.) HAPC (seapens/whips, sponges, anemones, corals, tunicates), 3.) non-specified species (grenadiers, crabs, starfish, jellyfish, unidentified invertebrates, benthic invertebrates, echinoderms, other fish, birds, shrimp), and 4.) other species (sculpins, unidentified sharks, salmon sharks, dogfish, sleeper sharks, skates, octopus, squid). The “other species” catch is included in the groundfish discards (Hiatt, this report).

In both the BSAI and GOA, non-specified catch comprised the majority of non-target catch during 1997-2007 (Figure 79). Non-specified catches are of the same order of magnitude in the BSAI and GOA. Catches of HAPC biota are higher in the BSAI than in the GOA and the catch of forage is higher in the GOA than in the BSAI.

In the BSAI, the catch of non-specified species and HAPC biota decreased since 2003. Scyphozoan jellyfish, grenadiers and sea stars comprise the majority of the non-specified catches in the BSAI. Grenadiers (including the Giant grenadier) are caught primarily in the flatfish, sablefish, and cod fisheries. Jellyfish and sea stars are caught primarily in flatfish fisheries. Benthic urochordata comprise the majority of HAPC biota catches in the BSAI, caught mainly by the flatfish fishery; this catch has decreased since 2004. The catch of forage species in the BSAI increased in 2006 and 2007 and was comprised mainly of eulachon that was caught primarily in the pollock fishery.

The catch of non-specified species in the GOA has been relatively low in the last few years; whereas, the catch of HAPC biota has been variable. Grenadiers comprise the majority of non-specified catch and they are caught primarily in the sablefish fishery, recently. Sea anemones comprise the majority of HAPC biota catch in the GOA and they are caught primarily in the flatfish fishery. The catch of forage species has undergone large variations, peaking in 2005 and decreasing in 2006 and 2007. The main species of forage fish caught are eulachon and they are primarily caught in the pollock fishery.

It should be noted that while total catch estimates are based on standardized quantitative sampling protocols, observers are instructed to visually estimate the percent retained for each species. Estimated discards, therefore, may be less accurate than target estimates because they are based on visual observations by observers rather than data from direct sampling. Catch since 2003 has been estimated using the Alaska Region's new Catch Accounting system.

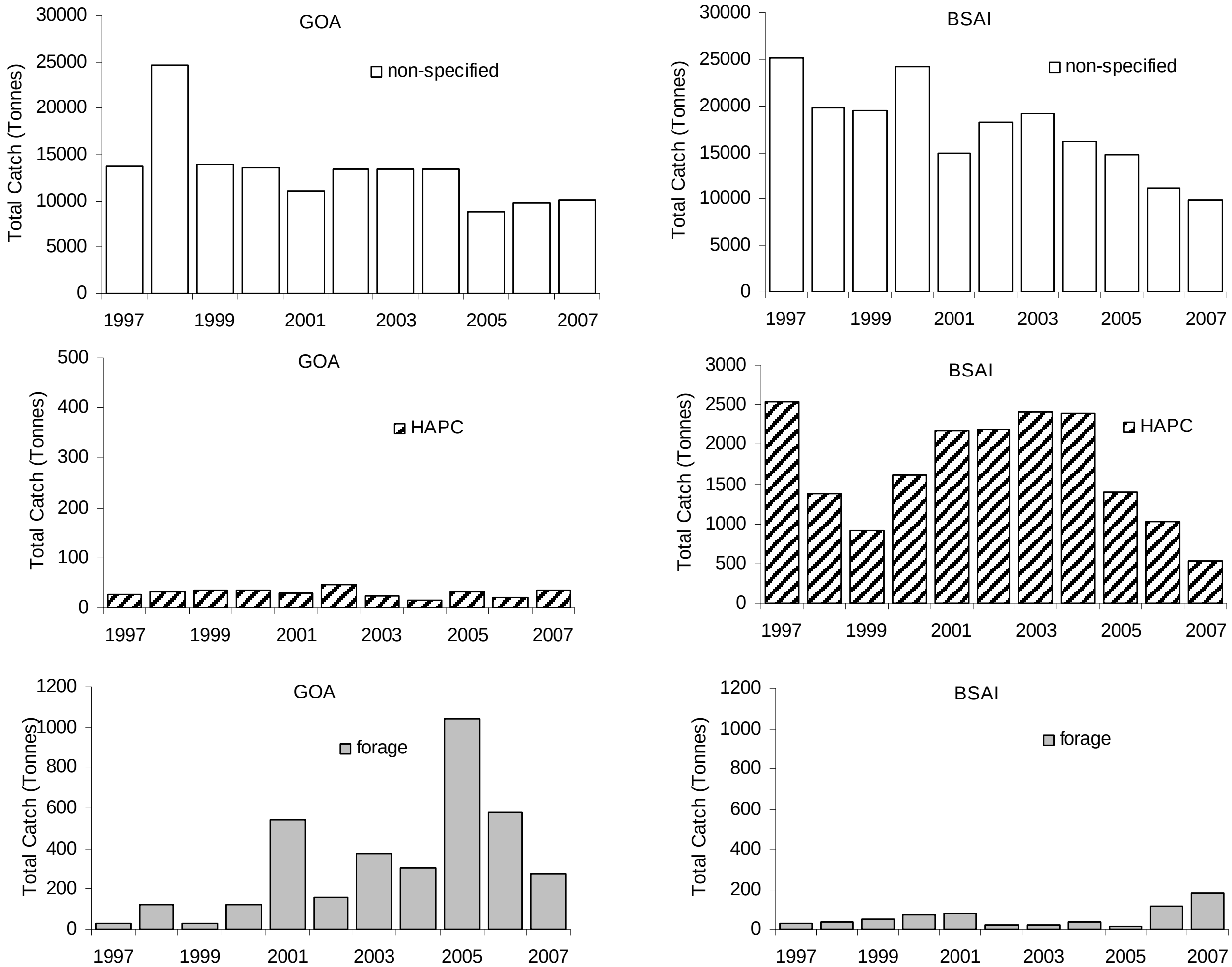

Figure 79. Total catch of non-target species (tonnes) in the GOA and BSAI areas by groundfish fisheries. Note: the scales of the y-axes are different in the HAPC biota graphs.

Ecosystem Goal: Maintain and Restore Fish Habitats

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

Contributed by Cathy Coon, NPFMC
Contact: Cathy.Coon@noaa.gov

Last updated: August 2007

Many trawl closures have been implemented to protect benthic habitat or reduce bycatch of prohibited species (i.e., salmon, crab, herring, and halibut) (Table 11 and Figure 80). 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 11. In general, year-round trawl closures have been implemented to protect vulnerable benthic habitat. Seasonal closures are used to reduce bycatch by closing areas where and when bycatch rates had historically been high. Additional measures to protect the declining western stocks of the Steller sea lion began in 1991 with some simple restrictions based on rookery and haulout locations, to specific fishery restrictions in 2000 and 2001. For 2001, over 90,000 nmi of the EEZ off Alaska was closed to trawling year-round. Additionally 40,000 nmi were closed on a seasonal basis. State waters (0-3nmi) are also closed to bottom trawling in most areas.

New closures implemented in 2006 as part of protection for Essential Fish Habitat encompasses a large portion of the Aleutian Islands (Figure 80). 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. For additional background on fishery closures in the Alaska EEZ see Witherell and Woodby (2005).

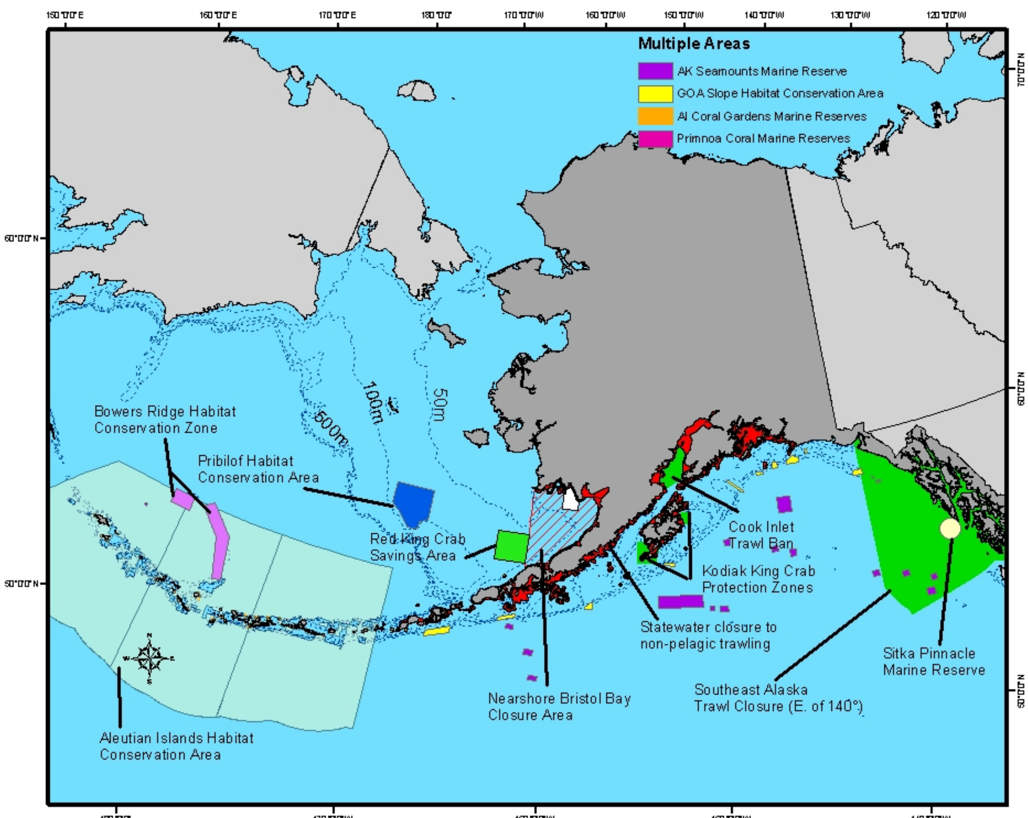

Figure 80. Year-round groundfish closures in Alaska's Exclusive Economic Zone.

Table 11. Time series of groundfish trawl closure areas in the BSAI and GOA, 1995-2006. 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; LLP= License Limitatin Program

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 at 42,000 chum salmon
	CHSSA	trigger	9,000 nm^2	closed at 48,000 Chinook salmon
	HSA	trigger	30,000 nm^2	trigger closure
	Zone 1	trigger	30,000 nm^2	trigger closure
	Zone 2	trigger	50,000 nm^2	trigger closure
	Pribilofs	year-round	7,000 nm^2	
	RKCSA	year-round	4,000 nm^2	pelagic trawling allowed
	Walrus Islands	5/1-9/30	900 nm^2	12 mile no-fishing zones
	SSL Rookeries	seasonal ext.	5,100 nm^2	20 mile extensions at 8 rookeries
1996	Bristol Bay	year-round	19,000 nm^2	expanded area 512 closure
	COBLZ	trigger	90,000 nm^2	trigger closure
2000	Steller Sea Lion protections			
	Pollock haulout trawl exclusion zones for EBS, AI ***** *areas include GOA*			
		* No trawl all year	11,900 nm^2	
		No trawl (Jan-June)*	14,800 nm^2	
		No Trawl Atka Mackerel Restrictions	29,000 nm^2	
2006	Essential Fish Habitat			
	Aleutian Island Habitat Conservation Area			
		No bottom trawl all year	279,114 nm^2	
	6 coral garden areas			
		No bottom contact gear all year	110nm^2	
	Bowers Ridge Habitat Conservation Zone			
	No mobile bottom tending fishing gear		5,286 nm^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
	SSL Rookeries	seasonal ext,	1900 nm^2	20 mile extensions
1998	Southeast trawl	year-round	52,600 nm2	adopted as part of the LLP
	Sitka Pinnacles Marine reserve	year-round	3.1 nm^2	
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*	
2006	Essential Fish Habitat			
	Gulf of Alaska Slope Habitat Conservation Area			
	No bottom trawl all year		2,100nm^2	
	Gulf of Alaska Coral Habiat Protection Measures			
	No bottom tending gear all year		13.5m^2	
	Alaska Seamount Habitat Protection Measures			
	No bottom tending gear all year		5,329m^2	

Hook and Line (Longline) fishing effort in the Gulf of Alaska, Bering, Sea and Aleutian Islands
Contributed by Cathy Coon, NPFMC
Contact: Cathy.Coon@noaa.gov
Last updated: October 2007

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 81. 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 82-87 show the spatial patterns and intensity of longline effort, based on observed data as well as anomalies based on year 2006. 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.

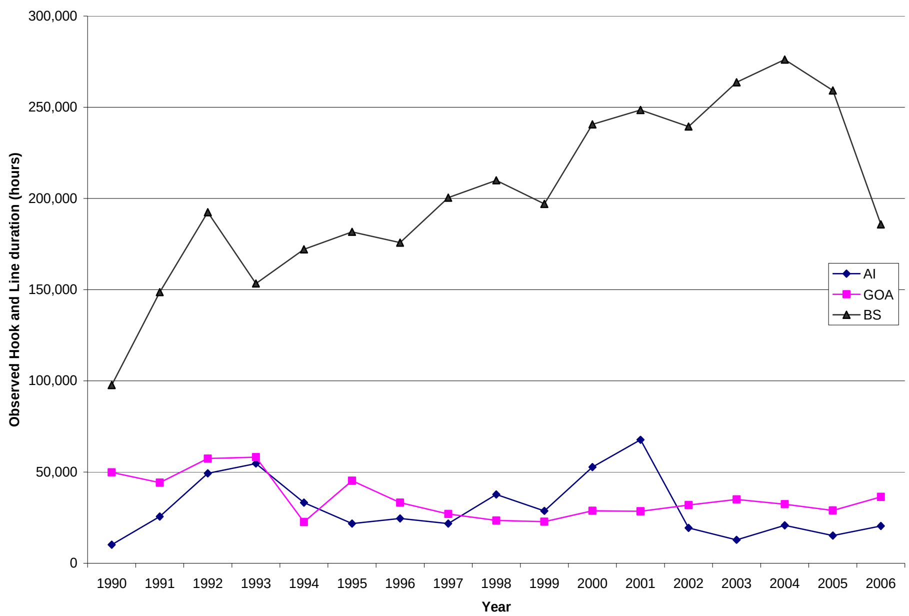

Figure 81. Estimated hook and line duration in the Gulf of Alaska, Bering Sea, and Aleutian Islands,1990-2006.

Bering Sea

For the period 1990-2006, there were a total of 198,867 observed longline sets in the Bering Sea fisheries. Spatial patterns of fishing effort were summarized on a 10km^2 grid (Figure 82). 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 2006, fishing effort was anomalously low throughout the main fishery footprint, and is not readily attributable to seasonal allocations or number of vessels fished (Figure 83).

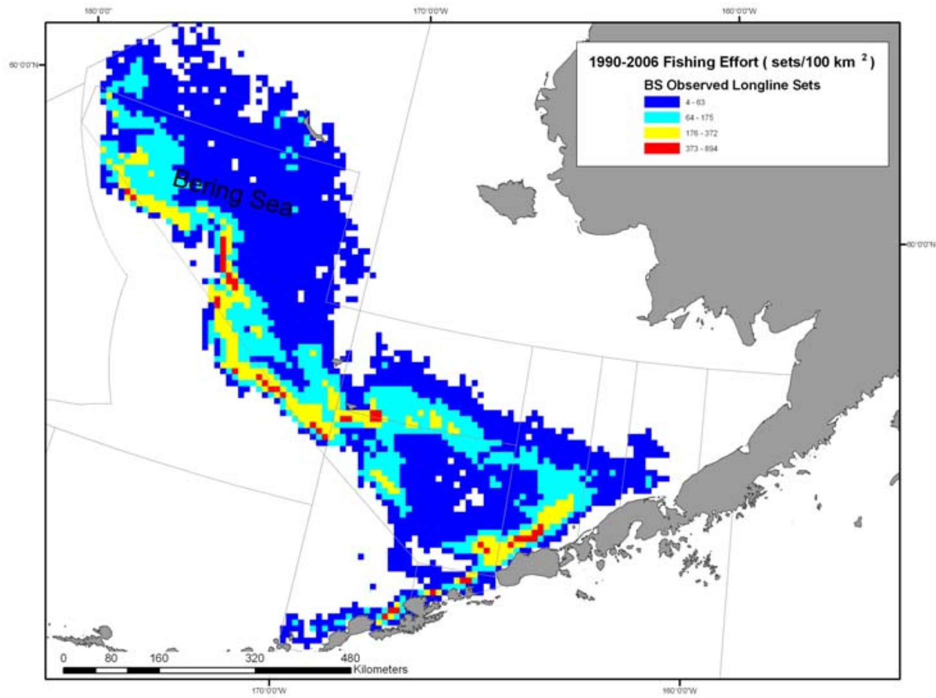

Figure 82. Spatial location and density of hook & line (longline) effort in the Bering Sea 1990-2006.

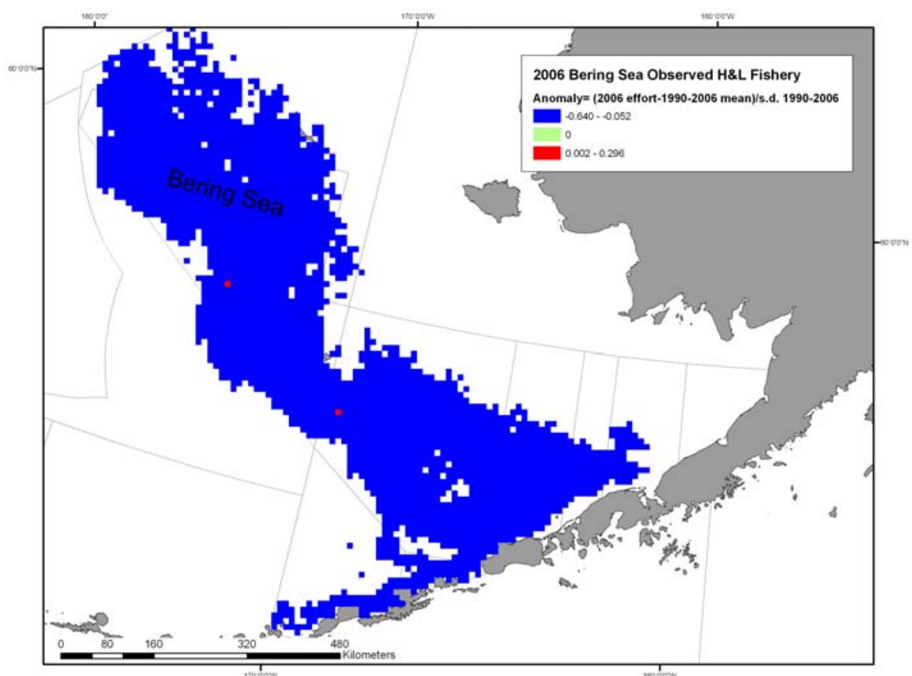

Figure 83. Anomaly plot for Bering Sea observed hook and line (longline) 2006, based on (estimated effort for 2006 - average effort from 1990-2006)/stdev(effort from 1990-2006).

Aleutian Islands

For the period 1990-2006 there were 38,839 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 84). 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 2006, fishing effort was anomalously low in areas 541 and 542 and was based primarily within the Pacific cod and sablefish fisheries. Some decreases occurred in the entire AI region with specific increases some local areas (Figure 85).

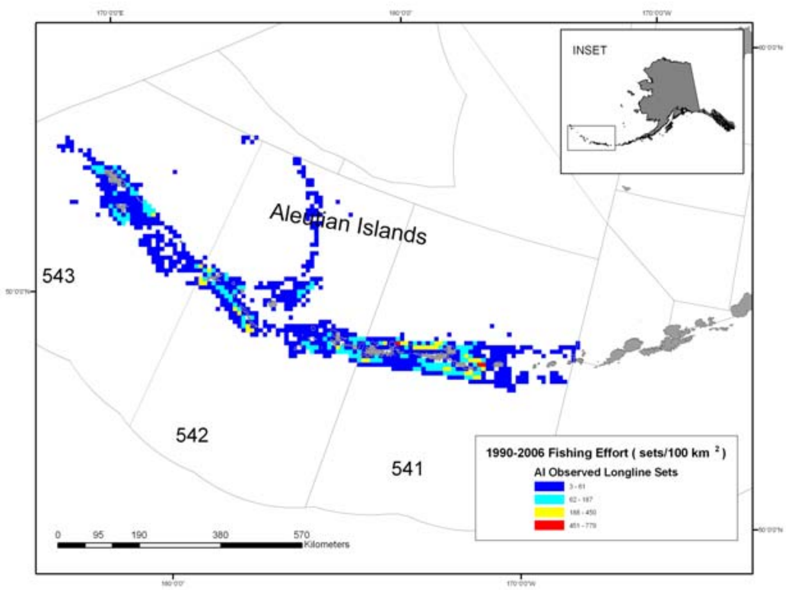

Figure 84. Spatial location and density of hook & line effort in the Aleutian Islands, 1990-2006.

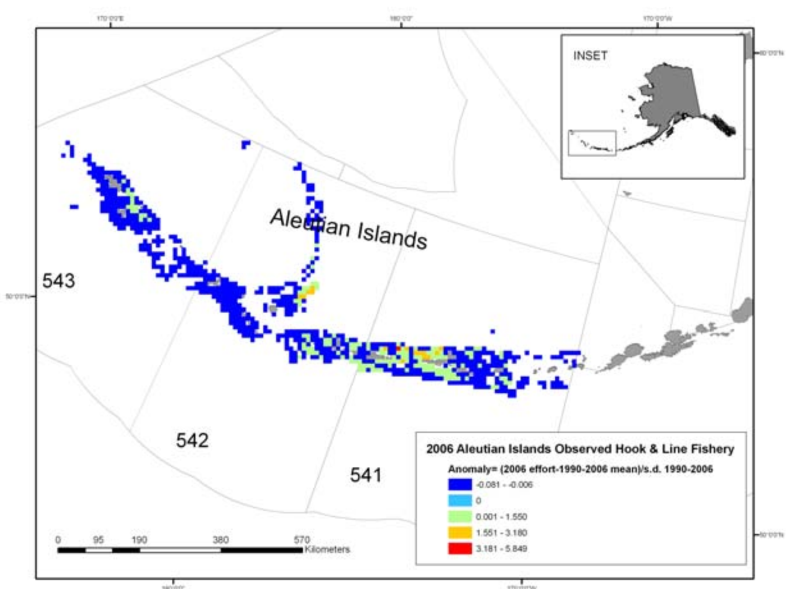

Figure 85. Anomaly plot for Aleutian Islands observed hook and line (longline) 2006, based on (estimated effort for 2006 - average effort from 1990-2006)/stdev(effort from 1990-2006).

Gulf of Alaska

For the period 1990-2006 there were 39,577 observed hook and line sets in the Gulf of Alaska. Patterns of high fishing effort were dispersed along the shelf (Figure 86). 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 2006, fishing effort anomalies were not readily attributable to seasonal allocations (Figure 87).

