APPENDIX C

Ecosystem Considerations for 2005

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

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INTRODUCTION

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

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

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 2000-2003 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.

This year, it was requested that contributors to the ecosystem considerations chapter provide actual time series data or make it available electronically. Time series data for many contributions will be available on the web, through the editor (with permission from the authors), or 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.

Also, new to the chapter this year, in the Ecosystem Assessment section, is the addition of an assessment of ecosystem responses to recent regime shifts.

Ecosystem Considerations sections from 2000 to the present are available on the Alaska Fisheries Science Center website at:
http://www.afsc.noaa.gov/refm/reem/Assess/Default.htm.

ECOSYSTEM ASSESSMENT of the Bering Sea/Aleutian Islands and Gulf of Alaska Management Regions

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Summary

This section utilizes time series presented in the Ecosystem Considerations section to provide an assessment of the BSAI and GOA ecosystems and their responses to human activity and climate variability. New this year, are visual and written summaries of the historical and current states of the two ecosystems and an assessment of the past, present, and future roles of climate variability in influencing those states. Based on basin-wide North Pacific climate-ocean indices, there appear to have been regime shifts in 1989 and in 1998. For previous regime shifts, such as in the mid-1940s and 1977, the pattern of sea surface temperature spatial variability implied a west-east dipole. Since 1989, the pattern of spatial variability has been dominated by a second pattern of sea surface temperature variability, which implies a north-south dipole. At regional scales the responses to these basin-scale changes may not be as coherent. It is important to note that regimes are defined as decadal scale periods, yet there are only 5 years of data available since 1998 with which to assess the new state. Given the variability in the indices since 1998, there is some uncertainty about the level of productivity of the new regime. There is growing evidence that some ecosystems are responding to the shift in 1998. The Gulf of Alaska shelf system had a weak response to the shift, appearing to shift towards cool water species, but that response is not persisting. Summer bottom temperatures in the Aleutian Islands appear to be about averate in 2004. However, the Bering Sea is projected to continue on its warm trajectory.

Another goal of this assessment and the Ecosystem Indicators section is to bring important research results to the attention of stock assessment scientists and fishery managers. Two examples of species that merit management attention are Northen fur seals and Giant grenadiers. Northern fur seal pup production has continued to decline in the Bering Sea (see Ecosystem Indicators, Marine Mammals section). Also, although there is no directed fishery for grenadiers in Alaska, substantial numbers are taken as bycatch in some longline fisheries. Grenadiers are long-lived and slow-growing, and a large proportion of the catch is female giant grenadier, raising concerns about the management of this particular species (see Ecosystem Indicators, Benthic Communities and Non-target Fish Species, Grenadiers in Alaska section).

Introduction

One goal of this assessment is to utilize the time series presented in the Ecosystem Considerations section to summarize the 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. Another purpose of this assessment is to provide a summary of the possible future effects of climate and fishing on ecosystem structure and function utilizing multispecies and ecosystem models. The modeling section will be added to the second draft of this assessment in October. The current draft focuses on the historical responses of ecosystem components to climate regime shifts.

The Ecosystem Status Indicators in the Ecosystem Considerations section provide the historical perspective of status and trends of ecosystem components and ecosystem-level attributes. An assessment of some of these important time series is presented in this section (Tables 1-4; for a more complete list of indicators see Table 5), much of which is a product of a North Pacific Marine Science Organization (PICES) study group report. The North Pacific Marine Science Organization (PICES) received a formal request for advice from the United States government in October 2003. The request asked for scientific advice on the implications of the 1998 regime shift for North Pacific fisheries. Following the strong 1997-1998 El Niño, the North Pacific climate underwent a rapid and striking transition, the persistence of which suggests that a regime shift had occurred. Previous regime shifts have had serious implications for ecosystems, and consequently for fish populations and the fishing industry. The PICES' Science Board convened a 20 member Study Group on Fisheries and Ecosystem Responses to Recent Regime Shifts (FERRRS) to provide a response to the United States' request for advice. This assessment presents summaries of both the BSAI and GOA ecosystems and an overall summary of the North Pacific that addresses the state and responses of ecosystems to climate variability, predictions of conditions in future years, and implications for management of marine resources.