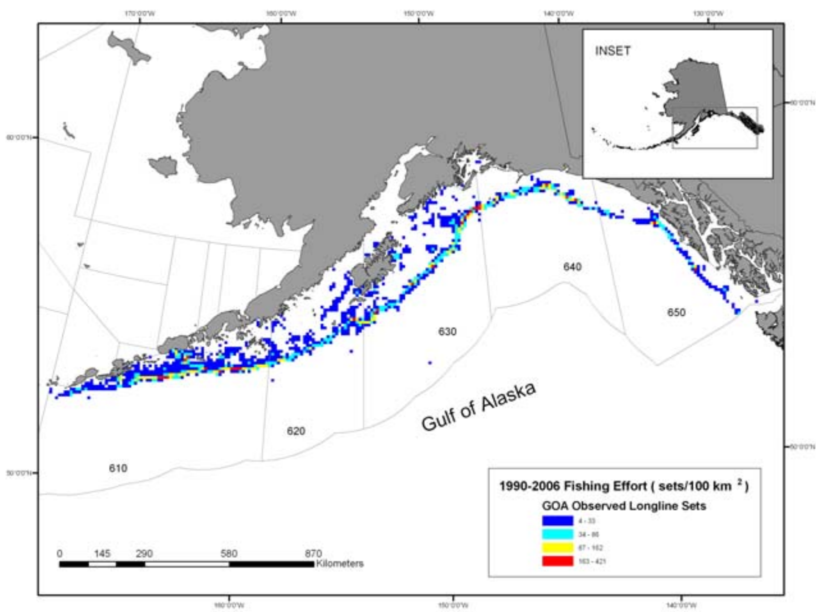

Figure 86. Spatial location and density of hook & line effort in the Gulf of Alaska, 1990-2006.

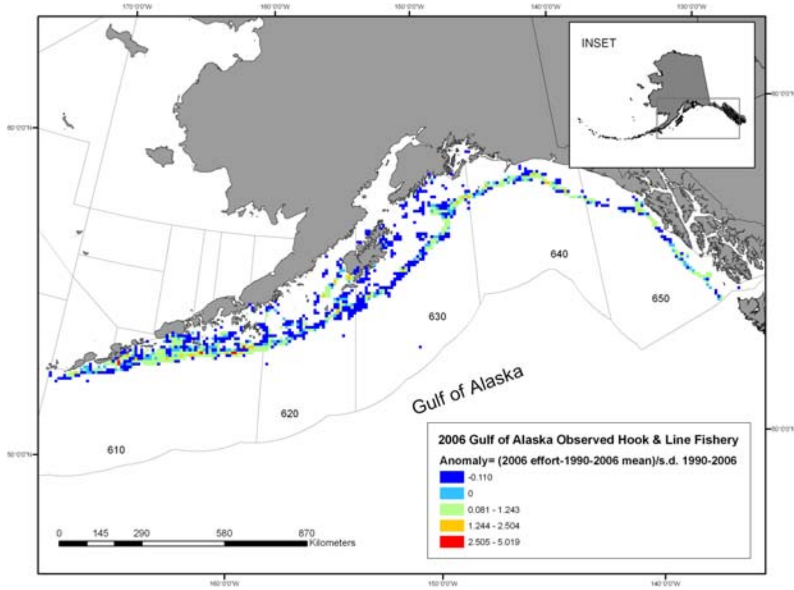

Figure 87. Anomaly plot for the Gulf of Alaska observed hook and line (longline) 2006, based on (estimated effort for 2006 - average effort from 1990-2006)/stdev(effort from 1990-2006).

Groundfish bottom trawl fishing effort in the Gulf of Alaska, Bering Sea and Aleutian Islands
Contributed by Cathy Coon, NPFMC
Contact: Cathy.Coon@noaa.gov
Last updated: October 2007

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 88). Effort in the Bering Sea remained relatively stable from 1991 through 1997, peaked in 1997, then declined (Figure 88). Some of the reduction of effort can be attributed to changes in the structure of the groundfish fisheries due to rationalization. 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, changes in environmental conditions, and/or increased bycatch rates of non-target species. These changes in effort can be observed by examining effort for the current year relative to the average effort in prior years of fishing (effort anomalies).

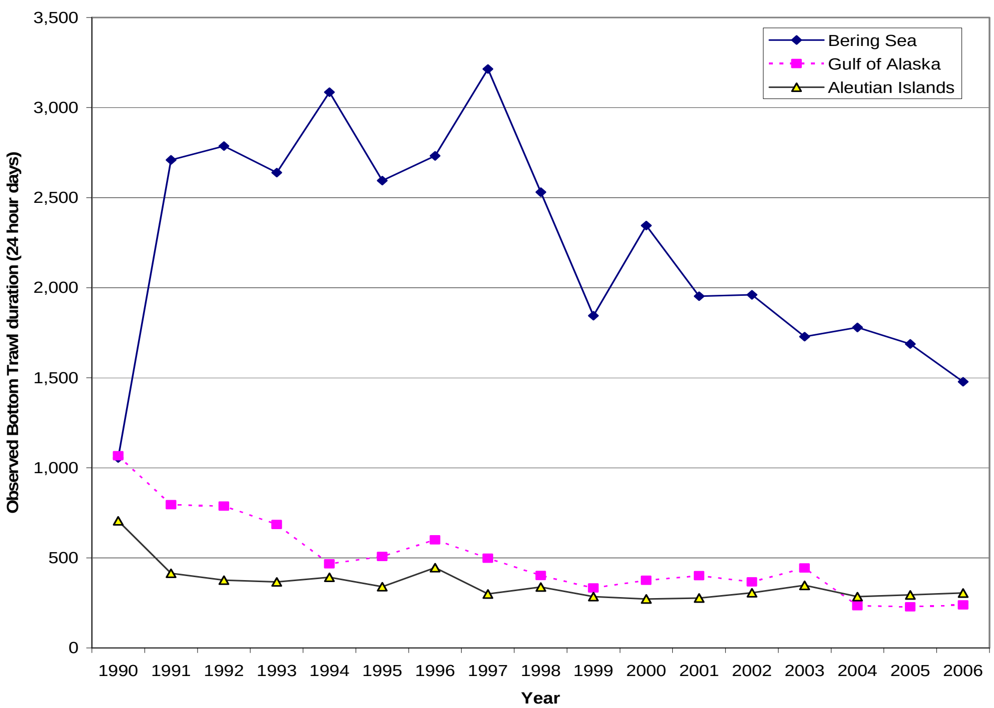

Figure 88. Annual duration in the Gulf of Alaska, Bering Sea, and Aleutian Islands of the non-pelagic trawl fisheries during 1990-2006.

Bering Sea

For the period 1990-2006, there were a total of 292,949 observed bottom trawl sets in the Bering Sea fisheries. During 2006, trawl effort consisted of 10,507 sets which was the lowest effort in the past 15 years. Spatial patterns of fishing effort were summarized on a 10 km^2 grid (Figure 89). 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. The primary catch in these areas was Pacific cod and yellowfin sole. In 2006, fishing effort was anomalously high in areas 509 and 516 (Figure 90), based on catches of Pacific cod, pollock and rockfish, and effort was low in the remaining areas of the fishing effort foot print.

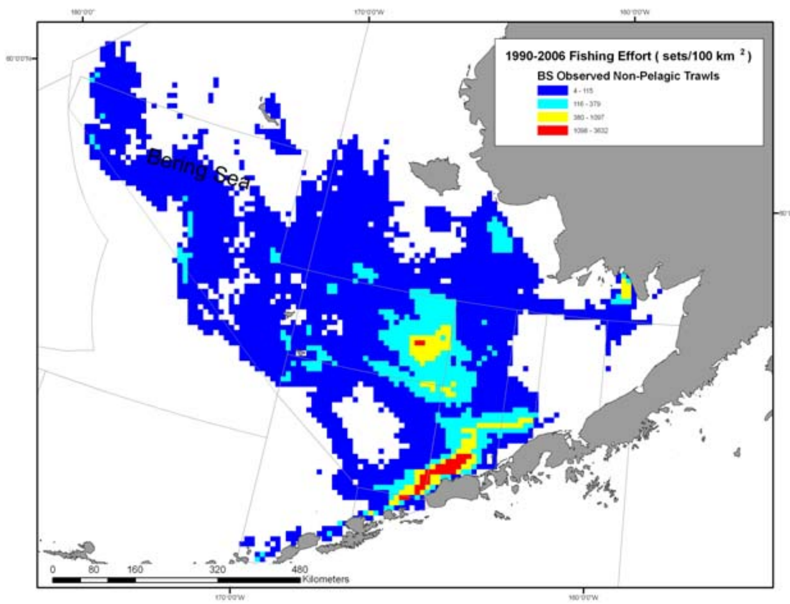

Figure 89. Spatial location and density of non-pelagic trawling in the Bering Sea, 1990-2006.

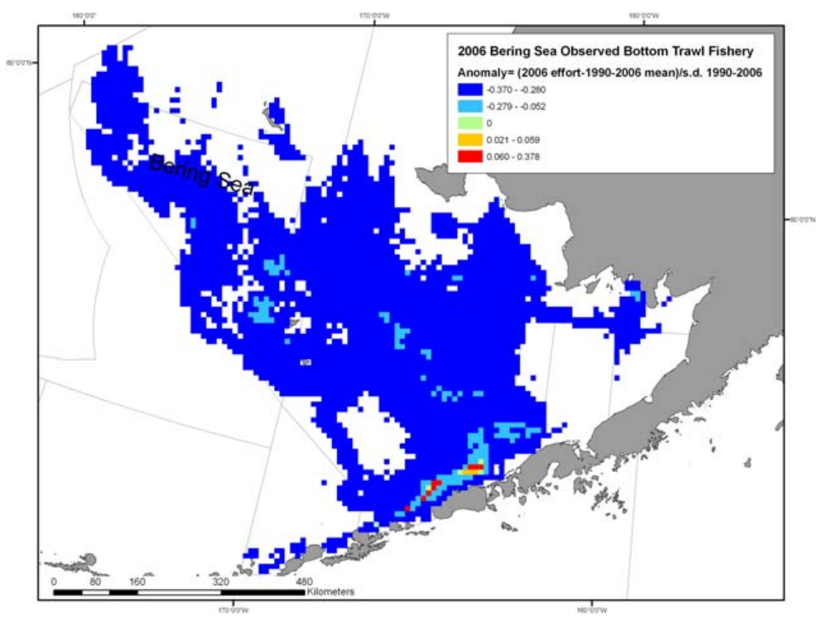

Figure 90. Anomaly plot for Bering Sea observed bottom trawling 2006, based on (estimated effort for 2006 - average effort from 1990-2006)/stdev(effort from 1990-2006).

Aleutian Islands
For the period 1990-2006 there were 47,831 observed bottom trawl sets in the Aleutian Islands. The spatial pattern of this effort was dispersed over a wide area. During 2006, the amount of trawl effort was 2,178 sets, which was the low for the 16 year period. Patterns of high fishing effort were dispersed along the shelf edge (Figure 91). 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 2006, fishing effort was anomalously high in some areas and was comprised of Atka mackerel, Pacific cod and rockfish fisheries (Figure 92). Many areas now have lower patterns of fishing which could be due to new management. In 2006, the Aleutian Islands Habitat Conservation Area (AIHCA) closed approximately 279,114 nm^2 to bottom trawl fishing in the three AI management areas.

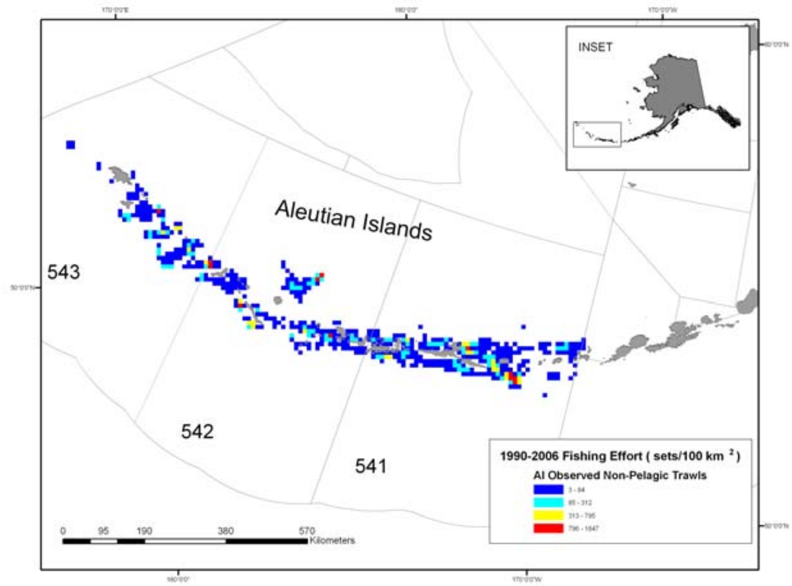

Figure 91. Spatial location and density of bottom trawl effort in the Aleutian Islands, 1990-2006.

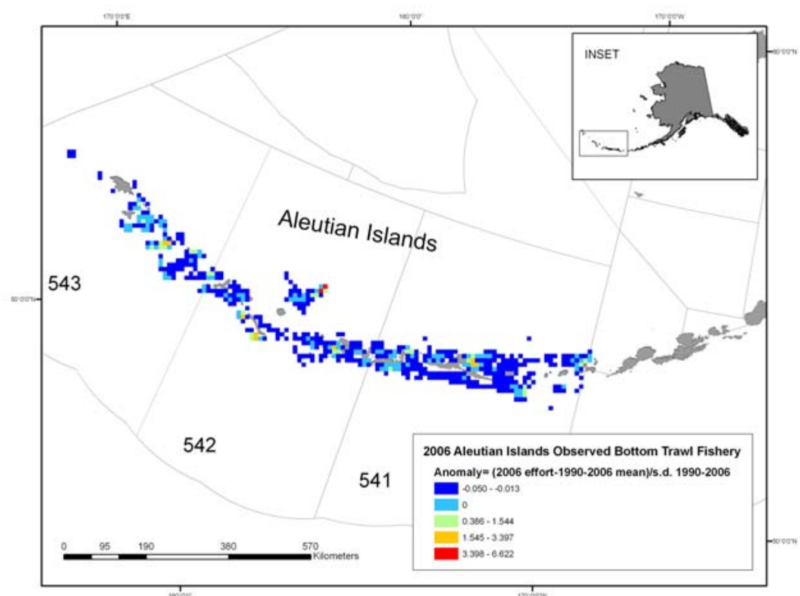

Figure 92. Anomaly plot for the Aleutian Islands observed bottom trawling 2006, based on (estimated effort for 2006 - average effort from 1990-2006)/stdev(effort from 1990-2006).

Gulf of Alaska

For the period 1990-2006 there were 80,887 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 2006, the amount of trawl effort was 2,045 sets, which was the low for the 16 year period. Patterns of high fishing effort were dispersed along the shelf edge with high pockets of effort near Chirkoff, Cape Barnabus, Cape Chiniak and Marmot Flats (Figure 93). 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 2006, fishing effort was anomalously low in most areas except a few, such as those located off Kodiak near Cape Barnabus and Marmot Flats (Figure 94).

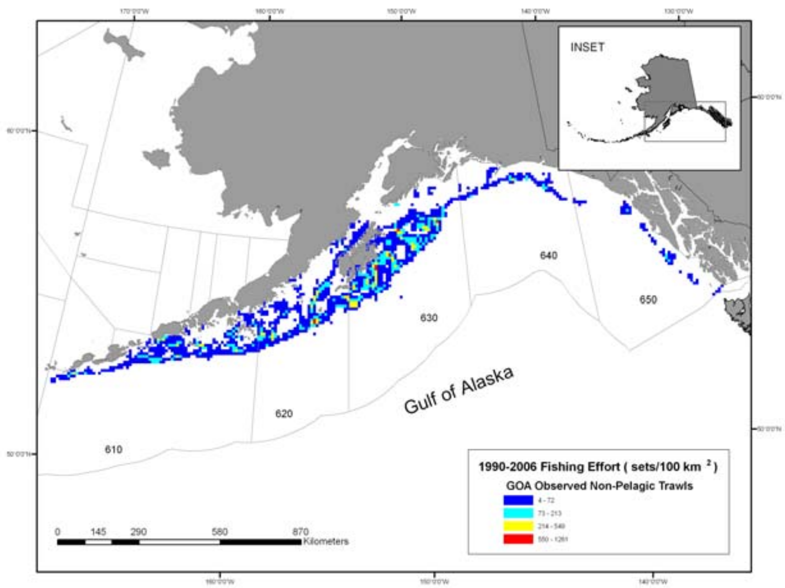

Figure 93. Spatial location and density of bottom trawl effort in the Gulf of Alaska, 1990-2006.

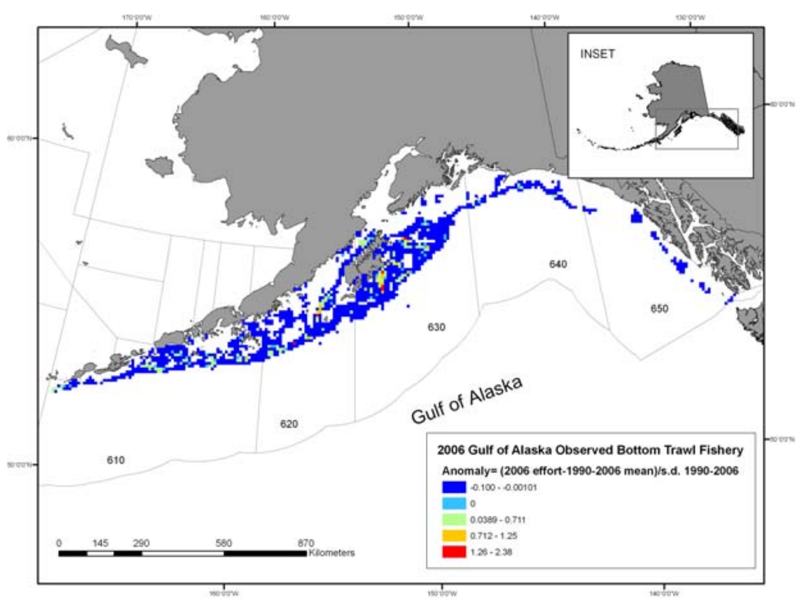

Figure 94. Anomaly plot for the Gulf of Alaska observed bottom trawling 2006, based on (estimated effort for 2006 - average effort from 1990-2006)/stdev(effort from 1990-2006).

Groundfish pelagic trawl fishing effort in the Gulf of Alaska, Bering Sea and Aleutian Islands
Contributed by Cathy Coon, NPFMC
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Effort in the pelagic trawl fisheries in the Bering Sea, Aleutian Islands, and Gulf of Alaska is shown in Figure 95. The magnitude of the Bering Sea trawl fisheries effort is four times larger than effort in both the Aleutian Islands and Gulf of Alaska combined. While this fishery is much larger than in the other two regions, smaller vessels that only require 30% observer coverage occur in larger proportions in the GOA and AI resulting in less documented fishing effort. Figures 96-100 show the spatial patterns and intensity of pelagic trawl effort by region, 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), changes in markets, changes in environmental conditions, and increased bycatch rates of non-target species. The Bering Sea pollock fishery (by volume) is the largest U.S. Fishery, and most of it is harvested with pelagic trawl nets. Effort in the Bering Sea has remained relatively stable from 1995 through present. Some of the consistency of effort can be attributed to changes in the structure of the groundfish fisheries due to rationalization. Effort in both the GOA and AI has decreased in the last six years, in part due to restricted fishing from Steller sea lion protection measures.

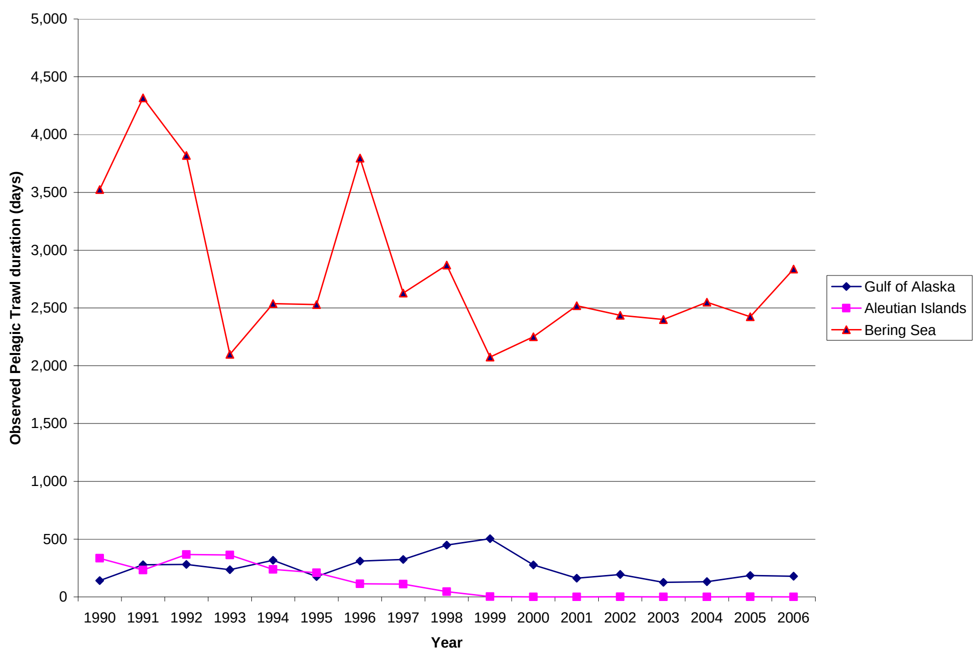

Figure 95. Observed pelagic trawl time in the Gulf of Alaska, Aleutian Islands, and Bering Sea, 1990-2006.

Bering Sea
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 species harvested within the eastern Bering Sea is walleye pollock (*Theragra chalcogramma*). Pollock occur on the sea bottom, the midwater and up to the surface. Most catch of pollock is taken at 50-300m.

In 1990, concerns about bycatch and seafloor habitats affected by this large fishery led the North Pacific Fishery Management Council to apportion 88 percent of TAC to the pelagic trawl fishery and 12 percent to the non-pelagic trawl fishery (North Pacific Fishery Management Council, 1999). For practical purposes, non-pelagic 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.

Pollock fishermen formed fish harvesting cooperatives to “rationalize” fishing activities, including resolving problems of overcapacity, promoting conservation and enhancing utilization of fishery resources. Under a co-op arrangement, fewer vessels are fishing and daily catch rates by participating vessels are significantly reduced since the “race for fish” ended in 1999.

Patterns in recent fishing effort (2006) indicate lower than average effort throughout the main footprint of the fishery (Figure 96). Some changes in fleet movement may be attributed to the AFA fishing coop structure and voluntary rolling hotspot closures to reduce the incidental take of Chinook and “Other Salmon” bycatch.

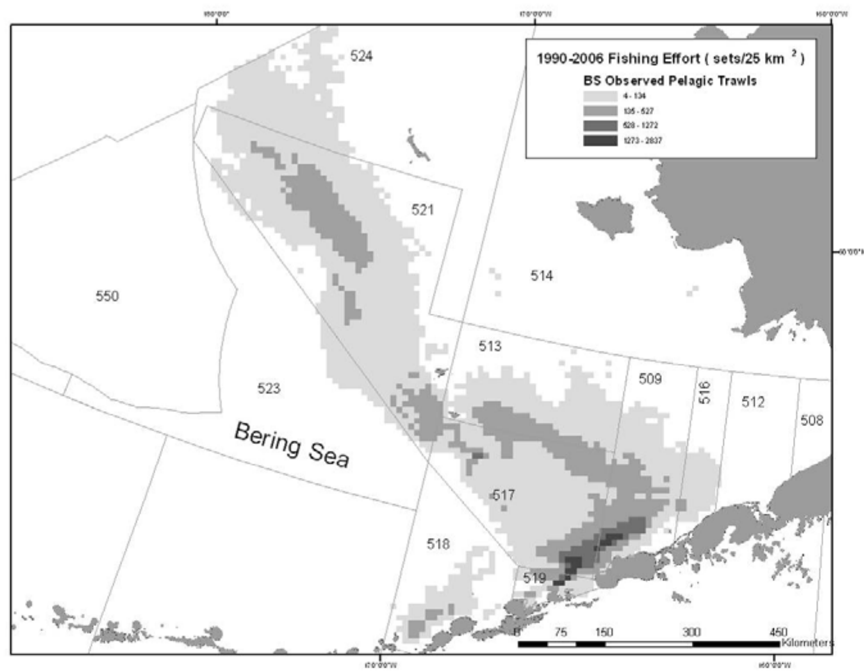

Figure 96. Spatial location and density of pelagic trawl effort in the eastern Bering Sea, 1990-2006.

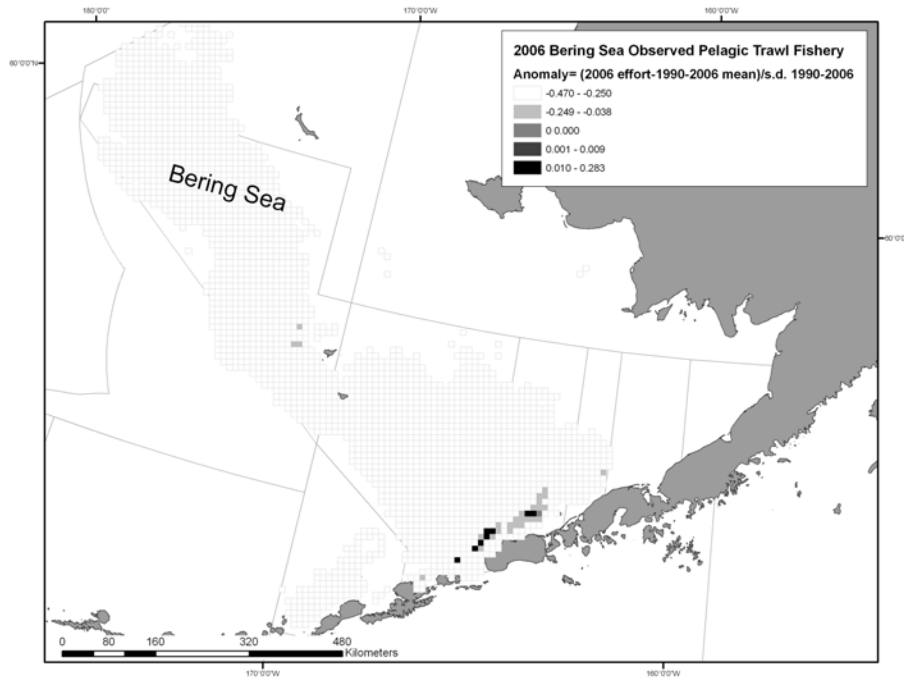

Figure 97. Anomaly plot for the Bering Sea observed pelagic trawling 2006, based on (estimated effort for 2006 - average effort from 1990-2006)/stdev (effort from 1990-2006).

Aleutian Islands

For the period 1990-2006 there were 6,991 observed bottom trawl sets in the Aleutian Islands. The spatial pattern of this effort is dispersed over a wide area. In 2001, 2003, 3004, and 2006 there were no observed pelagic trawl sets. Patterns of high fishing effort are dispersed along the shelf edge.

Management measures have affected the fishing effort in the Aleutian Islands. In recent years pollock fishing in the Aleutian Islands has been restricted by the Stellar Sea Lion Closures. The western distinct population segment of Steller sea lions occurs in the Aleutian Islands subarea and is listed as endangered under the Endangered Species Act (ESA). Critical habitat has been designated for this area, including waters within 20 nautical miles (nm) of haulouts and rookeries. Pollock is a principal prey species of Steller sea lions.

Aleutian Islands pollock had been harvested primarily in Steller sea lion critical habitat in the past until the Aleutian Islands subarea was closed to pollock fishing in 1999. In 2003, the Aleutian Islands subarea was opened to pollock fishing outside of critical habitat under regulations implementing the current Steller sea lion protection measures. Part of the 2004 Consolidated Appropriations Act required that the directed fishing allowance of pollock in the Aleutian Islands subarea be allocated to the Aleut Corporation. The Aleut Corporation harvested only about 1 percent of its initial 2005 pollock allocation due, in part, to difficulty in finding pollock. To harvest the fish, the Aleut Corporation is allowed to contract only with vessels under 60 feet length overall or vessels listed under the American Fisheries Act. The smaller vessels do not require observer coverage.

Additionally, closures implemented in 2006 as part of protection for Essential Fish Habitat will limit the areas where bottom trawl fishing can occur. The Aleutian Islands Habitat Conservation Area (AIHCA) closed approximately 279,114 nm2 to bottom trawl fishing in the three AI management areas.

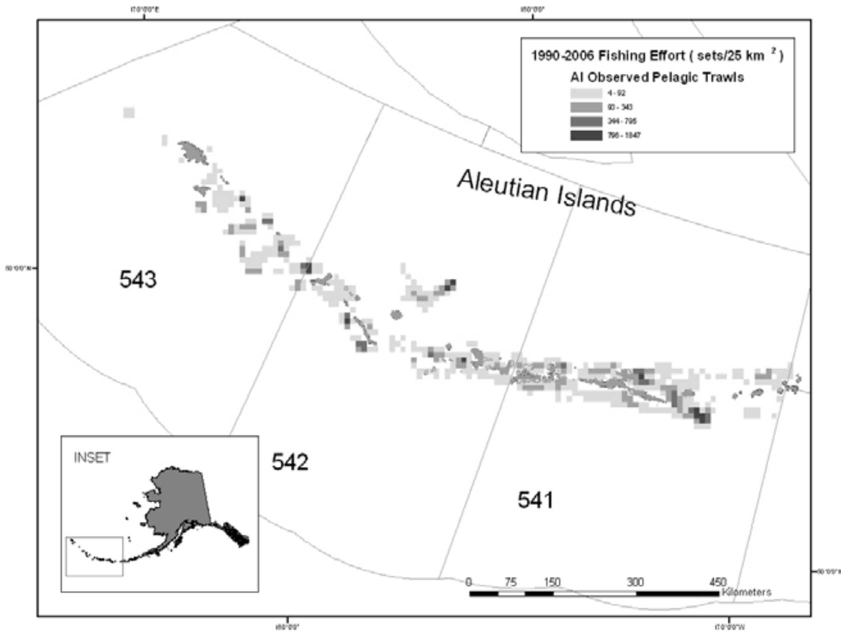

Figure 98. Spatial location and density of pelagic trawl effort in the Aleutian Islands, 1990-2006.

Gulf of Alaska

The GOA pelagic trawl fishery is a pollock fishery. The fleet is comprised of trawl catcher vessels that deliver their catch onshore for processing. For the period 1990-2006 there were 28,088 observed pelagic trawl sets in the Gulf of Alaska. The spatial pattern of this effort is much more dispersed than in the Bering Sea region. During 2006, the amount of trawl effort was 1,099 sets which was the low for the 16 year period. Areas of high fishing effort are dispersed along the shelf edge with high pockets of effort near Chirkoff, Cape Barnabus, Cape Chiniak, and Marmot Flats. A large portion of the trawl fleet in Kodiak is comprised of smaller catcher vessels that require 30% observer coverage, indicating that the actual amount of trawl effort would be much higher since a large portion is unobserved.

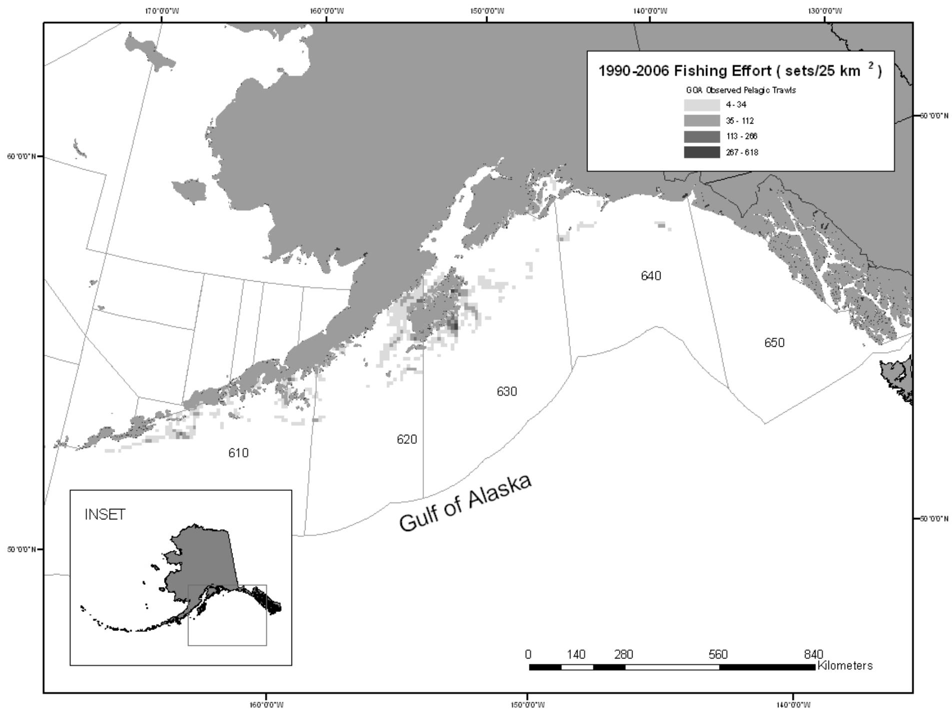

Figure 99. Spatial location and density of pelagic trawl effort in the Gulf of Alaska, 1990-2006.

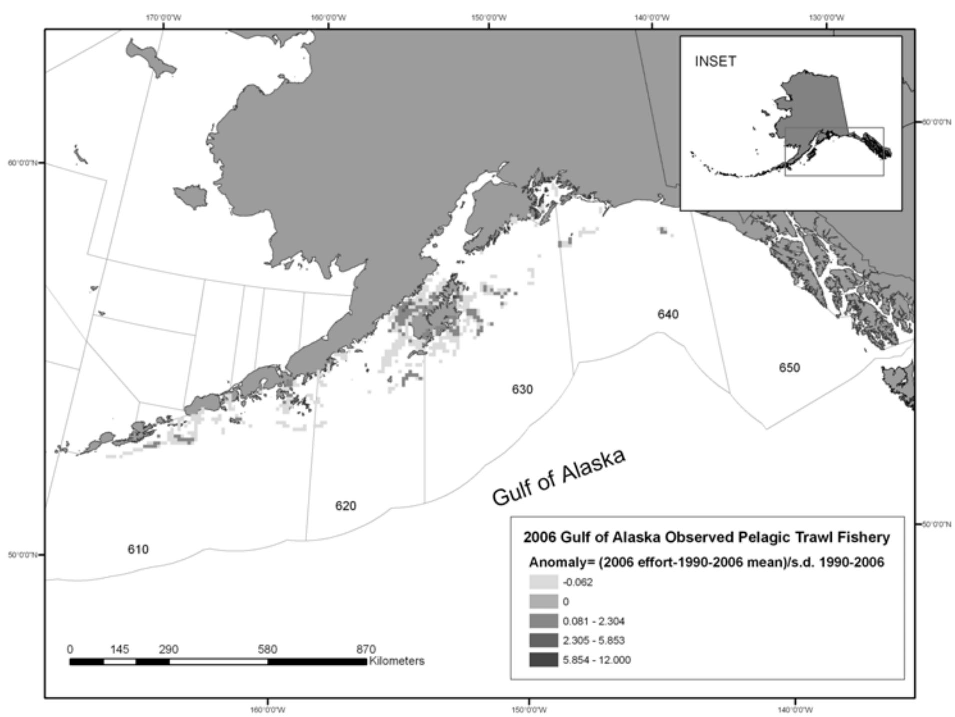

Figure 100. Anomaly plot for the Gulf of Alaska observed pelagic trawling 2006, based on (estimated effort for 2006 - average effort from 1990-2006)/stdev (effort from 1990-2006).

Pot fishing effort in the Gulf of Alaska, Bering Sea, and Aleutian Islands
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The amount of effort (as measured by the number of pots fished documented by an observer) in pot fisheries is used as an indicator for fishing effects. Effort in the pot fisheries in the Bering Sea, Aleutian Islands, and Gulf of Alaska is shown in Figure 101. The amount of pot effort fluctuates annually by region. However, annual observed estimates of pots set does not reflect the entire pot fishery. Most of the vessels using pot gear are catcher vessels either under 60' or between 60'-125'. These vessels either do not require an observer present or only on 30% of the fishing days. Fluctuations in the pot cod fishery may also be dependent on the duration and timing of the crab fisheries.

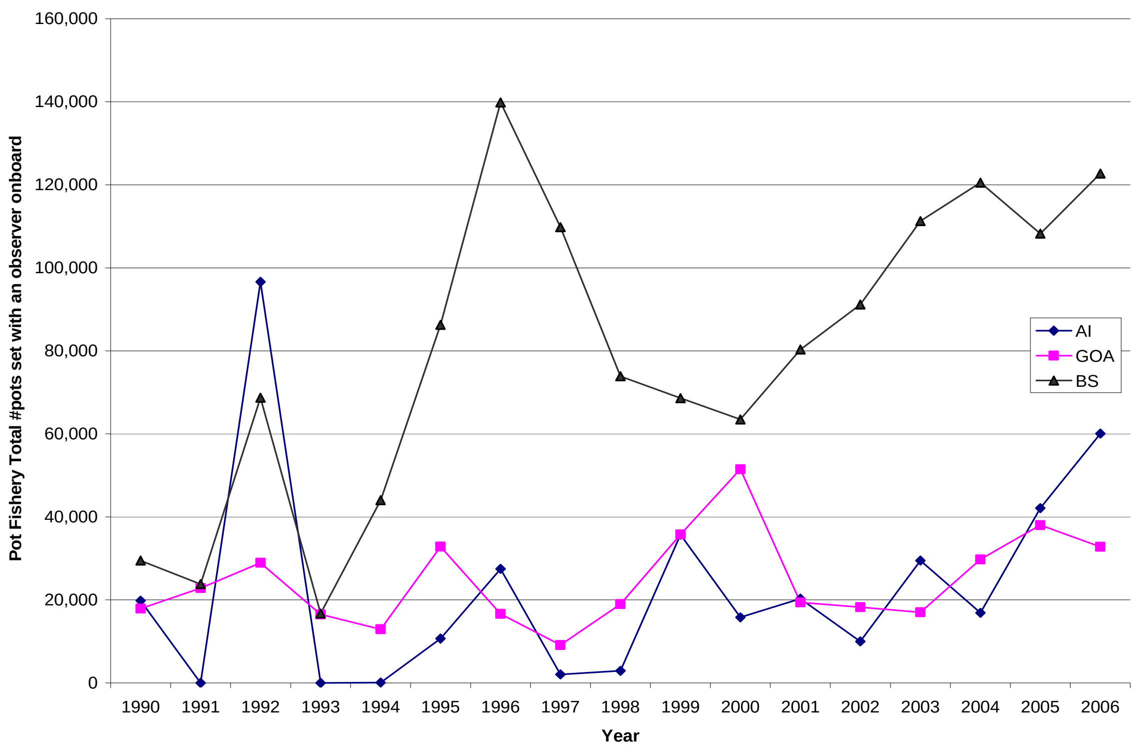

Figure 101. Estimated pot time in the Gulf of Alaska, Bering Sea, and Aleutian Islands during 1990-2006.

Pacific Cod is the primary groundfish fishery utilizing pot gear. The average weight of a fish is 8 to 9 pounds. The pot cod fishery is prosecuted with square pots set on single lines. The fishery begins at the end of the opilio crab fishery (March in recent years) and stops in April; a second season occurs during September and October (until the Bristol Bay red king crab fishery starts). Pots used in a directed cod fishery are modified crab pots, which are constructed with a steel bar frame (1.25-inch-diameter) and covered with tarred nylon mesh netting (3.5-inch stretched mesh). Pot sizes range from 6 to 8 feet square, with the average vessel using 7- by 7-foot pots. Each pot has two tunnel openings on opposite sides, with plastic "finger" funnels to retain the fish. An escape panel of untreated cotton must be sewn into the mesh. The pot is attached with a 6- to 8-foot bridle. The lower shots of line are made of floating poly, and the upper shot of line is made of sinking line. Attached to the line is a plastic buoy (bag), with an auxiliary buoy attached on a tether line.

The average number of pots per vessel is 120 with an estimated total of 6,000 pots in the fishery. The average number of days of fishing per year is 40 to 50 days. Pots are set and retrieved once every 24 hours. Pots are baited with chopped herring placed in hanging bait buckets in the center of the pot. On most vessels, the pot is tipped into the sea with a pot launcher. The shots of line are thrown overboard, followed by the buoys, and the pot sinks to the bottom. The pot rests directly on the bottom. The pot remains stationary on the bottom until it is retrieved, generally about 24 hours later. Pots are retrieved as follows: the crewman throws a hook between the buoys to get the line. The line is fed into the hauler, and the pot is brought aboard by a crane and placed on the pot hauler. Pacific cod are dumped into totes. The fish are put on ice below decks. The pots are rebaited and reset or stored if they are being moved or it is the end of the season. There is a very small footprint in this fishery (an estimated 0.17-square-mile footprint combined).

Bering Sea

For the period 1990-2006, there were a total of 28,805 observed pot sets in the Bering Sea fisheries. Spatial patterns of fishing effort were summarized on a 10km^2 grid (Figure 102). Areas of high fishing effort are north of Akutan and Unalaska. This fishery occurs mainly for Pacific cod which form dense aggregations for spawning in the winter months. Fishing effort anomalies are not readily attributable to seasonal allocations. In 2006, fishing effort was anomalously low throughout the main fishery footprint, with high points in areas 518-519, and is not readily attributable to seasonal allocations (Figure 103). Spatial and temporal changes to the fishery have occurred due to current Steller Sea Lion regulations.

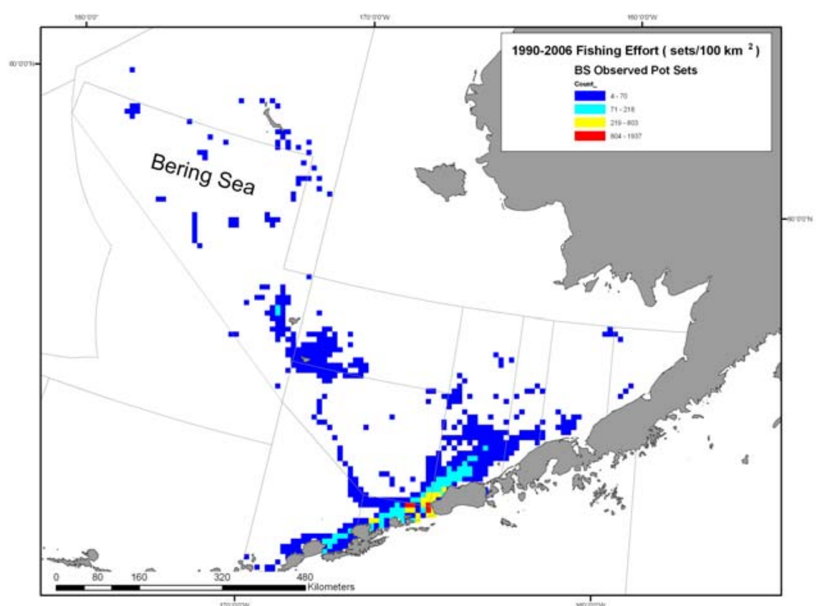

Figure 102. Spatial location and density of pot effort in the Bering Sea, 1990-2006.

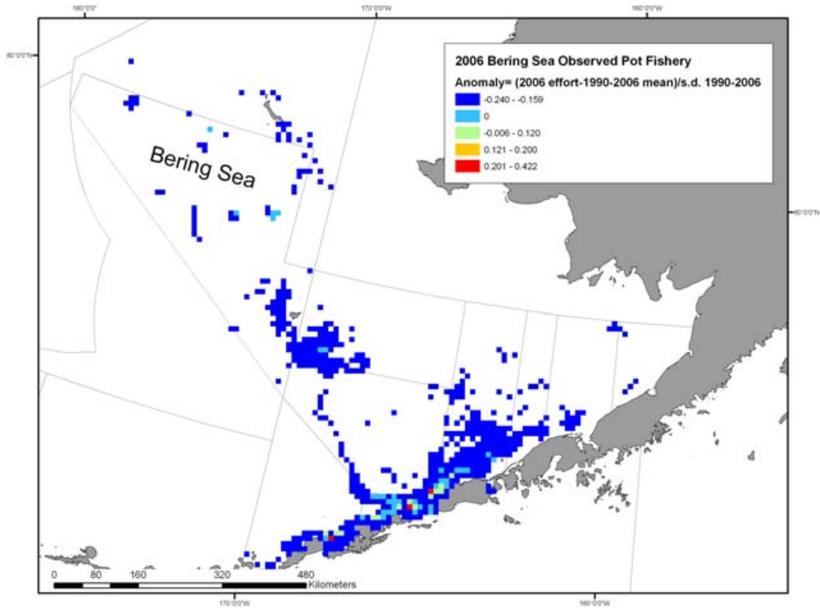

Figure 103. Anomaly plot for Bering Sea observed pot fishery in 2006, based on (estimated effort for 2006 - average effort from 1990-2006)/stdev(effort from 1990-2006).

Aleutian Islands

For the period 1990-2006 there were 9,913 observed pot sets sets in the Aleutian Islands. The spatial pattern of this effort is dispersed over a wide area. High fishing effort was dispersed along the shelf edge with high effort near Attu and Agattu Islands (Figure 104). In 2006, fishing effort was anomalously high near Atka Island and low in the entire Western and Central Aleutian Island reporting areas (Figure 105).