Recent Ecosystem Changes in the Bering Sea and Aleutian Islands

Bering Sea

The Bering Sea was subject to a change in the physical environment and an ecosystem response after 1977, a minor influence from shifts in Arctic atmospheric circulation in the early 1990s, and persistent warm conditions over the previous 3 years (Tables 1 and 2). A major transformation, or regime shift, of the Bering Sea occurred in atmospheric conditions around 1977, changing from a predominantly cold Arctic climate to a warmer subarctic maritime climate as part of the Pacific Decadal Oscillation (PDO) (Tables 1 and 2). This shift in physical forcing was accompanied by a major reorganization of the marine ecosystem on the Bering Sea shelf over the following decade. Surveys show an increase in the importance of pollock to the ecosystem. Weather data beginning in the 1910s and proxy data (e.g. tree rings) back to 1800 suggest that, except for a period in the 1930s, the Bering Sea was generally cool before 1977, with sufficient time for slow growing, long-lived, cold-adapted species to adjust. Thus the last few decades appear to be a transition period for the Bering Sea ecosystem.

A comprehensive report (NAS 1996) attributes the ecosystem reorganization toward pollock to the combination of fishing and the 1976 regime shift. They hypothesize that fishing of large whales increased the availability of planktonic prey, fishing on herring reduced competition, and fishing on flatfish reduced predation. The modeling study of Trites et al. (1999) noted that the increase in pollock biomass could not be explained solely by trophic interaction from these removals, and favored environmental shifts as an explanation. While the physical shift after 1976 was abrupt and pollock biomass increased rapidly, the ecosystem adjustment probably took a prolonged period as relative biomass shifted within the ecosystem. Biodiversity measures (richness and evenness) of roundfish, excluding pollock, decreased throughout the 1980s and were stable in the 1990s (Hoff 2003). Jellyfish, which share a common trophic level with juvenile pollock and herring, may have played a role in the ecosystem adjustment as their biomass increased exponentially beginning in the early 1980s, but recently have crashed in 2001-2003 (Tables 1 and 2).

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

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

The overall climate change occurring in the Arctic, as indicated by warmer atmospheric and oceanic temperatures and loss of 15 % of sea ice and tundra area over the previous two decades, is hypothesized to make the Bering Sea less sensitive to the intrinsic climate variability of the North Pacific. Indeed, when the waters off of west coast of the continental U.S. shifted to cooler conditions after 1998, the subarctic did not change(Victoria pattern), in contrast to three earlier PDO shifts in the 20th century. Thus it is projected that the Bering Sea will more likely continue on its current warm trajectory, with biomass transitioning northward allowing pollock a larger domain at the expense of cold and ice-adapted species, rather than transitioning back to a cold regime. Bering Sea indicators (climate and biological data) should be watched closely over the next five years to confirm or reject this hypothesis.

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. Biological conditions in the Aleutian Islands have changed since the 1980's, and it is too soon to discern if there was a change associated with the 1998 shift. Pollock and Atka mackerel do not appear to vary on a decadal-scale; however, the biomass of pollock appears to be higher than it was in the 1980's. Pacific Ocean perch population dynamics vary on a decadal-scale. For example, Pacific Ocean perch survival changed at approximate times of regime shifts, 1975 and 1989. There is not enough information on the early life history of Pacific Ocean perch to define a mechanism for the observed variations.

Table 1. Bering Sea/Aleutian Islands time series descriptions and sources presented in Table 2. Anomalies of these 34 time series were calculated by subtracting the mean and dividing by the standard error, based on the time series reported below. Most data was taken from the Ecosystem Indicators section, and the author is noted with the year of the Ecosystem Considerations section (2003 –last year's report, or 2004 – this report).