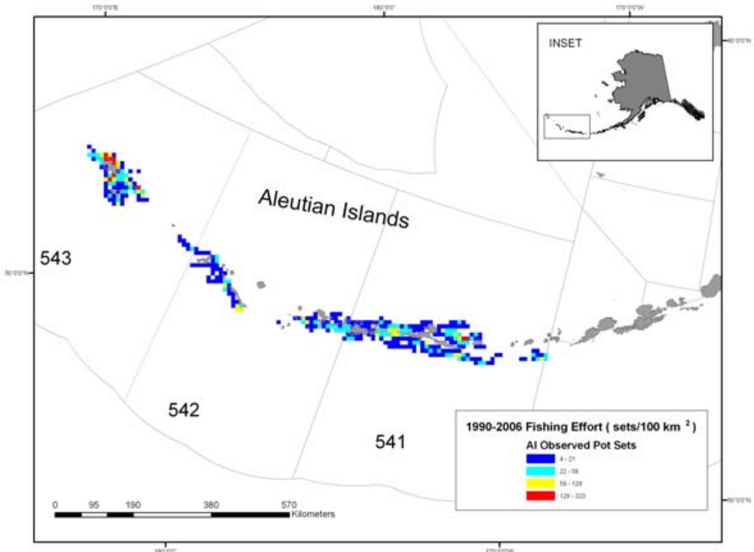

Figure 104. Spatial location and density of pot effort in the Aleutian Islands, 1990-2006.

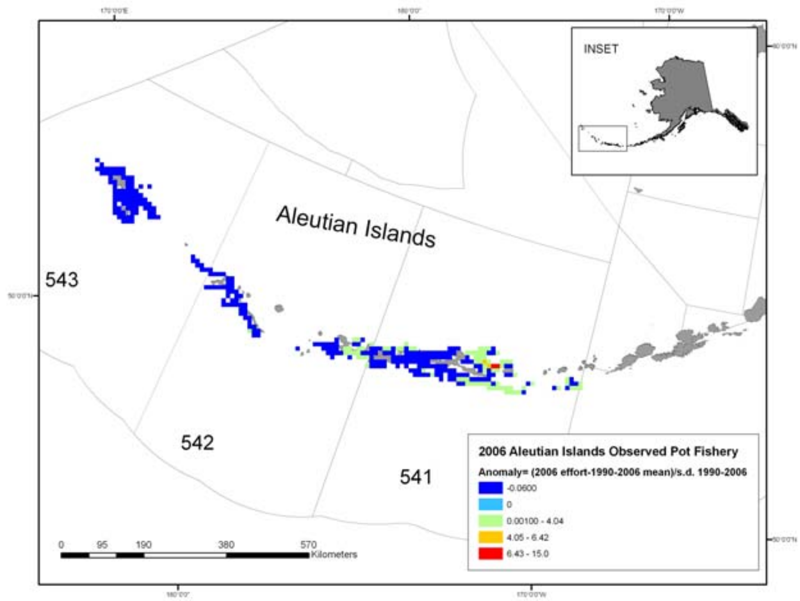

Figure 105. Anomaly plot for Aleutian Islands observed pot 2006, based on (estimated effort for 2006 - average effort from 1990-2006) / standard deviation (effort from 1990-2006).

Gulf of Alaska

For the period 1990-2006 there were 12,489 observed pot sets in the Gulf of Alaska. Patterns of high fishing effort were dispersed along the shelf with high concentrations around Kodiak Island (Figure 106). Fishing effort in 2006 was lower than the long-term average across most of the previously fished areas, with increased effort near Kodiak Island and King Cove (Figure 107). Approximately 100 boats participate in this fishery. Vessels used in the inshore fishery are all catcher vessels of small (less than 60-foot LOA) and medium size (60- to 125-foot LOA). The offshore fishery includes some catcher-processors ranging from 90 to over 125 feet. The A season fishery begins on January 1st and concludes in early March. The B season fishery opens September 1 and can be expected to last 6 weeks or less. There is also a state-managed fishery in state waters.

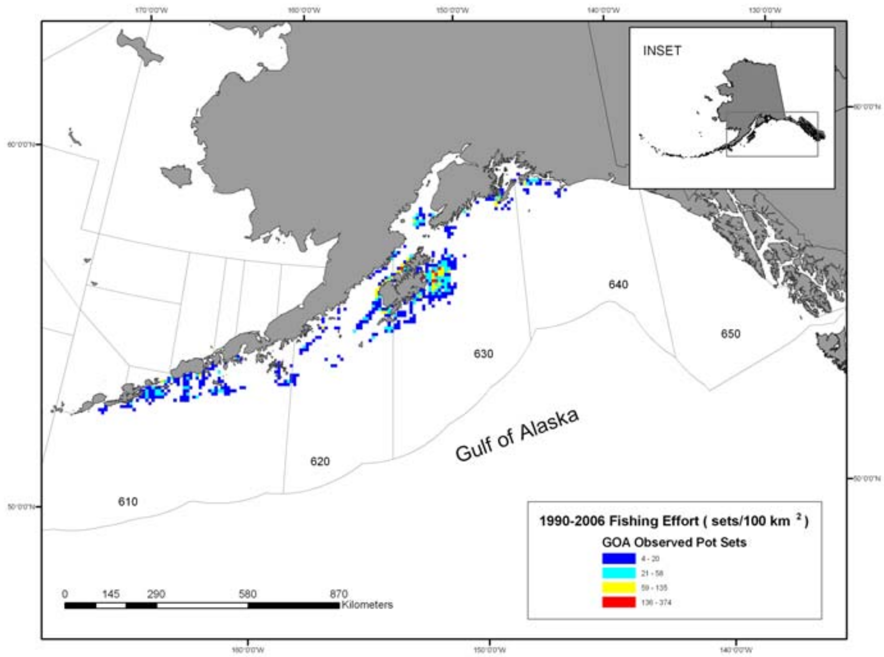

Figure 106. Spatial location and density of pot effort in the Gulf of Alaska, 1990-2006.

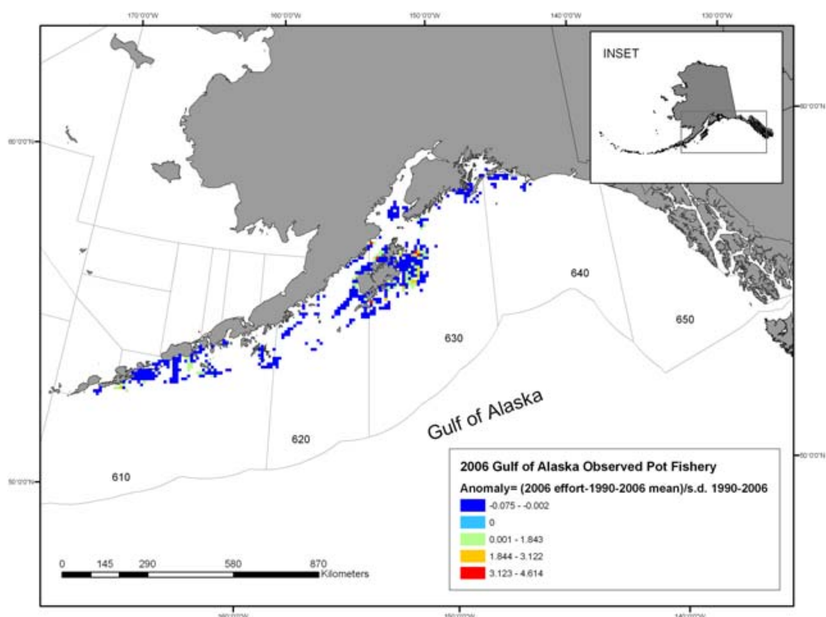

Figure 107. Anomaly plot for the Gulf of Alaska observed pot 2006, based on (estimated effort for 2006 - average effort from 1990-2006)/ st dev(effort from 1990-2006).

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

Trophic level of the catch

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Last updated: October 2007

To determine whether North Pacific fisheries were "fishing-down" the food web, the total catch, trophic level of the catch, and the Pauly et al. (2000) Fishery In Balance (FIB) Index in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska areas were determined. To estimate the trophic level of the catch, the catch of each species in a given year was multiplied by the trophic level of that species; products were summed across all species in a given year and divided by the total catch in that year. To calculate the FIB index (Pauly et al. 2000):

$$FIB=\log(Y_i \cdot (1/TE)^{TL_i})-\log(Y_0 \cdot (1/TE)^{TL_0}),$$

where Y_i is the catch in year i, TL_i the mean trophic level in the catch in year i, TE the transfer efficiency (assumed to be 0.1), and 0 refers to a year used as a baseline (first year in the time series).

Total catch levels and composition for the three regions show the dominance of walleye pollock in the catch from around the 1970s to at least the early 1990s (Figure 108). Other dominant species groups in the catch were rockfish prior to the 1970s in the Aleutian Islands and the Gulf of Alaska, and Atka mackerel in the 1990s in the Aleutian Islands. All these species are primarily zooplankton consumers and thus show alternation of similar trophic level species in the catch rather than a removal of a top-level predator and subsequent targetting of a lower trophic level prey.

Stability in the trophic level of the total fish and invertebrate catches in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska (Figure 109) are another indication that the "fishing-down" effect is not occurring in these regions. Although there has been a general increase in the amount of catch since the late 1960s in all areas, the trophic level of the catch has been high and stable over the last 25 years.

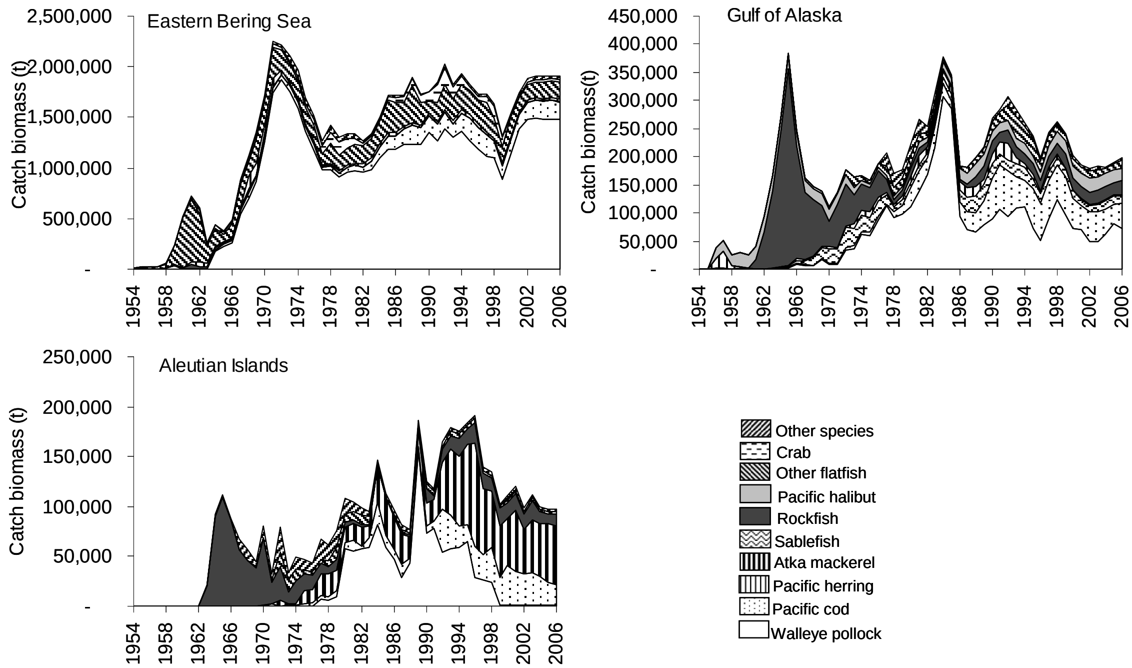

Figure 108. Total catch biomass (except salmon) in the EBS, GOA, and AI, 1954-2006.

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 109) to allow an assessment of the ecological balance of the fisheries. Unlike other regions in which this index has been calculated, such as the Northwest Atlantic, catches and trophic level of the catch in the EBS, AI, and GOA have been relatively constant and suggest an ecological balance in the catch patterns.

The single metrics of TL or FIB indices, however, may hide details about fishing events. We, therefore, plotted the trophic level of catches in the BS, AI, and GOA in a similar style to that recently published by Essington et al. (2006; see Figure 2 in the Ecosystem Assessment, this report). This further examination supports the idea that fishing-down the food web is not occurring in Alaska, and there does not appear to be a serial addition of lower-trophic-level fisheries in the BS or GOA. In general, it appears that fishing events are episodic in the AI and GOA, and pollock dominate catches in the BS.

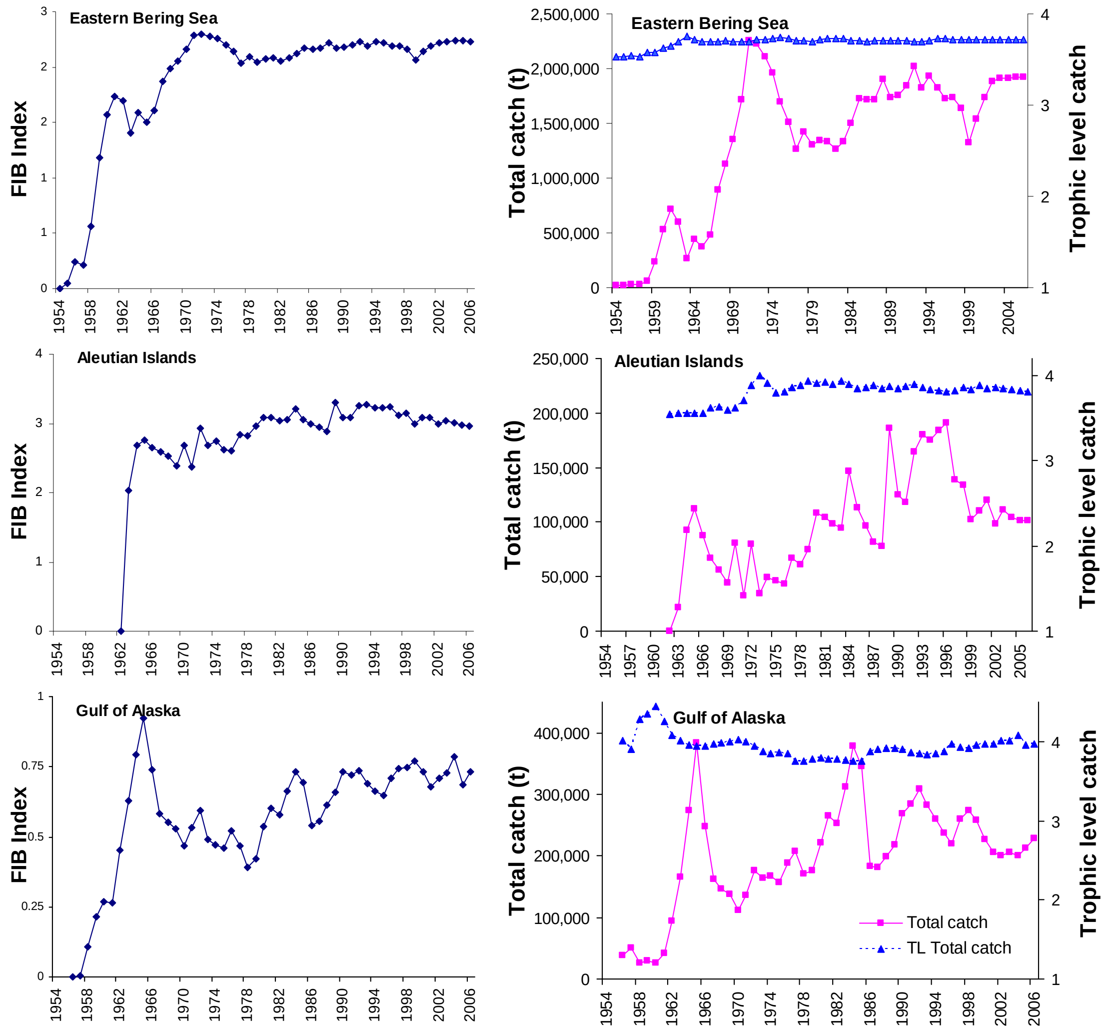

Figure 109. Total catch (groundfish, herring shellfish, and halibut) and trophic level of total catch in the EBS/AI and GOA, 1954-2006 (right column). Left column shows FIB index values for the EBS, AI and GOA, 1954-2006.

Fish Stock Sustainability Index and status of groundfish, crab, salmon and scallop stocks

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Last Updated: October 2007

Description of index: The Fish Stock Sustainability Index (FSSI) is a performance measure for the sustainability of fish stocks selected for their importance to commercial and recreational fisheries (http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm). The FSSI will increase as overfishing is ended and stocks rebuild to the level that provides maximum sustainable yield. The FSSI is calculated by assigning a score for each fish stock based on the following rules:

1. Stock has known status determinations:
    a) overfishing 0.5
    b) overfished 0.5
2. Fishing mortality rate is below the “overfishing” level defined for the stock 1.0
3. Biomass is above the “overfished” level defined for the stock 1.0
4. Biomass is at or above 80% of maximum sustainable yield (MSY) 1.0
(this point is in addition to the point awarded for being above the “overfished” level)

The maximum score for each stock is 4. The value of the FSSI is the sum of the individual stock scores. Since there are 230 stocks in the U.S, an overall FSSI score of 920 would be achieved if every stock scored a 4. In the Alaska Region, there are 35 FSSI stocks and an overall FSSI of 140 would be achieved if every stock scored the maximum value, 4.

Many species in Alaska are monitored as part of a group or complex, but are considered individually for the purposes of the report. The overfishing determination for the individual species is listed as “unknown”, but the species’ complex is determined to be “not subject to overfishing” based on the abundance estimates for the entire complex. This determination is applicable for some sharks, skates, sculpins, octopus, and squid complexes in the GOA Groundfish FMP. In the BSAI Groundfish FMP, similar determinations are made for some stocks in the sharks, skates, sculpins, octopus, rockfish, and flatfish complexes.

Status and trends:

No BSAI or GOA groundfish stock or stock complex is overfished and no BSAI or GOA groundfish stock or stock complex is being subjected to overfishing. Halibut is a major stock (not included in Table 12, since it is jointly managed with the West Coast) that is not considered subject to overfishing, is not approaching an overfished condition, and is not considered overfished. Two stocks are considered overfished: Pribilof Island blue king crab and St. Matthew Island blue king crab (Table 12). Four stocks of crabs are under continuing rebuilding plans: BS snow crab, EBS tanner crab, Pribilof Island blue king crab, and St. Matthew Island blue king crab. Table 12 summarizes the status of Alaskan groundfish, crab, salmon and scallop stocks or stock complexes managed under federal fishery plans in 2007 from the Annual Report on Status of Stocks available on the web at:
http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm

The current value of the FSSI for the U.S. is 516 of a possible 920, based on updates through October 15, 2007. The current overall Alaska FSSI is 114.5 of a possible 140, based on updates through October 15, 2007 (Table 13). The overall Bering Sea score is 67.5 of a possible maximum score of 88. The BSAI groundfish score is 49.5 of a maximum possible 52 and BSAI king and tanner crabs score 18 of a possible score of 36. The Gulf of Alaska groundfish score is 43 of a maximum possible 48. The sablefish, which are managed as a BSAI/GOA complex, score is 4.

Since August 2006, changes in overfished status and/or score of FSSI stocks as of August 18, 2006 in the Alaska Region include:

1. Aleutian Islands Walleye pollock: now considered not overfished and not approaching an overfished condition. Previously, these were undefined or unknown for this stock.

Factors causing trends: The groundfish stocks that had low scores in the BSAI include rougheye rockfish (1.5). The reasons for this low score are: it is undefined whether this stock is overfished and unknown if it is approaching an overfished condition.

The stocks that scored low in the GOA are shortspine thornyhead rockfish (indicator species for thornyhead rockfish complex) and yelloweye rockfish (indicator species for demersal shelf rockfish complex), which both scored 1.5. The reasons for these low scores are: it is undefined whether these species are overfished and unknown if they are approaching an overfished condition.

Table 12. Description of major and minor stocks managed under federal fishery management plans off Alaska, 2007. (Major stocks have landings of 200 thousand pounds or greater.)

		Overfishing?					Overfished?					
Stock Group	Number of Stocks and Stock Complexes	Yes	No	Not Known	Not Defined	NA	Yes	No	Not Known	Not Defined	NA	Approaching Overfished Condition
FSSI	35	0	32	3	0	0	2	27	0	6	0	0
Non-FSSI	34	0	25	8	1	0	0	6	0	28	0	0
Total	69	0	57	11	1	0	2	33	0	34	0	0

Table 13. This table was adapted from the Status of U.S. Fisheries website, which is updated quarterly: http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm . The information presented in this table was updated as of October 15, 2007.

Fishery Management Plan	**Stock**	**Overfishing? (Is Fishing Mortality above Threshold?) Post SFA**	**Overfished? (Is Biomass below Threshold?) Post SFA**	**Approaching Overfished Condition?**	**Management Action Required**	**Rebuilding Program Progress**	**FSSI**
GOA Groundfish	Walleye Pollock - Western/Central	No	No	No	N/A	N/A	4
GOA Groundfish	Pacific Cod	No	No	No	N/A	N/A	4
GOA Groundfish	Arrowtooth Flounder	No	No	No	N/A	N/A	4
GOA Groundfish	Pacific Ocean Perch [46]	No	No	No	N/A	N/A	4
GOA Groundfish	Northern Rockfish - Western / Central	No	No	No	N/A	N/A	4
GOA Groundfish	Flathead Sole	No	No	No	N/A	N/A	4
GOA Groundfish	Dusky Rockfish[47]	No	No	No	N/A	N/A	4
GOA Groundfish	Dover Sole[48]	No	No	No	N/A	N/A	4
GOA Groundfish	Rex Sole	No	No	No	N/A	N/A	4
GOA Groundfish	Shortspine Thornyhead [49]	No	Undefined	Unknown	N/A	N/A	1.5
GOA Groundfish	Yelloweye Rockfish [50]	No	Undefined	Unknown	N/A	N/A	1.5
GOA Groundfish	Rougheye Rockfish[51]	No	No	No	N/A	N/A	4
BSAI Groundfish	Walleye Pollock - EBS	No	No	No	N/A	N/A	4
BSAI Groundfish	Walleye Pollock - AI	No	No	No	N/A	N/A	4
BSAI Groundfish	Pacific Cod	No	No	No	N/A	N/A	4
BSAI Groundfish	Yellowfin Sole	No	No	No	N/A	N/A	4
BSAI Groundfish	Greenland Turbot	No	No	No	N/A	N/A	4
BSAI Groundfish	Arrowtooth Flounder[52]	No	No	No	N/A	N/A	4
BSAI Groundfish	Rock Sole[53]	No	No	No	N/A	N/A	4
BSAI Groundfish	Flathead Sole[54]	No	No	No	N/A	N/A	4
BSAI Groundfish	Pacific Ocean Perch	No	No	No	N/A	N/A	4
BSAI Groundfish	Atka Mackerel	No	No	No	N/A	N/A	4
BSAI Groundfish	Alaska Plaice	No	No	No	N/A	N/A	4
BSAI Groundfish	Northern Rockfish	No	No	No	N/A	N/A	4
BSAI Groundfish	Rougheye Rockfish	No	Undefined	Unknown	N/A	N/A	1.5
BSAI/GOAGroundfish	Sablefish[55]	No	No	No	N/A	N/A	4

BSAI Crabs	Blue King Crab - Pribilof Is.	No[56]	Yes	N/A	continue rebuilding	3/10-year plan	2
BSAI Crabs	Blue King Crab - Saint Matthews Is.	No[56]	Yes	N/A	continue rebuilding	6/10-year plan	2
BSAI Crabs	Golden King Crab -AI	Unknown	Undefined	Unknown	N/A	N/A	0
BSAI Crabs	Red King Crab - AI, Adak	Unknown	Undefined	Unknown	N/A	N/A	0
BSAI Crabs	Red King Crab - Bristol Bay	No	No	No	N/A	N/A	4
BSAI Crabs	Red King Crab - Norton Sound	Unknown	Undefined	Unknown	N/A	N/A	0
BSAI Crabs	Red King Crab - Pribilof Is.	No[56]	No	Unknown[3]	N/A	N/A	4
BSAI Crabs	Snow Crab - BS	No	No - rebuilding	No	continue rebuilding	6/10-year plan	3
BSAI Crabs	Tanner Crab - EBS	No[56]	No - rebuilding	N/A	continue rebuilding	7/10-year plan	3

3 This stock was assessed using pre-SFA criteria, but its status should be regarded as unknown. The stock assessment used static spawning potential ratio (SPR) to determine the overfished status, but static SPR is not an appropriate measure to determine overfished status; it is useful for measuring the overfishing status. Measures are being developed to list the correct status by the end of 2006.

46 Although Pacific ocean perch is managed separately in the Western, Central, and Eastern areas, with separate overfishing levels, ABCs, and TACs based on the proportion of biomass in each respective area, separate assessments are not conducted for each of these three regions; the assessment is based on aggregated data from throughout the Gulf of Alaska. Therefore, it is not appropriate to list separate status determinations for these three areas.

47 The Pelagic Shelf Rockfish Complex consists of the following stocks: Dark Rockfish, Dusky Rockfish, Widow Rockfish, and Yellowtail Rockfish. The overfished determination is based on Dusky Rockfish as an indicator species; the overfishing determination is based on the OFL, which is computed by using the dusky rockfish assessment combined with abundance estimates for the remainder of the complex.

48 The Deep Water Flatfish Complex consists of the following stocks: Deepsea Sole, Dover Sole, and Greenland Turbot. The overfished determination is based on Dover Sole as an indicator species; the overfishing determination is based on the OFL, which is computed by using the dover sole assessment combined with abundance estimates for the remainder of the complex.

49 The Thornyhead Rockfish Complex consists of the following stocks: Longspine Thornyhead and Shortspine Thornyhead. The overfishing determination is based on the OFL, which is computed using abundance estimates of Shortspine Thornyhead.

50 The Demersal Shelf Rockfish Complex consists of the following stocks: Canary Rockfish, China Rockfish, Copper Rockfish, Quillback Rockfish, Rosethorn Rockfish, Tiger Rockfish, and Yelloweye Rockfish. The overfishing determination is based on the OFL, which is computed by using estimates of Yelloweye Rockfish

51 Rougheye Rockfish was previously part of the Shortraker / Rougheye Rockfish Complex, which consisted of the following stocks: Rougheye Rockfish and Shortraker Rockfish. It is now assessed as a single stock and is no longer part of this complex.

52 Arrowtooth Flounder consists of Arrowtooth Flounder and Kamchatka Flounder. Arrowtooth Flounder accounts for the overwhelming majority of the biomass and is regarded as the indicator species for the complex. The overfished determination is based on the combined abundance estimates for the two species; the overfishing determination is based on the OFL, which is computed from the combined abundance estimates for the two species.

53 Rock Sole consists of Northern Rock Sole and Southern Rock Sole (NOTE: These are two distinct species, not two separate stocks of the same species). Northern Rock Sole accounts for the overwhelming majority of the biomass and is regarded as the indicator species for the complex. The overfished determination is based on the combined abundance estimates for the two species; the overfishing determination is based on the OFL, which is computed from the combined abundance estimates for the two species.

54 Flathead Sole consists of Flathead Sole and Bering Flounder. Flathead Sole accounts for the overwhelming majority of the biomass and is regarded as the indicator species for the complex. The overfished determination is based on the combined abundance estimates for the two species; the overfishing determination is based on the OFL, which is computed from the combined abundance estimates for the two species.

55 Although sablefish is managed separately in the Gulf of Alaska, Bering Sea, and Aleutian Islands, with separate overfishing levels, ABCs, and TACs based on the proportion of biomass in each respective region, separate assessments are not conducted for each of these three regions; the assessment is based on aggregated data from the Gulf of Alaska, Bering Sea, and Aleutian Islands regions. Therefore, it is not appropriate to list separate status determinations for these three regions.

56 Fishery in the EEZ is closed; therefore, fishing mortality is very low.

Total annual surplus production and overall exploitation rate of groundfish

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Last updated: August 2007

Description of indices: Total annual surplus production (ASP) of groundfish on the Eastern Bering Sea (EBS) and Gulf of Alaska (GoA) shelves from 1978-2005 was estimated by summing annual production across major commercial groundfish stocks for which assessments were available. These species represent at least 70-80% of the total catch retained in bottom trawl surveys. Assuming that all biomass estimates correspond to beginning of year estimates (prior to when the fishery occurs), annual surplus production in year *t* can be estimated as the change in total adult groundfish biomass across species from year *t* (B_t) to year *t*+1 (B_{t+1}) plus total catches in year *t* (C_t, All estimates of B and C are based on 2006 stock assessments, except flatfish and rockfish in the Gulf of Alaska are based on 2005 assessments; NPFMC 2006a, NPFMC 2005b):

$$ASP_t = \Delta B_t + C_t = B_{t+1} - B_t + C_t$$

An index of total exploitation rate within each region was estimated by dividing the total groundfish catch across the major commercial species by the combined biomass at the beginning of the year:

$$u_t = C_t / B_t$$

For details, see Mueter & Megrey (2006).

Status and trends: The resulting indices suggest high variability in groundfish production in the EBS (Figure 110) and a non-significant decrease in production between 1978 and 2005 (slope = - 63,150 mt / year, t = -1.49, p = 0.147). Annual surplus production in the GoA was much lower on average, less variable, and decreased slightly over the same time period (slope = - 6,330 mt/ year, t = -0.848, p = 0.405).

Total exploitation rates for the groundfish complex 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 111). Total exploitation has remained relatively constant in both systems from the mid-1980s to the present. The overall exploitation rate in the EBS reached a low of 7% in 1999 and increased to 11% by 2006, while the exploitation rate in the Gulf of Alaska has been less than 5% in recent years.

Because trends in annual surplus production in the Eastern Bering Sea are almost entirely driven by variability in walleye pollock, I computed ASP_t for the Bering Sea without walleye pollock (Figure 112). The results suggest a strong, significant decrease in aggregate surplus production of all non-pollock species from 1978 – 2005 in the Bering Sea (slope = -16,500 mt / year, t = -4.73, $p < 0.0001$). The trend reflects decreases in surplus production of most species, except arrowtooth flounder and Alaska plaice.

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. 1991-92 in the EBS) and lowest during periods of decreasing biomass (e.g. 1982-1984 in the GoA). In the absence of a long-term trend in total biomass, ASP is equal to the long-term average catch. Theory suggests that surplus production will decrease as biomass increases above B_{MSY}, which has been the case for a number of flatfish species (e.g. rock sole, flathead sole) and rockfish species (Pacific ocean perch, northern rockfish). Therefore the declines in production may be a density-dependent response to observed increases in biomass.

Exploitation rates are primarily determined by management and reflect a relatively precautionary management regime with rates that have averaged less than 10% across species over the last decade. Exploitation rates are much lower in the GoA because of the very limited exploitation of arrowtooth flounder, which currently make up the majority of the biomass in the GoA. If arrowtooth flounder is excluded, rates are comparable to those in the EBS.

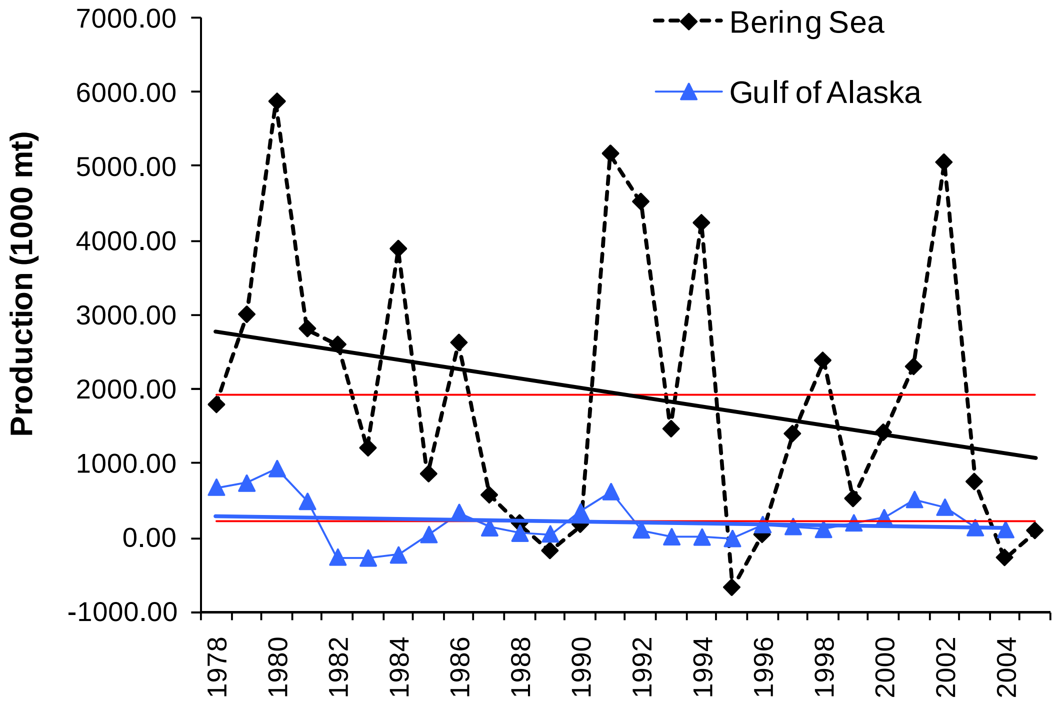

Figure 110. Total annual surplus production (change in biomass plus catch) across all major groundfish species in the Gulf of Alaska and Bering Sea with estimated linear trends (solid lines) and long-term means (red).

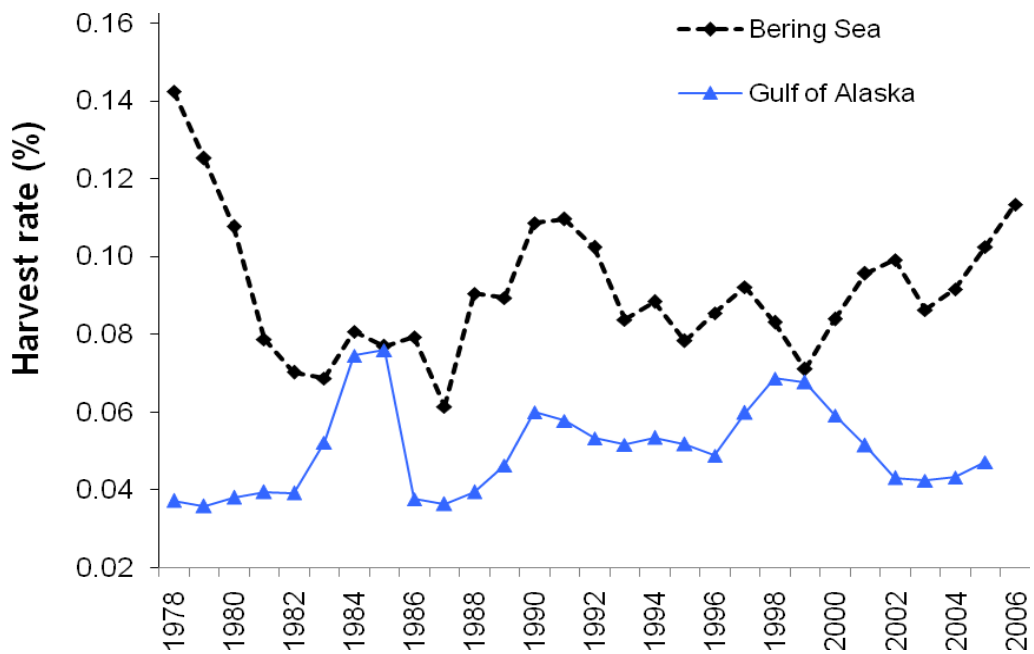

Figure 111. Total exploitation rate (total catch / total biomass) across all major groundfish species in the Gulf of Alaska and Bering Sea.

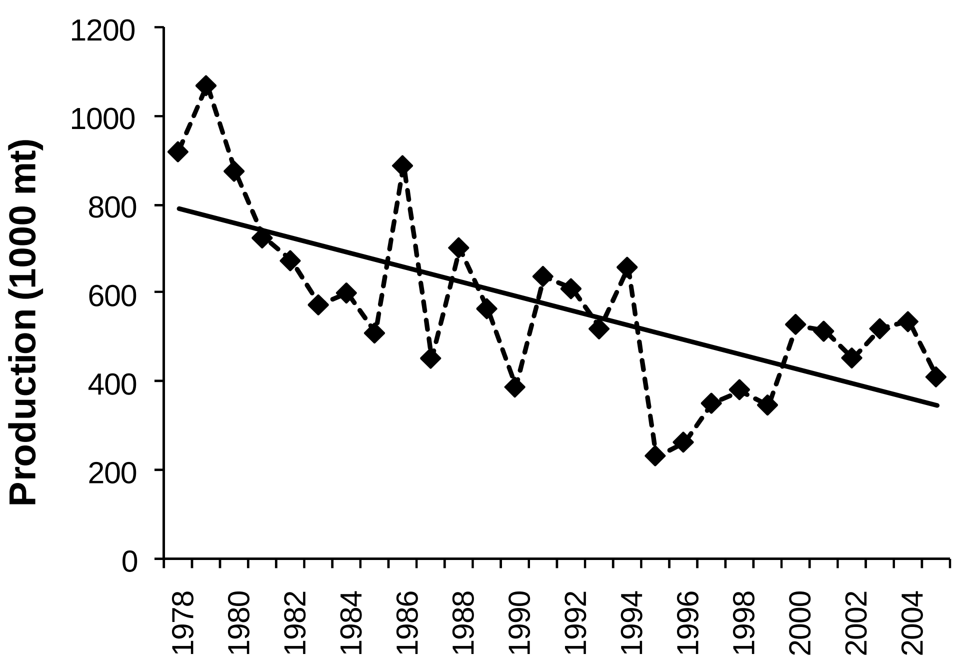

Figure 112. Total annual surplus production (change in biomass plus catch) across all major groundfish species, excluding walleye pollock, in the Bering Sea with estimated linear trend (solid line).

Community size spectrum of the bottom trawl-caught fish community of the eastern Bering Sea

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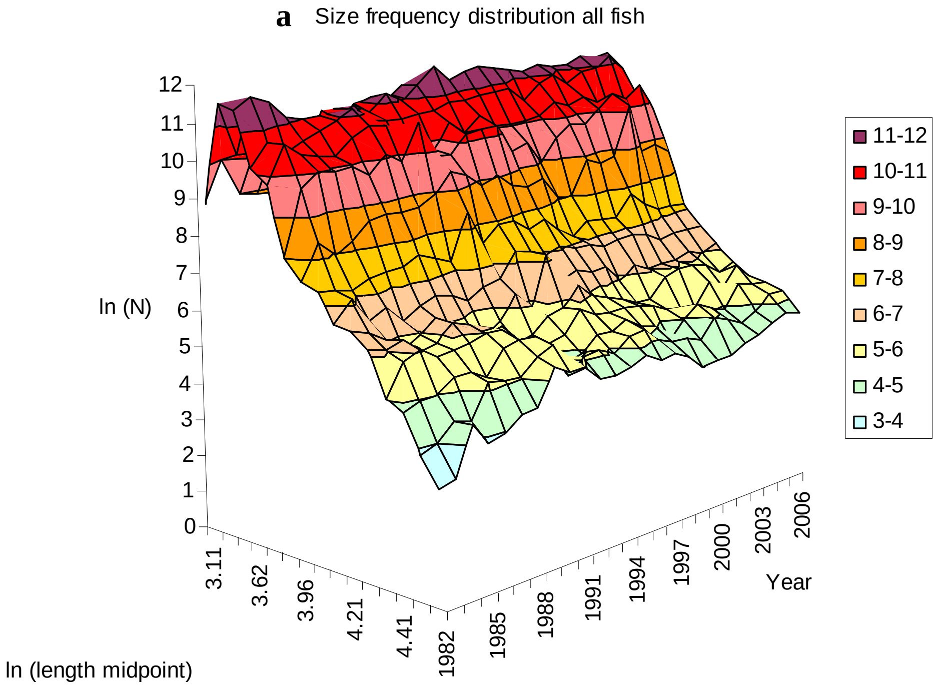
Ecosystem-based fisheries management requires analyses beyond assessments of species that are targets of fisheries. Recent efforts to summarize quantitative ecosystem indicators for fisheries management have identified size-based indicators as an important class of indicators for tracking fishery exploitation effects on fish communities (Cury and Christensen 2005, Kruse et al. 2006, Hall et al. 2006). 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 relative abundance of species using cumulative frequency distributions (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.

A change in the slope or intercept of the community size spectrum can be attributed to a number of factors, including a change in the relative number of large or small individuals due to fishing pressure or environmental variables, as well as a change in species dominance leading to differences in the average weight and therefore slope or intercept of the CSS. The eastern Bering Sea groundfish community appears to have fewer small individuals and more large individuals through time (Figure 113a), which is primarily due to nontarget fish (Figure 113b). The slope and intercept of the CSS decreased from 1982-1987, primarily due to significant decreases in the slopes and intercepts of non-target fish over time (Figure 114 a and b). Between 1994 and 2001, both the slope and intercept values were relatively stable, after which, they started to increase through 2006 (Figure 114 a and b). There was no significant change in slopes or intercepts for all fish (both commercial and nontarget fish combined) or for commercial fish over time (Figure 114 a and b). Nontarget fish, however, showed significant increases in slope and decreases in intercept. This would imply that, overall (and particularly for nontarget fish), the groundfish community has fewer small individuals and more large individuals through time. Factors other than fishing, such as the regime shift in 1988/89, may have had an influence on the community size spectrum.



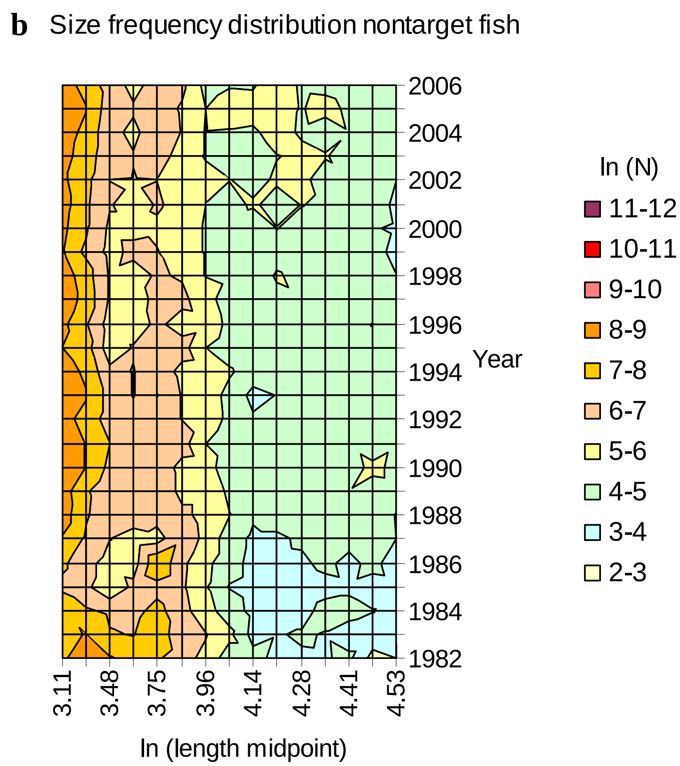


Figure 113. Eastern Bering Sea demersal fish (20-90 cm) community size spectrum (CSS), 1982-2006, for all fish in 3-D (a) and for non-target fish only in 2-D (b).

a

b

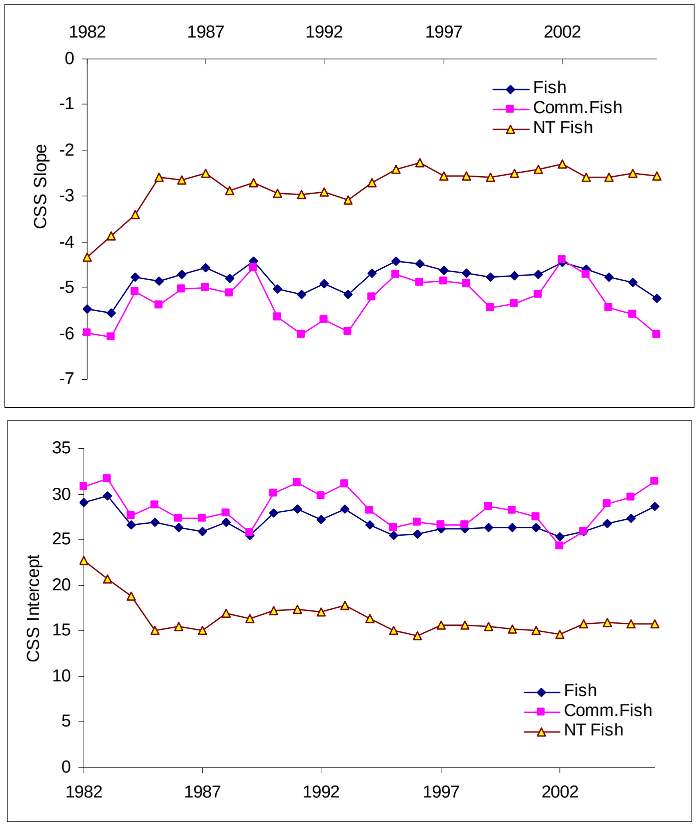


Figure 114. Eastern Bering Sea demersal fish (20-90 cm) community size spectrum (CSS), 1982-2006, changes in slope (a) and intercept (b) of the CSS, 1982 to 2006.

Ecosystem Goal: Humans are part of ecosystems

Fishing overcapacity programs

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Overview

Overcapacity, wherein there is an excessive level of investment or effort relative to the available fisheries resources, is considered a problem in fisheries throughout the world. The problem is often manifested in short fishing seasons, increased enforcement and safety problems, and reduced economic viability for vessel owners and crew-members. Overcapacity can, under certain conditions, have grave implications for conservation as well.

The North Pacific Fishery Management Council (Council) has developed several programs to address overcapacity in the Alaskan fisheries. Moratorium programs were implemented in the crab and groundfish fisheries to limit the number of harvesting vessels that may be deployed off Alaska, and access has since been limited further by replacing the moratoria with license limitation programs (LLP). However, rights-based management is increasingly being used to “rationalize” fisheries.