Time series	Period	Description	Index or process	Source
BERING SEA, ALEUTIAN ISLANDS				
Biotic time series				
Atka (R/S)	1977-2000	Atka mackerel log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
AK Plaice (R/S)	1975-1999	Alaska plaice log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
Cod (R/S)	1977-2002	Pacific cod log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
Pollock (R/S)	1964-2002	Walleye pollock log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
YFS (R/S)	1964-1998	Yellowfin sole log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
POP (R/S)	1960-1993	Pacific Ocean perch log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
Northerns (R/S)	1977-1993	Northern rockfish log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
GT (R/S)	1973-1999	Greenland turbot log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
ATF (R/S)	1976-1998	Arrowtooth flounder log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
Rock sole (R/S)	1975-1997	Rock sole log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
FHS (R/S)	1977-2000	Flathead sole log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
Total salmon catch	1900-2003	Total catch of Bristol Bay salmon	Productivity	Eggers 2004
Herring recruits	1978-2004	Togiak herring age-4 recruits	Productivity	West, 2004
Total crab biomass	1980-2002	Total crab biomass	Productivity	Otto and Stevens 2003
Jellyfish biomass	1982-2003	Jellyfish biomass in survey catches	Productivity	Walters 2003
Total CPUE	1982-2003	Total catch per unit effort of fish and invertebrates in bottom trawl surveys	Productivity	Mueter 2004
BS Diversity	1982-2003	Bering Sea groundfish diversity (Shannon-Wiener index)	Diversity	Mueter 2004
BS Richness	1982-2003	Bering Sea groundfish richness (average number of species per survey haul)	Richness	Mueter 2004
BLKI Productivity	1975-2002	Black-legged kittiwake productivity (fledglings per egg) at St. Paul Island	Productivity	D.E. Dragoo, USFWS, personal communication
RLKI Productivity	1975-2002	Red-legged kittiwake productivity (fledglings per egg) at St. Paul Island	Productivity	D.E. Dragoo, USFWS, personal communication
TBMU Productivity	1976-2002	Thick-billed murre productivity (fledglings per egg) at St. Paul Island	Productivity	D.E. Dragoo, USFWS, personal communication
COMU Productivity	1976-2002	Common murre productivity (fledglings per egg) at St. Paul Island	Productivity	D.E. Dragoo, USFWS, personal communication
Abiotic time series				
Ice Cover Index	1954-2004	A combination of 6 highly correlated ice variables	Water column conditioning	http://www.beringclimate.noaa.gov/index.html
Surface Winter Air Temp.	1916-2004	Surface winter air temperature	Water column conditioning	http://www.beringclimate.noaa.gov/index.html
PDO	1901-2004	Pacific Decadal Oscillation	Winter sea surface temperature; physical forcing	http://jisao.washington.edu/pdo/PDO.latest
May SST	1970-2004	May sea surface temperature	Spring sea surface temperature; physical forcing	http://www.beringclimate.noaa.gov/index.html
AOI	1951-2004	Arctic Oscillation Index	Sea level pressure; physical forcing	http://www.beringclimate.noaa.gov/index.html
Summer Bottom Temp.	1982-2003	Summer bottom temperature	Summer bottom temperature; physical forcing	http://www.beringclimate.noaa.gov/index.html
Human time series				
BS Trophic level of catch	1954-2003	Bering Sea trophic level of the catch	Ecological balance of fishing	Livingston 2004
AI Trophic level of catch	1962-2003	Aleutian Island trophic level of the catch	Ecological balance of fishing	Livingston 2004
Hook and Line Effort	1993-2002	Hook and line (longline) effort (number of hooks)	Fishing effort	Fitzgerald et al. 2003
AI Bottom Trawl Duration	1990-2001	Aleutian Island bottom trawl duration (24 hour days)	Fishing effort	Coon 2004
BS Bottom Trawl Duration	1990-2001	Bering Sea bottom trawl duration (24 hour days)	Fishing effort	Coon 2004
BS Pelagic Trawl Duration	1995-2003	Bering Sea pelagic trawl duration (24 hour days)	Fishing effort	Coon 2004

Table 2. The table on the next page displays standardized anomalies of 34 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 six divisions of anomalies. 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, and to minimize repeat information; however, there are some variables that will be added when those time-series become available. The time series included are: Bering Sea trophic level of catch, ice cover index, Aleutian Islands trophic level of catch, surface winter air temperature, total Bristol Bay salmon catch, PDO (Pacific Decadal Oscillation), Togiak age-4 herring recruits, May SST (sea surface temperature), COMU (Common Murre) productivity (fledglings per egg), AOI (Arctic Oscillation Index), Atka (Atka mackerel) log-transformed recruit per spawning biomass, total CPUE (Catch per unit effort) for all fish and invertebrates, BS diversity, Jellyfish biomass, AK plaice (Alaska plaice) log-transformed recruit per spawning biomass, Cod log-transformed recruit per spawning biomass, pollock log-transformed recruit per spawning biomass, BS richness, Total crab abundance, BLKI (Black-legged kittiwake) productivity (fledglings per egg) at St. Paul Island, TBMU (Thick-billed murres) productivity (fledglings per egg) at St. Paul Island, RLKI (Red-legged kittiwake) productivity (fledglings per egg) at St. Paul Island, YFS (yellowfin sole) log-transformed recruit per spawning biomass, POP (Pacific Ocean perch) log-transformed recruit per spawning biomass, Northerns (Northern rockfish) log-transformed recruit per spawning biomass, GT (Greenland turbot) log-transformed recruit per spawning biomass, ATF (arrowtooth flounder) log-transformed recruit per spawning biomass, Rock sole log-transformed recruit per spawning biomass, FHS (flathead sole) log-transformed recruit per spawning biomass, Summer bottom temperature, AI bottom trawl duration (24 hour days), BS bottom trawl duration (24 hour days), BS pelagic trawl duration (24 hour days). See Table 1 for a description of time series.