An Individual Fishing Quota (IFQ) program has been used to manage the halibut and fixed gear sablefish fisheries since 1995. Rather than explicitly limiting the number of harvesting vessels, this program grants quota holders the privilege of harvesting a specified percentage of the Total Allowable Catch (TAC) each year. A similar program developed by the Council, beginning in 2005, placed management of most crab fisheries of the Bering Sea and Aleutian Islands (BSAI) under a quota system, in which quota shares were issued to harvesters (including vessel captains) and processors. The program also includes community protection measures (hence the term "three-pie" program), and provides for voluntary harvesting cooperatives. Some features of this crab program had to be authorized by Congressional action. The Council also is considering comprehensive rationalization of Gulf of Alaska (GOA) groundfish fisheries and sector allocations of groundfish in the BSAI. Congress has provided additional statutory tools to help relieve overcapacity. The American Fisheries Act (AFA) retired nine catcher-processors, limited entry of additional harvesting vessels, authorizes harvesting cooperatives to which a portion of the total allowable catch of BSAI pollock is granted, prevents pollock fishery participants from expanding historical activities to other fisheries, and stabilized deliveries to shoreside processors. Congress later authorized a BSAI crab "buyback" program that, if approved by industry, will retire crab licenses, vessels, and vessel histories prior to implementation of the crab quota program. And, as a prelude to the more complex GOA rationalization program, the National Marine Fisheries Service (NMFS), in response to a Congressional mandate and in consultation with the Council, is developing a two-year demonstration quota program for Central Gulf of Alaska rockfishes.

Moratorium on New Vessels

A moratorium on new vessel entry into the federally managed groundfish and crab fisheries was implemented in 1996. The program was considered a place holder while more comprehensive management measures were developed. The owners of 1,864 groundfish and 653 crab vessels held moratorium fishing rights at the time the program was sunsetted (December 31, 1999). In addition to limiting the number of vessels the moratorium also restricted the lengths of vessels that could be deployed under moratorium permits. Qualifying vessels that were less than 125' in length overall received licenses that had a maximum length overall of 120 percent of the qualifying vessel's length on June 24, 1992, or up to 125', whichever is less; vessels that were 125' or longer could not increase their length. The concern over increasing vessel length arises because such actions can increase harvesting capacity even though additional vessels are prohibited from entering a fishery, thus undermining the effectiveness of the moratorium.

License Limitation Program for Groundfish and Crab

The LLP for groundfish and crab vessels was implemented on January 1, 2000 to replace the vessel moratorium. The original LLP, approved in 1995, was intended as the second step in fulfilling the Council's commitment to develop a comprehensive and rational management program for fisheries off Alaska. Amendments to that program recommended by the Council in 1998 and April 2000 tightened the LLP program and included additional restrictions on crab vessel numbers and on fishery crossovers. The amendments also limited participation in the non-trawl BSAI Pacific cod fisheries. The LLP reduced the number of vessels eligible to participate in the BSAI crab fisheries by more than 50% relative to the vessel moratorium (down to about 347 licenses, of which 145 were licensed for the 2006/07 crab fishing year and 91 were used in rationalized fisheries). The number of current LLP groundfish licenses (1,830) 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 1,457 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 eligible to participate only in Gulf of Alaska fisheries). These vessels have typically had relatively small catch histories in past years. The LLP Program is being modified to accommodate changes implemented under the Crab Rationalization Program (CR Crab). In addition to crab endorsement changes resulting from new quota fisheries, some groundfish licenses were modified to incorporate "sideboard" restrictions, as they have become known, on GOA groundfish activities to avoid "spillover" effects of excess crab capital on groundfish fisheries.

At present, the Council is considering reducing "latent" capacity in groundfish fisheries by creating a new "recent participation" requirement for licenses and endorsements. Under such a program, it is likely that harvesting privileges unused in recent years as a result of provisions of existing programs (such as AFA cooperatives) would be exempted from these requirements.

License Limitation Program for Scallops (LLPS)
The LLPS was implemented in 2001 to replace a 1997 temporary vessel moratorium program for this fishery. Under the LLPS, nine persons were issued transferable licenses authorizing them to deploy vessels in the scallop fishery off Alaska. The licenses restrict the lengths of vessels and the size and amount of gear that may be used.

Bering Sea and Aleutian Islands Crab Rationalization and Buyback
The North Pacific Fishery Management Council developed, and NMFS has implemented, a plan to rationalize the BSAI crab fishery.

A statutory change to the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) authorized an industry-funded buyback program for the crab fisheries. This program permanently retired the fishery endorsements of 25 vessels, and LLP crab licenses and vessel histories; as well as 15 limited entry licenses for groundfish (and some halibut quota share) associated with those histories. The program was approved by an industry referendum in which a majority of participants approved the proposed effort reduction and a debt retirement burden of $97.4 million.

The Council also developed, and NOAA Fisheries Service, has implemented, the Crab Rationalization Program (CR Crab). This program includes allocations to Community Development Quota Groups, an allocation of one species of king crab to the community of Adak, and a complex quota system for harvesters and processors called the "three-pie voluntary cooperative program". CR Crab program attempts to balance the interests of several identifiable groups that depend on these fisheries. Allocations of harvest shares are made to harvesters, including captains. Processors are allocated processing shares. Community protection measures are designed to help provide economic viability of fishery-dependent communities. Designated regions are allocated landings and processing activity to preserve their historic interests in the fisheries. Harvesters are permitted to form cooperatives to realize efficiencies through fleet coordination. The novelty of the program has compelled the Council to include several safeguards into the program, including a binding arbitration program for the resolution of price disputes and extensive economic data collection and review programs to assess the success of the rationalization program. These safeguards, together with the Council's continuing development of the program through a series of ongoing amendments and clarifications, demonstrate the Council's commitment to a fair and equitable rationalization program that protects the interests of those dependent on the BSAI crab fisheries.

As of June 2007, NOAA Fisheries Service has initially issued one or more types of harvesting quota to 489 distinct persons; and processing quota to 26 persons. For harvesters, NOAA Fisheries initially issued quota to 270 applicants who qualified based on holding a transferable LLP crab license; and to 231 individuals who qualified for "Captain" (also known as "crew") shares by virtue of both historic and recent participation in these crab fisheries. Fishing under Crab Rationalization began with two Aleutian Islands golden king crab fisheries, in August 2005. During the first year of the program, fishery managers determined that for conservation reasons, the Bering Sea *Chionoecetes bairdi* Tanner crab (BST) biomass should be managed in two separate fisheries. Just prior to the start of the second crab fishing year, NMFS issued all current holders of BST quota shares for both the new Eastern and Western Bering Sea *C. bairdi* fisheries. As of the end of the second crab fishing year under rationalization, 472 persons were holding harvesting QS and 29 were holding PQS. Of the persons holding harvesting QS, 270 held "owner" type, and 214 individual persons held "crew" type.

NMFS is preparing regulations to support a Statutory program change as part of crab FMP Amendment 25. This change would allow persons initially issued certain types of harvesting QS or PQS to annually combine the harvester and processor IFQ/IPQ held by them and their affiliates into catcher processor IFQ for use in the north region. This change would preserve economic benefits from crab-related tax revenues collected by the State of Alaska and shared with northern communities.

The Council received an 18-month status report on crab rationalization in April, 2007, and is analyzing several proposed program changes. The Council will consider a major program review after the first three program years.

Sablefish and Halibut Individual Fishing Quotas

The halibut and sablefish fisheries provide good examples of how the Council is working to control overcapacity in fisheries off Alaska. From 1975 to 1994 the Central Gulf of Alaska halibut fishing seasons decreased from approximately 125 days to single day openings, while catches increased. Faced with very short seasons and increasing fishing effort, the Council recommended an IFQ program for both the halibut and fixed gear sablefish fisheries. These programs were initiated in 1995. After implementation, the traditional short, pulse fisheries were extended to more than eight months long. IFQs have allowed participants to better match fishing capacity with the amount of fish they are allowed to harvest during a year, improving economic efficiency for harvesters and decreasing gear conflicts on fishing grounds, among other salutary effects. In recent years the numbers of vessels and persons have declined, even as the TACs have been increasing. A total of 4,829 persons were initially issued halibut quota share (QS) and 1,054 were initially issued sablefish QS. At the end of 2006, 3,246 persons held halibut QS and 869 held sablefish QS. The number of vessels landing halibut in the IFQ fishery declined from 3,450 in 1994 to 1,255 at the end of 2006; the number landing sablefish in the IFQ fishery declined from 1,191 in 1994 to 372 in 2006.

American Fisheries Act

The AFA, passed in late 1998, among other things limited the number of harvesting and processing vessels that would be allowed to participate in the BSAI pollock fishery. Only harvesting and processing vessels that met specific requirements, based on their participation in the 1995-97 fisheries are eligible to harvest BSAI pollock. At the inception of the AFA, 21 catcher/processors and 112 catcher vessels qualified, or were specifically identified, as eligible to participate under the AFA guidelines. Nine other catcher/processors were bought out at a cost of $90 million.

Specific provisions in the AFA allow for the formation of cooperatives among catcher/processors, among the catcher vessels that deliver to the catcher-processors, among eligible motherships and catcher vessels in the mothership sector, and among the eligible catcher vessels in the inshore sector of the BSAI pollock fishery. Within each cooperative, each member company is then contractually allocated a percentage share of the total cooperative allocation based on its historical catch (or processing) levels. The catcher-processor cooperative is called the Pollock Conservation Cooperative (PCC) and is made up of eight companies that own 19 of the 20 catcher-processors currently eligible to fish in the pollock fishery (the fishing privileges of the 21st eligible vessel were purchased by the PCC in 2000, and one eligible vessel has not joined the PCC). The catcher vessel cooperative is called the High Seas Catchers' Cooperative (HSCC), and comprises seven catcher vessels authorized under the AFA to deliver to the eligible catcher/processors (these vessels had traditionally delivered the majority of their pollock to catcher/processors).

Under the AFA, the PCC is currently allocated 91.5% of the total offshore pollock allocation (the rest is allocated to members of the HSCC). When the new fishery cooperative structure was adopted in 1999, not all of the eligible catcher/processors fished during the 1999 late winter and early spring pollock seasons; four catcher/processors opted not to fish during the winter season and six chose not to fish during the summer season. This pattern continued in 2000 and 2001 when four and three catcher/processors were idle in the winter season, respectively. Five of the catcher/processors were idle in both 2000 and 2001 for the summer season. In 2002, three vessels were idle in the winter season and four were idle in the summer season. For 2003 to 2006, three vessels were idle during the winter and five vessels were idle in the summer season. The variations in vessel participation can probably be attributed to the variations in the pollock TAC.

The HSCC is allocated 8.5% of the offshore pollock allocation. However, since the formation of the cooperative, they have leased much of their TAC allocation for pollock to catcher/processors. In fact, since 1999, none of the seven HSCC vessels have engaged in directed fishing for pollock, choosing instead to lease their catch to the AFA catcher/processor fleet.

The AFA also authorizes three motherships to participate in the BSAI pollock fishery. In 1998, 31 vessels landed greater than 10 mt of pollock to be processed by offshore motherships. In 1999, this number decreased to 27. In 2000, the first year in which a cooperative was operating in the mothership sector, 19 of the 20 catcher vessels eligible to deliver pollock to these motherships actually did so. The same number of vessels made deliveries to motherships in 2001, dropped to 17 vessels annually in 2002 and 2003, increased to 18 in 2004, and dropped to 17 in both 2005 and 2006.

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, fell to 84 in 2005, and decreased again to 83 in 2006.

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

Two recent acts of Congress provided additional authority and guidance to the Council and NMFS for developing and implementing dedicated access privilege (DAP) programs. Under these authorities, the Rockfish Pilot Program, a BSAI groundfish capacity reduction ("buyback") program, and Amendment 80 to the FMP for the BSAI are in various stages of development or implementation by the Council and/or NMFS.

Rockfish Pilot Program

Congress granted NMFS specific statutory authority to manage Central GOA rockfish fisheries in Section 802 of the Consolidated Appropriations Act of 2004 (Pub. L. 108-199; Section 802). The North Pacific Fishery Management (Council) was required to establish the Rockfish Pilot Program, to provide exclusive harvesting and processing privileges for a specific set of rockfish species and for associated species harvested incidentally to those rockfish in the Central GOA, an area from 147E W. long. to 159E W. long. The Program is intended to increase resource and improve economic efficiency for harvesters and processors who participate in the fishery. Initially for two years, later extended to the five year period through December, 2011, exclusive harvesting and processing privileges will be allocated for three primary rockfish species and for five incidentally harvested secondary species in the Central GOA. NMFS also allocated a portion of the total GOA halibut mortality limit to participants based on historic halibut mortality rates in the primary rockfish species fisheries.

Under the Rockfish Program NMFS:

1. Assigned quota share (QS) for primary rockfish species to an LLP license with a trawl gear designation in the Central GOA.
2. Established eligibility criteria for processors to have an exclusive privilege to receive and process primary rockfish species and secondary species allocated to harvesters in this Program.
3. Allows a person holding a LLP license with QS to form a rockfish cooperative with other persons (i.e., harvesters) on an annual basis.
4. Allows rockfish cooperatives to transfer all or part of their CFQ to other rockfish cooperatives, with some restrictions.
5. Provides an opportunity (annually) for a person not in a rockfish cooperative, but who holds an LLP license with QS, to fish in a limited access fishery.
6. Establishes a small entry level fishery for Central GOA rockfish for harvesters and processors not eligible to receive QS under this Program.
7. Allows holders of catcher/processor LLP licenses to opt-out of the Program annually, with certain limitations.
8. Limits the ability of processors to process catch outside the communities in which they have traditionally processed primary rockfish species and associated secondary species.
9. Establishes catch limits, commonly called "sideboards", to limit the ability of participants eligible for this Program to harvest fish in fisheries other than the Central GOA rockfish fisheries.
10. Created a monitoring and enforcement mechanism to ensure that harvesters maintain catches within their annual allocations and will not exceed sideboard limits.

In 2007, QS was initially awarded and attached to 62 distinct LLP licenses, 47 of which were catcher processor licenses and 15 of which were catcher vessel licenses. LLP holders formed 7 catcher vessel harvesting cooperatives. Cooperatives may transfer primary species allocation to other cooperatives.

Capacity Reduction in Non-Pollock Groundfish Fisheries of the Bering Sea and Aleutian Islands

Under the Consolidated Appropriations Act of 2005 (Public Law 108-447) and Consolidated Appropriations Act of 2004 (Public Law 108-199), NMFS implemented a capacity reduction program pursuant to applicable provisions of the MSA (15 U.S.C. 1861a(b-e)). The program will reduce current and future effort in the non-pollock groundfish fisheries in the Bering Sea and Aleutian Islands through a "buyback" program to retire vessels, licenses, and vessel histories. The legislation provides for a total loan of up to $75 million and authorizes specific amounts for four subsectors in the fishery: longline catcher processors, AFA trawl catcher processors, non-AFA catcher processors, and pot catcher processors. A separate program will be developed for each subsector, with the first, for longline catcher processors, currently in regulatory development. The objective of the program is to achieve a permanent reduction of capacity to: increase post-reduction harvester's productivity, help financially stabilize the fishery, and help conserve and manage fishery resources.

On September 29, 2006, NMFS published the final rule in the **Federal Register** (71 FR 57696) to implement this buyback program. On January 5, 2007, the Freezer Longline Conservation Cooperative (FLCC) submitted their Fishing Capacity Reduction Plan (Plan) to the NMFS Financial Services Division. The Plan included four (4) formal offers for catcher processor groundfish licenses that would be removed from the fishery, and that the FLCC members had selected. The 4 offers included three (3) active fishing licenses that were associated with 3 catcher processor vessels. The fourth offer was that of an inactive license, with no vessel associated with the license. The total amount of the government loan was $35 million, to be repaid over a thirty (30) year period using a percentage of future fish landings of

BSAI Pacific cod.

On March 16, 2007 NMFS approved the FLCC's plan. On March 21, 2007, NMFS issued ballots to the voting members of the FLCC to vote in a referendum to determine industry support of the fishing capacity reduction loans. On April 6, 2007, voting in the referendum was completed, with 87 percent participation in the referendum. Thirty-four (34) voters cast ballots, unanimously in favor of the reduction plan. Therefore, the referendum was successful, and the referendum voters approved the repayment fees for the $35 million fishing capacity reduction loan.

On April 26, 2007, NMFS issued a payment tender notice in the **Federal Register** (72 FR 20836), and provided thirty (30) days for public notice before tendering payment. On May 29, 2007, NMFS disbursed payments to the owners of the 4 fishing licenses that were being relinquished as part of the reduction capacity program. In exchange for payment, the owners relinquished their fishing licenses, reduction privilege vessels where appropriate, and fishing histories. NMFS has completed the reduction program except for implementing the industry fee system for repaying the reduction loan, which NMFS plans to publish later in FY 2007.

Amendment 80

In response to requirements of the Consolidated Appropriations Act of 2005 (Public Law 108-447) in 2007, NMFS published a Proposed Rule in the **Federal Register** (72 FR 30052) and is preparing a Final Rule with regulations to implement Amendment 80 to the FMP for the Bering Sea and Aleutian Islands (BSAI). Amendment 80 pertains to the non-AFA trawl catcher processor participant subsector. Under this Amendment, vessels owned, and/or LLP licenses held, by eligible participants would be allocated quota for target groundfish species, based on historic participation. Including combinations of allocated species and fishing areas, there would be a total of 11 quota categories. Quota holders would annually receive pound allocations based on quota holdings, and could elect to form harvesting cooperatives or participate in a limited access fishery. Cooperatives and the limited access fishery would each be allocated amounts of bycatch of Pacific halibut and crab, which are prohibited species in groundfish fisheries; and could conduct inter-cooperative allocation transfers. Caps would limit the amounts of quota a person could hold at any time. Sideboard provisions would limit "spillover" effects of this program on other fisheries and required reporting would allow NMFS and the Council to monitor the efficacy of the program over time. Proposed regulations list 28 vessels and LLP groundfish licenses that would be designated Amendment 80 vessels and licenses, respectively.

Amendment 85

At its April, 2006 meeting, the Council took final action on Amendment 85 to the FMP for the BSAI, which would modify the current annual allocations of BSAI Pacific cod (after deductions for the CDQ fishery) among jig, trawl, and fixed gear (hook-and-line and pot) subsectors. The recommended allocations were determined based on a set of historic participation criteria, with consideration for small boats and coastal communities dependent on the Pacific cod resource. The Council also recommended seasonal apportionments for jig and trawl gear and a hierarchy for reallocating projected unused allocations among the various sectors. The number of eligible persons subject to this Amendment would be reduced to the extent that prior capacity reduction programs first reduce the size of the fleet.

Guided Sport Halibut

On March 31, 2007, the Council recommended a moratorium on entry into the guided sport fishery for IPHC areas 2C and 3A, using a control date of December 9, 2005. This sector has been operating under a guideline harvest level (GHL) for several years. For both areas the GHL has been exceeded, in 2C by a substantial amount in 2006, with future service demand expected to increase. Under the program, NMFS would issue Federal licenses to individual U.S. citizens and to primarily U.S.-owned businesses with historical participation based on required State logbook reporting and State and USCG licensing. Other program features include:

1. minimum participation tests to receive a license(s);
2. caps on the number of licenses that could be held by a person;
3. transferability of most permits, with a prohibition on permit leasing;
4. permit endorsements for numbers of clients;
5. special licenses to be issued to communities identified under IFQ Amendment 66; and
6. a military hardship provision.

The Council is considering additional measures to supplement guided sport needs, including "compensated reallocation" in which annual allocation of halibut could be purchased from the commercial fishery for use in guided sport fisheries.

Groundfish fleet composition

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Last updated: August 2007

Fishing vessels participating in federally-managed groundfish fisheries off Alaska principally use trawl, hook and line, and pot gear. The pattern of changes in the total number of vessels harvesting groundfish and the number of vessels using hook and line gear have been very similar since 1994. They both were high in 1994 and then decreased annually through 1998 before increasing in 2000. The total number of vessels was about 1,453 in 1994, decreased to 1,170 in 1998, and was 868 in 2006, the most recent year for which we have complete data (Figure 115). Hook and line vessels accounted for about 1,161 and 546 of these vessels in 1994 and 2006, respectively. The number of vessels using trawl gear decreased from 255 in 1994 to 204 in 2003, and has remained roughly constant at about 200 vessels since 2003. During the same period, the number of vessels using pot gear peaked in 2000 at 341, decreased to a low of 179 in 2002, increased again to 197 in 2003, and, like the number of trawl vessels, has remained right around 200 since 2003. Vessel counts in these tables were compiled from blend and Catch-Accounting System estimates and from fish ticket and observer data. Vessel counts in this report are slightly higher than in previous reports because we've refined our estimation method to include vessels that deliver to other vessels, as reported in fish tickets, that don't appear in our other data sources.

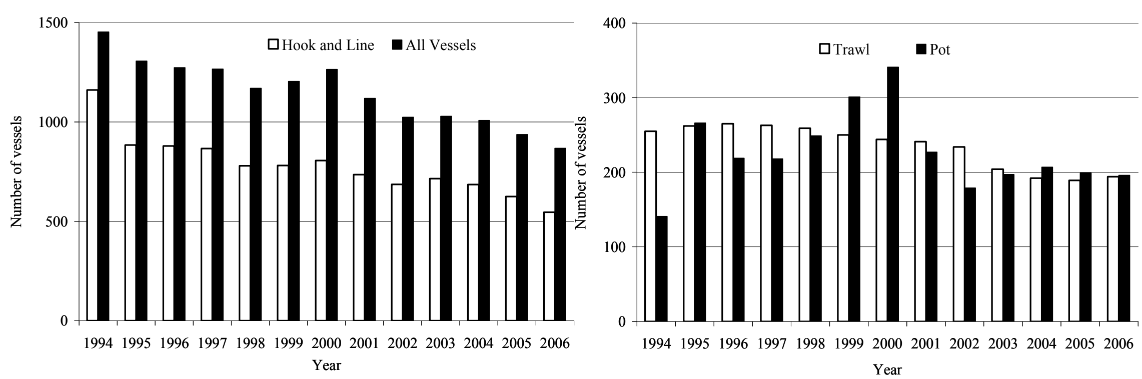

Figure 115. Number of vessels participating in the groundfish fisheries off Alaska by gear type, 1994-2006.

Distribution and abundance trends in the human population of the Gulf of Alaska

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Last updated: October 2007

Description of Indices: This report describes the distribution and abundance over time of human populations in the Gulf of Alaska (GOA) (including Southeast Alaska, Cook Inlet, and Prince William Sound). The population was calculated by aggregating Census values for selected communities into four geographic areas (Alaska Peninsula, Kodiak, South Central, and Southeast) for each decade between 1920-2000 (data from U.S. Census Bureau), and yearly between 1990-2006 (data from the Alaska Department of Labor and Workforce Development (ADLWD 2007)). This approach is concordant with research on arctic communities that uses crude population growth or loss as a general index of community viability (Aarsaether and Baerenholdt 2004).

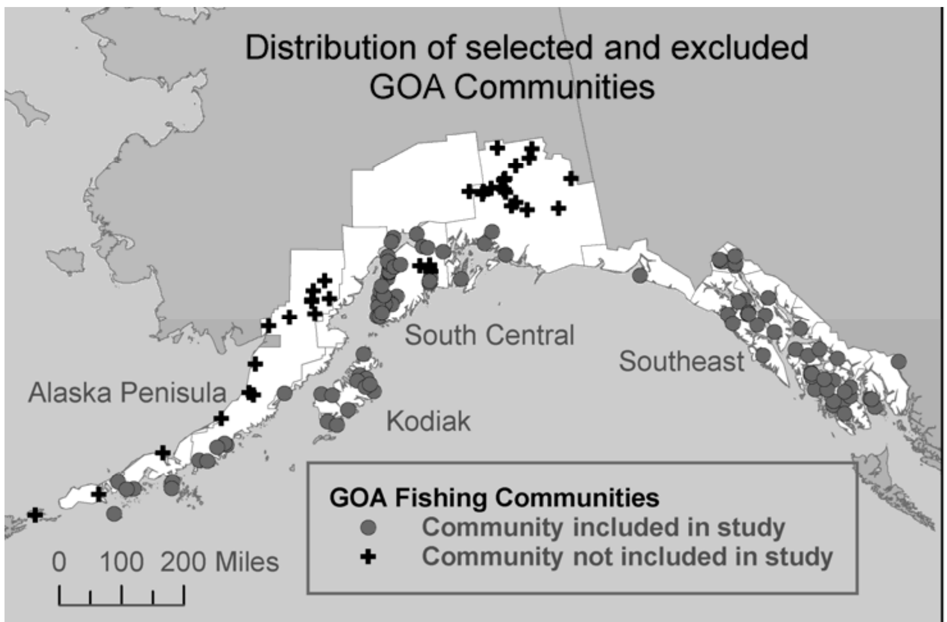

Figure 116. Distribution of selected GOA communities by Boroughs and Census Areas. Map created by Angie Greig, AFSC.

The 108 GOA fishing communities selected for use in this report comprise most of the population in each of these Census Areas: 51% for Alaska Peninsula, 71% for Kodiak, and 97 and 98% for South East and South Central, respectively (see Figure 116). Communities were selected if they were within 25 miles of the coast, and/or if they had historical involvement in Gulf of Alaska subsistence or industrial fisheries (per Sepez et al. 2005), and/or if they were included in one of the North Pacific Fishery Management Council's GOA fishery programs, such as the Community Fisheries Quota (CFQ) program. Following CFQ community selection parameters, towns near the Gulf of Alaska but located on the Bering Sea/Aleutian Island Large Marine Ecosystem (BSAI LME) were excluded. These settlements are included in the demographic analysis of BSAI communities (Poole and Sepez 2006a, 2006b).

The U.S. Census counts populations based on place of residence on April 1 of the Census year. In many fishing communities in Alaska, the population fluctuates greatly during the year according to the fishing season. Due to an influx of processing workers, salmon ports may have much higher populations in the summer, crab and groundfish ports in the winter. Census data do not differentiate between long-term residents and transient residents, and do not capture these seasonal population fluctuations.

Status and Trends:

The overall population of GOA fishing communities in 2000 was over 21 times larger than its 1920 population – growing from 18,533 to 394,655 (Figure 117). While all areas of the GOA grew over this time frame, the vast majority of the growth occurred in the city of Anchorage after 1950. The proportion of people living in GOA communities relative to the total Alaskan population has increased from around 34% of the state total of 55,036 in 1920 to almost 63% of the total Alaskan population of 626,931 in 2000. Forty-two percent of the total Alaska population lives in Anchorage.

Nearly all of Alaska's rural areas, including GOA, have had a positive average population growth rate since 1990 (Figure 118). Fifty-four GOA fishing communities (or 50%) have had a positive average annual percent change during the period between 1990 and 2006. Forty-seven showed a negative average annual percent change and three towns remained at zero, but were included in this study because they had populations prior to 1990.

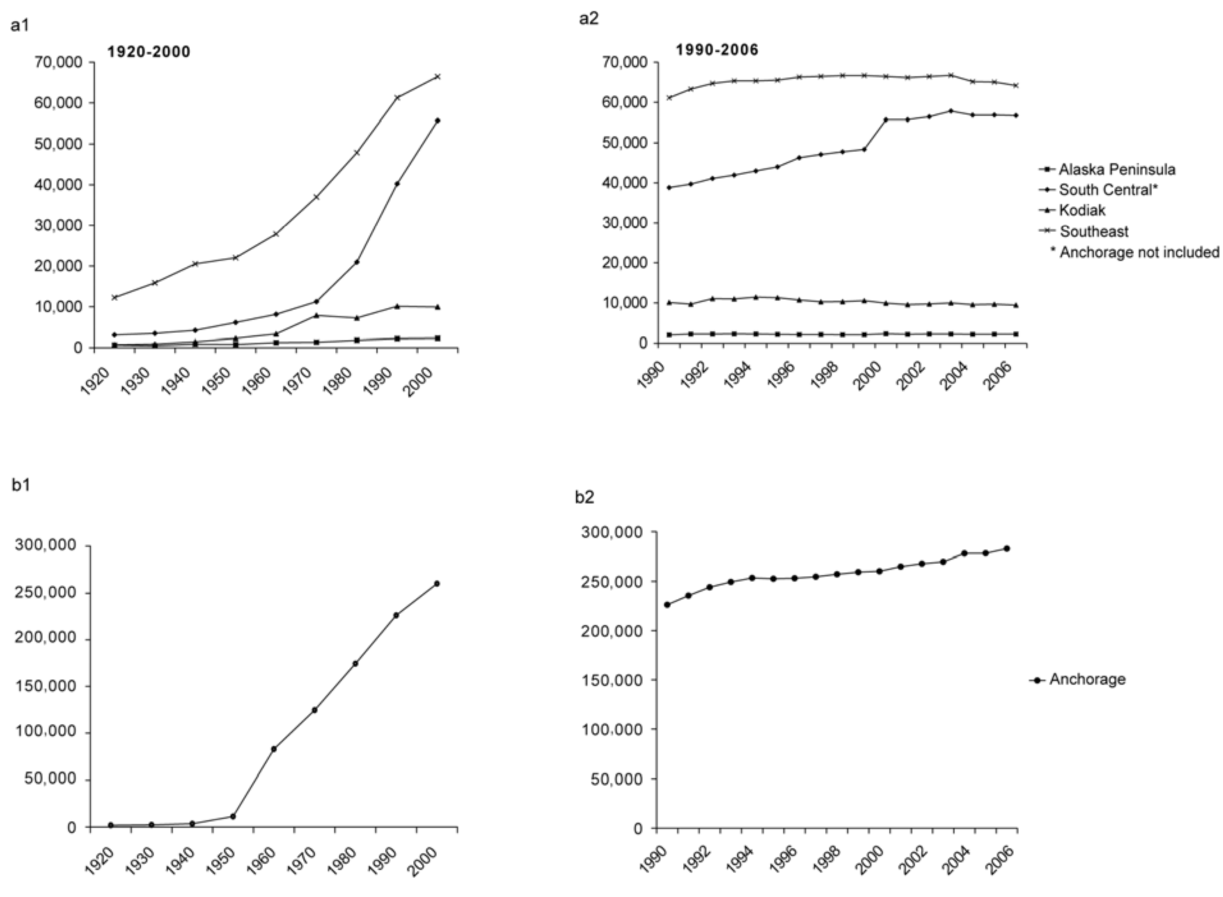

Figure 117. Population of GOA communities per region, with Anchorage displayed separately due to scale: a1.) every 10 years from 1920-2000 (data source: U.S. Census Bureau); a2.) annually from 1990-2006 (data source: ADLWD); b1.) Anchorage every 10 years from 1920-2000; b2.) Anchorage annually from 1990-2006.

Overall, Alaska has one of the highest intra- and interstate migration levels of any US state (Williams 2004). However, these figures differ dramatically across GOA communities. Between 2000-2004 Aleutians East Borough, Lake and Peninsula Borough, Valdez-Cordova, and Yakutat exhibited some of the highest gross migration rates in Alaska with 25.9-30.1% of the population entering or leaving. Gross migration in Alaska averaged 11.6% in 2004.

Alaska has the highest share of indigenous Americans of any US state (one person in five). Alaska Natives make up 82% of the population of the remote rural Census Areas, 90% when excluding regional hubs (Goldsmith et al. 2004). In the GOA, the Alaska Peninsula is comprised of a Census Area with the lowest percent Native population, Aleutians East (38.6% Native) and one of the highest, Lake and Peninsula (over 69% Native). South Central (including Anchorage), Kodiak, and Southeast were all more than 69% non-Native.

Alaska has one of the highest population concentrations in the United States with 42% of its population concentrated in Anchorage. New York (also with 42% of its population in New York City) is the only other state with such a high percentage of its population clustered in one location. The state with the 3rd largest population concentration in one place is Hawaii with 31% of its population in Honolulu. With respect to isolation from the nearest major American city, Anchorage is second only to Honolulu. Honolulu is located 2554 miles from Los Angeles while Anchorage lies 1432 miles from Seattle.

Factors Causing Trends:
The overall population growth in the GOA region since 1920 reflects state and national trends. The GOA growth rate lags slightly behind state trends and is ahead of national trends. The two key factors affecting population growth rates are natural increase (birthrates subtracting mortality), and migration. Both factors affect the GOA region.

The municipality with the greatest population increase between 1990 and 2004 was the municipality of Anchorage which grew by 37,841 people during this time (Williams 2006). Except for the Matanuska-Susitna Borough, every area with positive population growth saw their natural increase outstrip their net migration between 2000 and 2004 (Williams 2006). Between 2000 and 2004, birth rates in the state were lowest in the Aleutian chain and in Southeast Alaska.

Changes in patterns of natural resource extraction and military presence explain many of the recent population trends in the GOA. Cut-backs in the Coast Guard account for Kodiak’s population decline in the 1990s (Williams 2006). The fishing industry accounted for community growth, decline, and in some cases abandonment in the Aleutians, Lake and Peninsula, and Kodiak areas. The Aleutians East gained population at this time because of the movement of a substantial amount of groundfish processing on shore (Williams 2004). Other fishing communities, specifically those most dependent on salmon, were impacted by a sharp decline in ex-vessel prices. A loss of timber harvesting and wood processing jobs in the 1990s led to major population decreases in some Southeast communities. Populations decreased to zero or near zero in Whitestone, Cube Cove, and Hobart Bay. The population decreased to zero in Ivanof Bay on the Alaska Peninsula as well. Historically, the sharp increase in Anchorage’s population began with the military buildup during and after WWII, but it was oil development, beginning in the late 1970s, that fueled unprecedented growth.

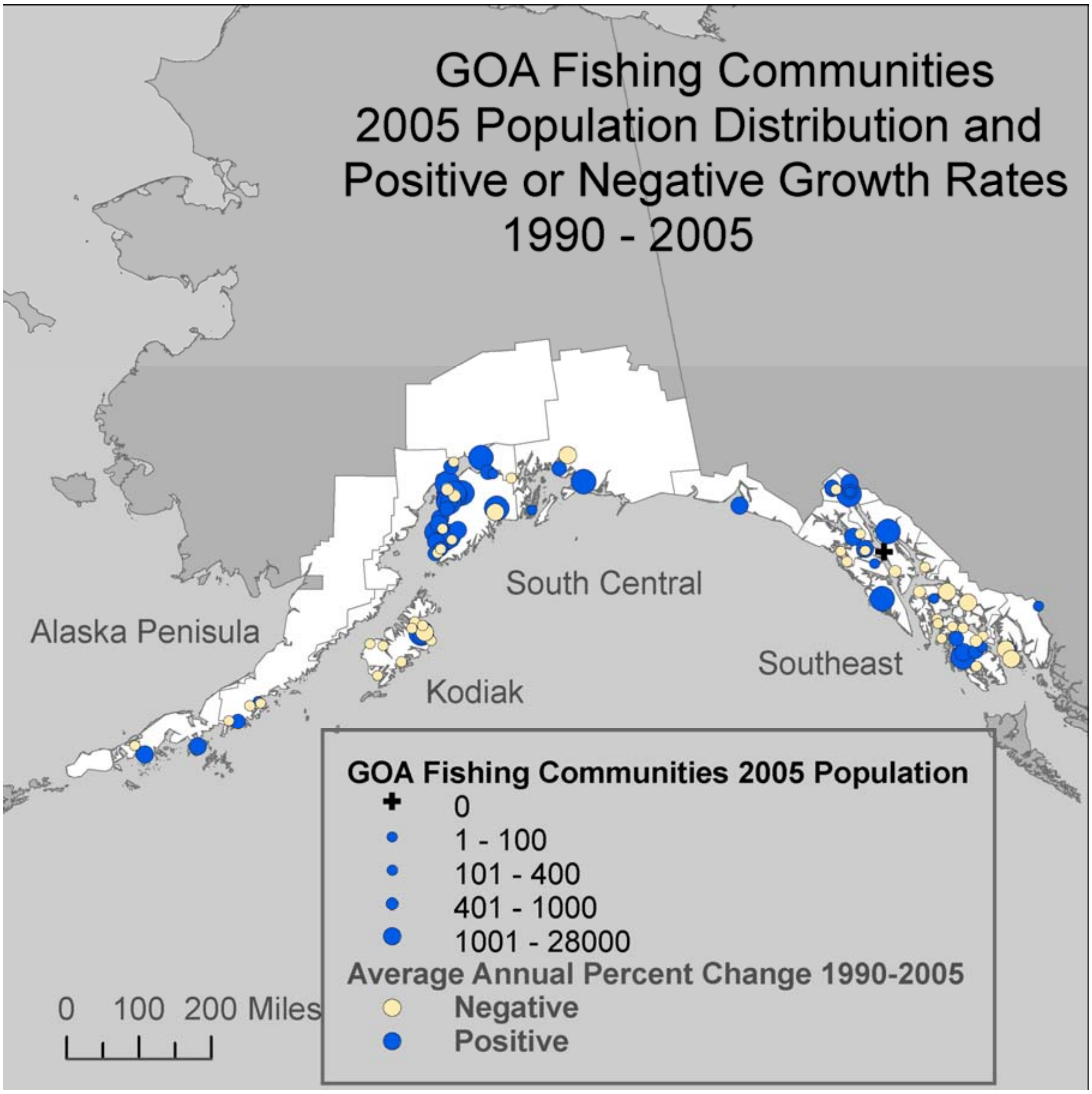

Figure 118. GOA fishing communities. 2005 population distribution and positive or negative growth rates, 1990-2005. Map created by Angie Greig, AFSC.

Impacts:
Population decline or growth in small communities can factor into health care provision, education, land use, environmental impacts, transportation, and other social services (Williams 2004). Over 36% of federal dollars allocated to Alaska depend in some way on population. State programs attach many services, such as education funding, to population. Fishery management programs to support small communities in the Gulf of Alaska use population criteria as part of eligibility requirements.

The concentration of a state's population in a single city, Anchorage, concentrates goods, services, trade, and travel routes in one place. The concentrated population also allows for services (e.g., medical treatment, business and technology support, entertainment) that would not otherwise be sustainable in the state and attracts people to the area due to increased employment and education opportunities. The population growth and concentration in Anchorage has also had negative impacts on the surrounding area through sprawl into the Matanuska-Susitna valley, increased regional hunting and fishing pressures and lower take per capita, increased recreation demand, and loss of agricultural land due to high speculative land values (Fischer 1976).

Isolation of a city from trade and transportation networks and other major population centers can be more important than concentration of the population. While in the past, the cost of living in Anchorage was significantly more than other American cities, on average it is now less expensive to live in Anchorage than in New York or Honolulu (Fried and Robinson 2007). Isolation effects also impact rural areas that rely on Anchorage or Seattle for goods, with prices much higher in rural areas due to transportation costs.

Distribution and abundance trends in the human population of the Bering Sea/Aleutian Islands

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See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

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APPENDIX 2

Essential Fish Habitat Research by AFSC

See the 2006 report in the "Assessment Archives" at: http://access.afsc.noaa.gov/reem/ecoweb/index.cfm

Effects of Fishing Gear on Seafloor Habitat

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In 1996, the Alaska Fisheries Science Center (AFSC) initiated a number of seafloor habitat studies directed at investigating the effects of fishing on seafloor habitat. 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 Principal Investigators - Chris Rooper and Mark Zimmermann (AFSC – RACE), and Jennifer Boldt (University of Washington)
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> **Last updated: August 2007**

Linking the specific benefits of habitats to fish is important in determining Essential Fish Habitat. It is believed that juvenile fish habitats can influence recruitment to adult fish populations through density dependence that occurs in nursery areas. The objectives of this study were to examine a potential nursery area for juvenile Pacific ocean perch (POP, *Sebastes alutus*), determine the specific microhabitats used by juvenile POP, and compare the distribution of juvenile POP to adults. Juvenile POP habitat use was examined at three sites near Samalga Pass in the Aleutian Islands. Presence or absence and density estimates of juvenile POP were made from underwater video collected at 11 transects and from 6 bottom tows at the study sites. Juvenile POP were found predominantly in mixed sand and boulder substrata to the exclusion of most other habitat types (Figure 119). Juvenile POP were found within one body length of complex structure such as boulders, upright coral or sponges. There were higher densities of juvenile POP at the site south of Samalga Pass than at the other sites, while adult POP were found in highest abundance at the site north of Samalga Pass. An examination of large-scale patterns of juvenile and adult POP distribution indicated juveniles use shallower depth zones on the continental shelf (Figure 120). Combined with the geographic separation we observed in this study, this suggests juvenile POP use nursery habitats that are different from adult POP. Conservation and management of this species should address the habitat requirements of juveniles to maintain the goal of healthy adult populations. Details of the study may be found in Rooper and Boldt (2005), Rooper and Zimmermann (2007) and Rooper et al. (*in press*). This project was supported by a grant from the North Pacific Research Board.

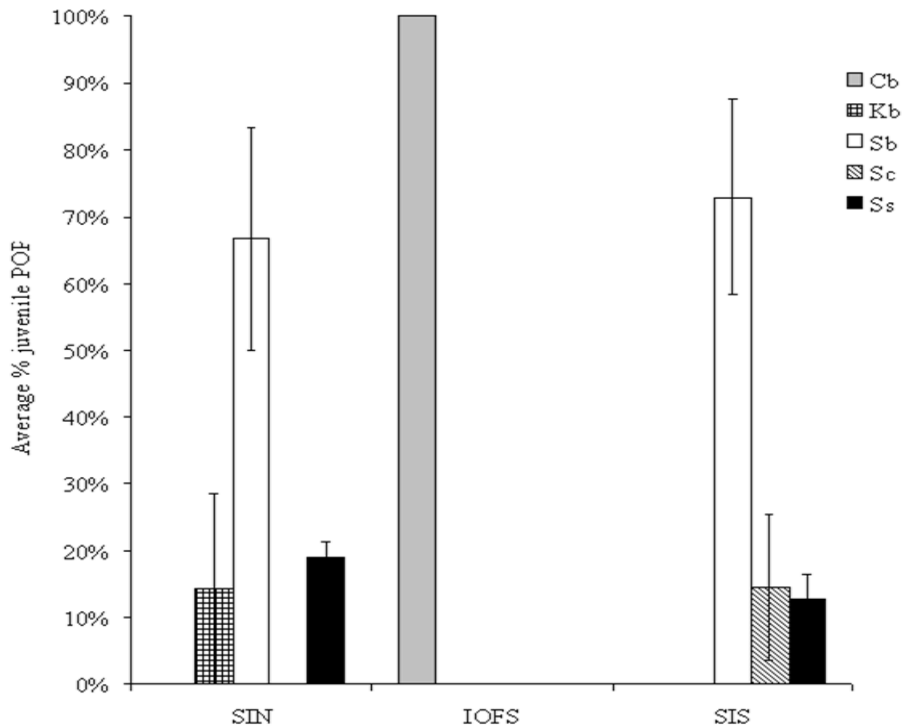

Figure 119. Mean percentage (SE) of juvenile Pacific ocean perch (POP) observed within each substrate type at each of the three study sites; Samalga Island north (SIN), Islands of Four Mountains south (IOFS) and Samalga Island south (SIS). Substrate classifications represented are sand-boulder (Sb), sand-sand (Ss), sand-cobble (Sc), rock-boulder (Kb), and cobble-boulder (Cb).

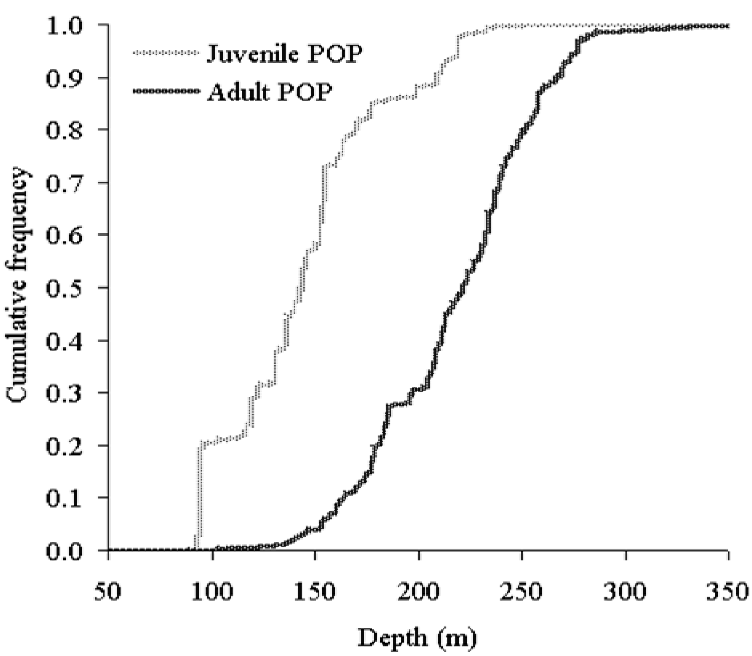

Figure 120. Cumulative frequency distribution of juvenile and adult Pacific ocean perch (POP) catch per unit effort (CPUE) collected during NMFS trawl surveys of the Aleutian Islands (1994, 1997, 2000, 2002 and 2004).

Bogoslof Island mapping and colonization. Principal Investigators - Mark Zimmermann (AFSC - RACE), Jennifer Reynolds (U. Alaska Fairbanks), and Chris Rooper (AFSC - RACE)
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Last updated: October 2007

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 potential 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 purpose is to provide information needed for fisheries management by defining an upper bound on the time needed for recovery.

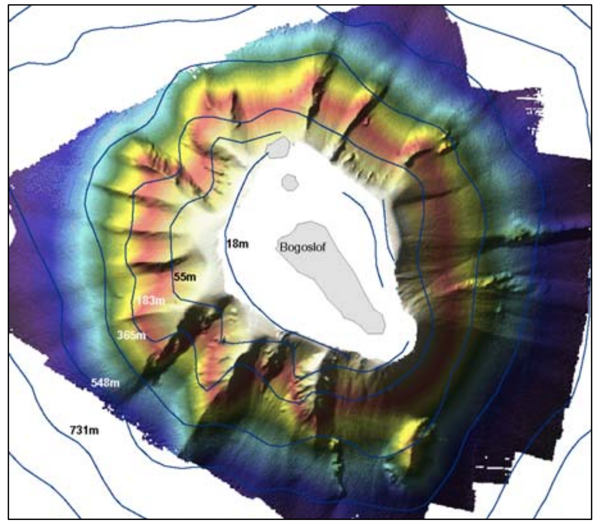

Figure 121. Preliminary multibeam map of the seafloor surrounding Bogoslof Island. Relief is artificially shaded from the northwest.