Bering Sea/Aleutian Islands

Year	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Normalized time series
BS Trophic level of catch	.	.	+	+	+	+	+	+	.	.	+	+	+	+	.	.	.	.	.	.	+	.	.	.	.	+	+	.	.	+	+	+	+	+		1954-2003
Ice Cover Index	.	+	+	.	+	+	+	.	-	--	.	-	-	.	.	.	.	-	.	-	.	+	+	-	.	+	--	.	+	.	+	--	+	-	-	1954-2004
AI Trophic level of catch	-	-	.	+	.	.	.	.	.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	.	.	.	.	.	.	.	.	.	.	.		1962-2003
Surface Winter Air Temp.	.	--	--	.	-	--	--	.	+	++	+	+	+	.	.	+	.	+	-	+	.	-	.	.	.	-	++	.	.	.	-	++	-	+	+	1916-2004
Total salmon catch	+	-	-	-	-	-	-	-	.	+	+	+	.	++	++	+	.	.	.	+	++	+	++	+++	++	+++	++	.	-	+	+	.	.	.		1900-2003
PDO	+	-	--	.	-	-	-	+	.	-	.	+	.	+	+	+	+	++	+	-	.	--	.	.	+	-	.	.	+	.	-	.	.	++	.	1901-2004
Herring recruits									.	-	-	+++	+++	+	.	.	-	.	.	-	-	+	.	.	.	.	.	.	-	-	.	.	-	-	.	1978-2004
May SST	+	-	-	.	+	-	-	+	++	++	+	++	-	+	-	-	-	.	.	.	.	.	-	+	.	-	+	.	-	-	.	.	.	+	+	1970-2004
COMU Productivity							.		+							+	-	+	+	.	.		.				.	-		-	.	+	+			1976-2002
AOI	-	.	.	+	.	+	+	--	-	-	.	.	.	.	.	-	-	-	.	++	+	+	+	++	.	+	-	.	.	+	+	-	+	.	-	1951-2004
Atka (R/S)								++	+	.	.	-	-	-	.	.	+	+	++	+	-	.	.	-	-	.	--	-	+	+	-					1977-2000
Total CPUE													-	.	-	--	-	.	.	.	.	.	.	+	++	+	.	.	.	.	.	.	.	++		1982-2003
BS Diversity													-	-	-	-	-	-	-	-	.	+	+	.	+	+	+	+	++	.	.	+	-	-		1982-2003
Jellyfish biomass													-	-	-	-	-	-	-	-	-	.	.	.	+	.	+	+	+	+	+++	.	.	.		1982-2003
AK Plaice (R/S)						++	++	+	.	.	.	.	--	--	.	-	-	.	-	.	-	+	.	+	-	.	.	.	.	.						1975-1999
Cod (R/S)								+++	++	++	+	.	+	-	.	.	-	-	-	.	.	-	.	-	-	-	.	.	.	.	.	-	.			1977-2002
Pollock (R/S)	-	-	.	.	+	+	+	+	++	+	+	.	+	-	.	-	--	--	-	.	.	.	+	-	-	.	.	-	-	.	.	-	-			1964-2002
BS Richness													+	+	.	--	-	--	-	-	.	+	.	+	.	-	.	.	+	.	.	+	-	++		1982-2003
Total crab biomass											+	.	.	-	-	-	-	.	.	+	++	++	.	.	.	.	.	.	.	-	-	-	-			1980-2002
BLKI Productivity						+	+	+	.	+					-	.	.	.	+	-	.		.	.	-	-	-	.	+	-	+	-	++			1975-2002
TBMU Productivity							++	.	+						--	.	.	.	.	.	.		.				.	-	--	.	.	.	+			1976-2002
RLKI Productivity						.	++	+	-	.					-	.	.	-	+	-	.	-	.	.	.	-	-	.	+	.	+	-	+			1975-2002
YFS (R/S)	+	+	++	++	++	+	+	.	.	.	.	.	-	.	-	-	-	-	-	-	-	.	-	-	-	-	-	-	-							1964-1998
POP (R/S)	.	.	.	.	.	.	+	+	+	+	+	++	+	+	+	+	+	.	.	.	-	-	-	-												1960-1993
Northerns (R/S)								+	.	.	.	-	-	.	++	.	-	.	+	+	-	-	-	+												1977-1993
GT (R/S)				+	+	+	+	++	+	+	.	-	--	-	.	+	.	.	-	.	+	-	-	-	-	.	-	-	-	.						1973-1999
ATF (R/S)							+	.	.	+	++	.	.	+	+	+	++	+	.	.	.	-	-	--	-	-	-	-	-							1976-1998
Rock sole (R/S)						+	.	.	.	.	+	+	+	+	+	+	+	+	.	.	.	.	-	-	-	--	-	--								1975-1997
FHS (R/S)								+	+	+	++	++	+	+	+	+	.	.	.	.	.	.	-	-	-	-	-	-	-	-	-					1977-2000
Summer Bottom Temp.													-	+	.	.	-	+	.	+	.	.	-	+	-	-	+	.	+	--	-	.	+	++		1982-2003
Hook and Line Effort																								-	-	-	-	.	.	.	+	++	+			1993-2002
AI Bottom Trawl Duration																					++	.	+	+	.	.	+	-	-	-	-	-				1990-2001
BS Bottom Trawl Duration																					-	.	+	.	+	+	+	+	-	-	-	--				1990-2001
BS Pelagic Trawl Duration																										.	++	.	+	-	-	.	.	.		1995-2003

Legend

+++	X>2.6
++	2.6>X>1.6
+	1.6>X>0.5
.	0.5>X>-0.5
-	-0.5>X>-1.6
--	-1.6>X>-2.7
	no data