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 121). Preliminary analysis of these mapping data was used to create the first subsurface geological interpretation of Bogoslof. One finding is that the great majority of volcanic eruptions on Bogoslof occur through vents on the summit platform which create hard substrate on the uppermost slopes. For example, a single lava flow crosses the south edge of the summit platform. This region might provide a suitable area for ROV transects examining colonization of a seafloor area of a known age. Another finding is that the submarine slopes to 750m depth are dominated by downslope transport of volcanic debris and erosion of bedrock into knife-edge ridges. Debris fans blanket the seafloor between these ridges, and are expected to include the volcanic products from historical eruptions. Finer-scale interpretation of the seafloor morphology, prediction of benthic habitat, and assessment of seafloor age are ongoing. Analysis of video recordings from two 1995 Phantom ROV dives on the eastern, upper slopes of Bogoslof (90-230m), courtesy of Rick Brodeur and Morgan Busby, show clear differences in substrate and invertebrate colonization between the two sites, as well as along-track changes in the second dive. Changes in seafloor character observed in the dive video match features in the new multibeam sonar data. These dives provide valuable constraints on geological and habitat interpretation of the new maps.

Deep-sea coral distribution and habitat in the Aleutian Archipelago. Principal Investigators - Robert Stone (AFSC - ABL), Jon Heifetz (AFSC - ABL), Doug Woodby (ADFG), and Jennifer Reynolds (University of Alaska, Fairbanks)
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Last update: October 2007

A study funded by the North Pacific Research Board, NOAA's Undersea Research Program, and NOAA Fisheries was initiated in 2003 to examine deep-sea coral habitat in the central Aleutian Islands. The comprehensive study was prompted by the discovery of coral gardens, a unique benthic habitat type for high-latitude ecosystems, during pioneer work conducted by the Auke Bay Laboratory in 2002. Fieldwork commenced in June of 2003 with a 23 day habitat mapping cruise on the RV *Davidson* and 12 day cruise to collect video transect data with the *Delta* submarine. Field work continued in June – August 2004 with a 15 day *Delta* submarine cruise and a 15 day *Jason II* ROV (Woods Hole Oceanographic Institute) cruise aboard RV *Roger Revelle* (Scripps Institution of Oceanography) to collect additional video transect data.

The goal of this research is to provide information on corals and sponges in the Aleutians that is needed for making critical fishery management decisions to protect coral and sponge habitats. There four objectives that address specific scientific issues: 1) Assess the distribution and abundance of corals and sponges in the central Aleutians with respect to major environmental factors and construct a predictive model based on the assessment, 2) Assess the importance of corals and sponges as habitat for commercially important fish and invertebrates, 3) Assess the extent of fishing gear impacts on coral and sponge habitats, and 4) Collect soft corals (Order Alcyonacea), stony corals (Order Scleractinia), hydrocorals (Order Stylasterina), gorgonians (Order Gorgonacea), black corals (Order Antipatharia), and sponges to describe new species, aid in taxonomic revisions presently underway, and determine the reproductive schedule and larval dynamics of gorgonians and hydrocorals.

Habitat mapping of seventeen sites covering 2,600 km^2 at depths of 30 – 3,800 m coupled with visual observations to 2,950 m were used to collect biological information and develop predictive models that relate coral and sponge distribution to environmental characteristics. Habitats dominated by bedrock and cobble supported the highest densities of corals. Diversity of corals and sponges increased from deep to shallow water. For the predictive model, explanatory variables included depth, slope, and rugosity with depth and slope being the most important factors. Models of coral and sponge presence/absence north of the Aleutian Islands Archipelago were more successful than models south of the Archipelago. The most damage and disturbance to coral and sponge communities occurred at depths < 800 m which generally corresponded to the depth limit of the majority of fisheries that use bottom contact gear. There was a consistent positive relationship between damage and disturbance levels and intensity of bottom trawling, whereas results varied for other gear types. Some commercial fish and crab species aggregate in habitats where corals are abundant, making these habitats at risk to fishing gear impacts. Protective measures implemented in the Aleutian Islands include restricting bottom trawling to historically fished areas. While this protective measure may halt the expansion of bottom trawling to areas not fished, the conservation of coral and sponge habitat in fished areas is still of primary concern. 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.nprb.org/

Red tree coral (*Primnoa* spp.) habitat in the eastern Gulf of Alaska.
Principal Investigator - Robert Stone (AFSC - ABL)
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Last updated: October 2007

The submersible *Delta* was used in 2005 to delineate the extent of *Primnoa* thickets in two areas of the eastern Gulf of Alaska (Fairweather Ground and Cape Ommaney). Five small areas at the two sites (46 km^2 total) were designated as Habitat Areas of Particular Concern (HAPCs) by the National Marine Fisheries Service in June 2006 and the use of all bottom contact fishing gear is now prohibited in those areas. The purpose of the research was to provide detailed data on the distribution of *Primnoa* in the areas so that the efficacy of the closures to protect the thickets from incidental disturbance can be predicted. Additional objectives of the research are to assess the present condition of the thickets, examine the fine-scale use of the coral habitat by FMP species, and collect specimens for taxonomic identification.

Video footage was collected on nine transects at each site and red tree corals and biota were enumerated along more than 32 km at both sites combined. Approximately 85% of the video footage has been analyzed to date. Preliminary results indicate that the *Primnoa* thickets are more extensive than previously thought and that only about 50% of the thickets at both sites appear to be protected. These findings may prompt a reexamination of the HAPC boundaries during the next few years. Approximately 15% of the colonies observed at the two sites have been damaged by past fishing activities and some species particularly the yelloweye rockfish, *Sebastes ruberrimus*, is highly associated with *Primnoa*. A model will be constructed using both biotic and abiotic variables to predict the fine-scale location (i.e. kilometers) of *Primnoa* thickets in the Gulf of Alaska. These data are planned for presentation at the Fourth International Deep Sea Coral Symposium in 2008.

Nursery habitat mechanisms and function for juvenile flatfishes. Principal Investigator – Allan W. Stoner (AFSC - RACE)
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Last updated: August 2007

The juveniles of many fish species have restricted distributions relative to adults, often occupying nearshore nurseries. Nurseries are typically characterized by high food availability and elevated temperatures which support rapid growth, as well as lower predator abundance than offshore waters, which enhances survival. These areas are also often characterized by seafloor structural complexity which can provide refuge from predation for juvenile fishes. Camera sled surveys for juvenile flatfishes in three key nursery grounds near Kodiak from 2002-2006, as well as laboratory experiments, have shown that juvenile rock sole and Pacific halibut exhibit preference for habitats with physical structure created by large benthic invertebrates, biogenic structures such as worm tubes, and sand waves. Models incorporating data on these seafloor features, acquired though video analysis, were found superior to models utilizing only physical parameters such as depth, sediment size, temperature and salinity. Experiments in large laboratory pools revealed that predation vulnerability of age-0 yr rock sole and Pacific halibut decreases substantially in the presence of structurally complex habitat, as predator search behavior was impeded and prey escape behavior was facilitated. These experiments support an accumulating body of evidence that emergent structure in nursery habitats may play a critical role in the survival and recruitment of juvenile flatfishes.

Recent field experiments around Kodiak Island AK also demonstrate that juvenile flatfish are highly sensitive to predator density. During 2003 and 2004, seafloor structural complexity was enhanced through addition of bivalve shell (5 shells/m^2) in replicated plots. The modified plots and reference plots were monitored with a towed camera sled over the following month to track changes in the fish fauna. Laboratory experiments with northern rock sole and Pacific halibut had shown that large and small flatfishes were attracted to structurally complex habitats, but that age-0 yr flatfish would avoid habitats containing high densities of larger/older flatfish. When the field manipulation was conducted in a nursery with low densities of larger flatfish, age-0 yr fish were attracted to the shell plots, where they increased in abundance. In contrast, when conducted in a nursery with high densities of large flatfish, age-0 yr fish avoided the shell plots where larger fish had aggregated. New field experimentation in 2007 indicates that these larger flatfish, including adult yellowfin, rock sole and Pacific halibut, are the numerically dominant predators upon juveniles in these nurseries. This experimentation also revealed that predation increases with depth, perhaps explaining why juveniles are typically more abundant in the shallower portion of these nurseries.

In addition to direct removal of prey, predators may have indirect effects upon prey populations. Laboratory experiments conducted in 2006 demonstrate that chronic predation risk suppresses juvenile flatfish growth. Prior laboratory experiments had demonstrated that age-0 yr northern rock sole are highly risk averse, remaining inactive and buried when confronted with predators. When grown if the presence of predators over a 6 wk period, age-0 rock sole feeding behavior was inhibited and growth suppressed compared to control fish. These results suggest that nurseries with differing predator densities may be characterized by different juvenile growth rates, and highlight the need for a more holistic understanding of nursery function and their function in sustaining exploitable adult fish populations.

Short-term trawling effects and recovery monitoring in the eastern Bering Sea (2001-present). Principal Investigators - Robert A. McConnaughey and Stephen Syrjala (AFSC - RACE Division)
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Last updated: October 2007

Whereas earlier work was 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 (Before-After, Control-Impact) 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 studied previously (McConnaughey et al. 2000, McConnaughey et al. 2005). During a 35-day cruise in 2001, 6 pairs of predesignated 21-km 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 trawls) and 0.1 m2 van Veen grab samples for infauna (n=144 total grabs at 2 per epifauna site). At each infauna-sampling site, a second grab sample (n=144 total grabs) 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 after one year in the experimental corridors 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. The final recovery monitoring event is currently scheduled for summer 2009.

Processing of all 2001 and 2002 samples is completed and statistical analyses are underway. In general, the study area is characterized by very-fine olive-gray sand at 44-57 m depths. The side scan imagery and occasional video samples indicate a generally smooth seafloor, probably due to sizable storm waves and strong tidal currents that regularly disturb the area. Derelict crab pots are scattered throughout the study area and there is evidence of extensive feeding by walrus. Very diverse epifaunal and infaunal communities are represented there, with approximately 60 and 160 taxonomic groups respectively. Preliminary analyses indicate that the median density of 82% of grouped taxa declined in the trawled corridors, while median density increased in the other groups (two crab species, empty gastropod shells and gastropod egg masses).

A systematic framework for assessing mobile fishing gear effects. Principal Investigators Robert A. McConnaughey and Cynthia Yeung (AFSC – RACE Division)
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Last updated: October 2007

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 (McConnaughey and Smith 2000; sections: Infauna community as indicator of essential fish habitat in the southeastern Bering Sea) and (2) analyzing spatial patterns of the benthic invertebrates themselves (section: Spatial and temporal patterns in eastern Bering Sea invertebrate assemblages; Yeung and McConnaughey 2006). 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 a calibrated vertical-incidence echosounder for synoptic seabed classification. Principal Investigators Robert A. McConnaughey and Stephen Syrjala (AFSC – RACE Division)
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Last updated: October 2007

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; Simrad EK-500) along a 9,000 nm trackline in the eastern Bering Sea (EBS) during a 1999 hydroacoustic fishery survey on the *R/V Miller Freeman* (Preston *et al*. 2004).

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 can then be used to group 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. A total of 14 distinct classes of bottom types (clusters) were identified from the 38 kHz data. Alternatively, the three principal components may themselves be used to represent acoustic seabed diversity as continuous variables.

As a first step toward evaluating the utility of vertical-incidence acoustic sampling and statistical characterization of the seabed, the three principal components derived from over 6 million echoreturns collected in 1999 were merged with 22 years of RACE trawl survey data for eight species of EBS groundfish and two species of crab, namely: Alaska plaice (*Pleuronectes quadrituberculatus*), yellowfin sole (*P. asper*), flathead sole (*Hippoglossoides elassodon*), rock sole (*Lepidopsetta* spp.), arrowtooth flounder (*Atheresthes stomias*), Pacific halibut (*Hippoglossus stenolepis*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), snow crab (*Chionoecetes bairdi*), and opilio crab (*C. opilio*). A GAM analysis showed statistically significant contributions of the echoreturns to the best models for each species. The full models explained 31-77% of variability in abundance, with 2–13% of that total contributed by the acoustic predictors. These results are similar to, but less compelling than, another recent study using a side scan sonar in the EBS (Yeung and McConnaughey 2008). This suggests there are important differences in the relative costs and benefits of different acoustic systems and these should be considered when developing plans for broad-scale (EEZ) seabed mapping. A manuscript is being prepared.

Reconnaissance mapping with side scan sonar. Principal Investigators Robert A. McConnaughey and Cynthia Yeung (AFSC – RACE Division)
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Last updated: October 2007

Upon completion of the 2002 bottom trawl impacts study in the eastern Bering Sea, a reconnaissance of Bristol Bay seafloor habitats was undertaken using a high-resolution 455 kHz side scan sonar (Klein 5410). The Klein 5410 side scan sonar system is co-owned with the NOAA Office of Coast Survey. The reconnaissance effort was centered on an 800 mi^2 area of central Bristol Bay that has never been surveyed by NOAA hydrographers or their predecessors. The primary research objective is to identify large homogenous regions that would be the basis for more systematic study of mobile gear effects. Secondary objectives include (1) a comparison of expert and unsupervised classification methods for EFH characterization, (2) a study of walrus feeding ecology, (3) an evaluation of the usefulness of sonar backscatter data for characterizing groundfish distributions, and (4) potential updates of nautical charts for the area.

A 150 m swath of bathymetric data and imagery was collected along survey lines totaling nearly 600 linear miles. The survey intentionally intersected six of the Bering Sea trawl study corridors currently being studied 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.

A subset of the data was classified using geological (expert) 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 by the geologist. Further experimentation with the image patch size chosen for the statistical classification may improve the correlation between the methods.

The distribution of two types of feature associated with walrus foraging were observed: (a) small (<<1 m diameter) shallow pits, often in clusters ranging in density from 5 pits per hectare to 35 pits per hectare; and, (b) more abundant, narrow, sinuous furrows, typically 5 to 10 m long with some reaching 20 m or more. Most foraging marks were in less than 60 m water depth in areas of sandy seafloor that were smooth, hummocky or characterized by degraded bedforms; the absence of foraging marks in other areas may be related, in part, to their more dynamic nature (Bornhold et al. 2005).

Acoustic variables from *QTC* software processing of raw digital backscatter data were used in multiple linear regression to model individual species abundance from bottom-trawl survey data. The acoustic variables are the three Q-values (Q1, Q2, Q3) representing the first three principal components of the data derived from image analysis of backscatter echoes, and a complexity metric (compx) measuring the variance of Q-values in a geographic area. Habitat models for flathead sole (*Hippoglossoides elassodon*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), red king crab (*Paralithodes camtschaticus*), basket star (*Gorgonocephalus eucnemis*), and sponges (Porifera) include acoustic variables as significant predictors. For these six taxa, full models explained 67-86% of variability in abundance, with 9-54% of that total contributed by the acoustic predictors (Figure 122). These results suggest that acoustic data could advance habitat research for some bottom-associated marine species. A report of this study by Yeung and McConnaughey has been accepted for publication in the ICES Journal of Marine Science.

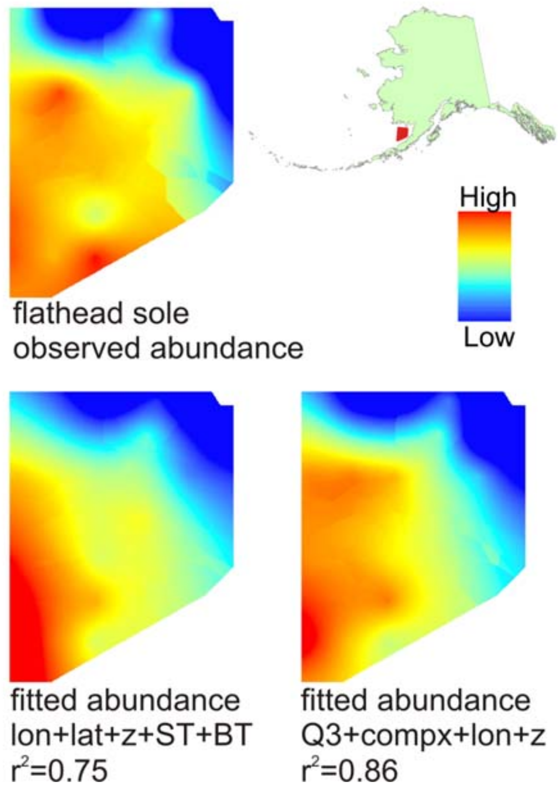

Figure 122. Abundance of flathead sole (log kg/ha) in 2002 modeled by multiple linear regression using only standard environmental variables available from trawl survey (lat = latitude; lon = longitude; z = depth; BT = bottom temperature; ST = surface temperature), and using the best combination of these environmental variables and additional acoustic variables from a 38 kHz vertical-incidence echosounder (which significantly improved the model fit). The Bristol Bay study area is indicated in red in inset map of Alaska.

Infauna as a component of essential fish habitat in the southeastern Bering Sea.

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Last updated: October 2007

Surficial sediment type, as determined from grab samples or sonar backscatter, can explain a significant portion of the variation in the distributions of some fishes and invertebrates in the eastern Bering Sea (McConnaughey and Smith 2000; Yeung and McConnaughey 2008). These are mostly species that are closely associated with the seafloor. The diets of some, particularly the small-mouthed flatfishes, often include infauna such as polychaetes and worms. The infauna community is also shaped by the characteristics of the surficial sediment. These inter-relationships suggest that the infauna community can be an important component of favorable habitat for certain fishes/invertebrates.

Infauna communities have long been a measure of ecological impact on soft-bottom habitats. Studies on gear effects, for example, employ changes in the species composition and size structure of the infauna and epifauna communities before and after disturbance as a metric (McConnaughey et al. 2000; McConnaughey et al. 2005). Infauna communities may also prove to be a useful environmental variable in defining habitat and predicting distribution of some bottom-associated fishes/invertebrates. An initial test of this hypothesis will be conducted using recent information on infauna (RACE Habitat Research) and on the distribution (RACE annual bottom-trawl survey) and diet (REFM Food Habits Lab) of bottom-trawl caught species in the southeastern Bering Sea.

During the FISHPAC acoustic survey of the southeastern Bering Sea benthic habitat in 2006, two grab samples each were taken at each of 26 selected stations (http://www.afsc.noaa.gov/RACE/groundfish/hrt/fishpac.php). All of these stations lie within the established sampling area of the annual RACE bottom-trawl survey, and many were at the fixed trawl stations. The collector was a 0.1 m^2 van Veen grab sampler on a Seabed Observation and Sampling System (SEABOSS), which also had a digital camera to photograph the bottom area where the sample was taken. One sample at each station was used for grain size analysis to aid the interpretation of bottom types and groundtruthing of acoustic data; the other was processed for infauna.

Polychaetes are by far the most abundant infauna in the samples, and are thus the focus of our study. They were identified to at least the family level. Grain size was analyzed with a Malvern Mastersizer 2000 laser particle sizer. Multivariate ordination methods will be used to identify infauna communities, the correspondence between the communities and sediment grain size, and between the communities and target trawl species with polychaete diets. Correspondence will indicate possible ecological relationships between infauna communities and target species, and whether grain size is a good proxy for infauna communities. The significance of infauna as an indicator of essential fish habitat will be evaluated.

Development of a long-range side scan sonar for EFH research.
Robert A. McConnaughey (AFSC – RACE Division).
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Last updated: October 2007

The broad scope of the EFH mandate requires an efficient process for identifying and mapping habitat. Although research indicates surficial sediments affect the distribution and abundance of many groundfish species, direct sampling with benthic grabs and remote sensing with multibeam echosounders are prohibitively expensive over large areas. The development of a quantitative Long Range Side Scan Sonar (LRSSS; 180 kHz) capable of very broad coverage (>1 km swath) addresses the need for greater efficiency when mapping and characterizing the seafloor for fisheries and habitat research. Research and development of the LRSSS and its fiber-optic interface have been progressing since 2004. A prototype LRSSS was successfully deployed and data were acquired during the 2006 FISHPAC experiment in the southeastern Bering Sea (http://www.afsc.noaa.gov/RACE/groundfish/hrt/fishpac.php). In addition to side scan sonar, the LRSSS towfish also carries an independent vertical-incidence echosounder, an integrated multibeam echosounder, sophisticated navigational instruments, and a triplet of optical scatter sensors that measures the concentration of chlorophyll-a, dissolved organics and total particulates.

Evaluating acoustic backscatter for efficient characterization of Essential Fish Habitat in the eastern Bering Sea (FISHPAC). Robert A. McConnaughey, Cynthia Yeung (AFSC – RACE Division), LT Jay Lomnicky (NOAA Corps, billeted to AFSC – RACE Division).
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Last updated: October 2007

The first FISHPAC field experiment was conducted in the southeastern Bering Sea in the summer of 2006 aboard the NOAA ship FAIRWEATHER (http://www.afsc.noaa.gov/RACE/groundfish/hrt/fishpac.php). The scientific objective of the cruise was to evaluate the utility of acoustic backscatter data for characterizing EFH, while simultaneously comparing the performance of five different sonar systems. The five systems included two hull-mounted multibeam echosounders on FAIRWEATHER (50 kHz, 100 kHz); a high-resolution interferometric side scan sonar (455 kHz), a prototype long-range side scan sonar

(LRSSS; 180 kHz), and a vertical incidence echosounder (38 kHz) mounted on the LRSSS towfish. Multiple passes were made along 720 nm of survey tracklines spanning strong gradients of groundfish abundance, as represented in a time series of fixed-station annual trawl survey catches. Three sampling devices - (1) a Free Fall Cone Penetrometer (FFCPT), (2) a SEABed Observation and Sampling System (SEABOSS), and (3) a Towed Auto-Compensating Optical System (TACOS) - were used at selected stations on the tracklines to groundtruth acoustic backscatter and assemble a multifaceted understanding of the seafloor. The performance of each acoustical system will be evaluated based on the degree of statistical correlation between normalized backscatter and fish density. The benefits and costs of each system will be compared to identify the most appropriate system for broad-scale mapping of the Bering Sea shelf. Acoustic data are being processed in collaboration with FISHPAC research partners: the University of New Hampshire Center for Coastal and Ocean Mapping and the NOAA Pacific Hydrographic Branch. FFCPT data processing and sediment grain size analysis have been completed. Infauna identification in collaboration with scientists in the AFSC Resource Ecology and Fisheries Management (REFM) division is also completed. Processing and analysis of sonar data, as well as TACOS and SEABOSS imagery are underway. As part of NOAA's Integrated Coastal and Ocean Mapping effort, modern bathymetry data have been submitted for updating nautical charts of the area.