Recent Ecosystem Changes in the Gulf of Alaska

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

There were both physical and biological responses to all regime shifts in the GOA; however, the primary reorganization of the GOA ecosystem occurred after the 1977 shift. After 1977, the Aleutian Low intensified resulting in a stronger Alaska current, warmer water temperatures, increased coastal rain, and, therefore, increased water column stability. The optimal stability window hypothesis suggests that water column stability is the limiting factor for primary production in the GOA (Gargett 1997). A doubling of zooplankton biomass between the 1950's- 1960's and the 1980's indicates production was positively affected after the 1977 regime shift (Brodeur and Ware 1992). Recruitment and survival of salmon and demersal fish species also improved after 1977 (Tables 3 and 4). Catches of Pacific salmon in Alaska increased, recruitment of rockfish (Pacific Ocean perch) increased, and flatfish (arrowtooth flounder, halibut, and flathead sole) recruitment and biomass increased. There are indications that shrimp and forage fish, such as capelin, were negatively affected by the 1977 shift, as survey catches declined dramatically in the early 1980's (Anderson 2003, Tables 3 and 4). The decline in marine mammal and seabird populations, observed after the 1977, shift may have been related to the change in forage fish availability (Piatt and Anderson 1996).

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

There is some indication that the GOA ecosystem may have weakly responded to the 1998 regime shift. Increased storm intensity from 1999 to 2001 resulted in a deeper mixed layer depth in the central GOA, and coastal temperatures were average or slightly below average. After 1998, coho survival increased in southern BC, shrimp catches increased in the northern GOA (*but have since declined again in 2003)*, and the 1999 year class of both walleye pollock and Pacific cod was strong in the northern GOA. Recruitment information from longer-lived species will be available in the near future, enabling scientists to determine if there were other responses to the 1998 climate shift.

It is apparent that many components of the Gulf of Alaska ecosystem respond to decadal-scale variability in climate and ocean dynamics. It is unknown if changes observed after the 1998 shift will persist in the Gulf of Alaska and how long the current conditions in the Gulf of Alaska will last. Predicting regime shifts will be difficult until the mechanisms that cause the shifts are understood (Minobe 2000). 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 Gulf of Alaska that fit some of these criteria include sockeye and pink salmon, juvenile fish abundance, ichthyoplankton, as well as zooplankton biomass and composition.

Table 3. Gulf of Alaska time series descriptions and sources presented in Table 4. Anomalies of these 26 time series were calculated by subtracting the mean and dividing by the standard error, based on the time series reported below. Most data was taken from the Ecosystem Indicators section, and the author is noted with the year of the Ecosystem Considerations section (2003 –last year's report, or 2004 – this report).

Time series	Period	Description	Index or process	Source
GULF OF ALASKA				
Biotic time series				
Sablefish (R/S)	1960-1999	Sablefish log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
Cod (R/S)	1977-2001	Pacific cod log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
Pollock (R/S)	1969-2001	Walleye pollock log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
POP mean (R/S)	1977-1998	Pacific Ocean perch log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
Northerns (R/S)	1977-1995	Northern rockfish log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
Thornyheads (R/S)	1967-1992	Thornyhead rockfish log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
ATF (R/S)	1961-1997	Arrowtooth flounder log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
FHS (R/S)	1984-1997	Flathead sole log-transformed recruit per spawning biomass	Productivity	NPFMC; Boldt et al. 2004
Total salmon catch	1900-2003	Total GOA salmon catch	Productivity	Eggers 2004
Herring recruits	1980-2003	Southeast Alaska age-3 herring recruits	Productivity	Dressel et al. 2004
Pandalid cpue	1972-2003	Pandalid shrimp catch per unit effort in ADFG small mesh survey	Productivity	Anderson 2004
Eulachon cpue	1972-2003	Eulachon catch per unit effort in ADFG small mesh survey	Productivity	Anderson 2004
Sandfish cpue	1972-2003	Sandfish catch per unit effort in ADFG small mesh survey	Productivity	Anderson 2004
Pricklebacks cpue	1972-2003	Prickleback catch per unit effort in ADFG small mesh survey	Productivity	Anderson 2004
Total CPUE	1990-2003	Total catch per unit effort of fish and invertebrates in bottom trawl surveys	Productivity	Mueter 2004
Diversity	1990-2003	Gulf of Alaska groundfish diversity (Shannon-Wiener index)	Diversity	Mueter 2004
Richness	1990-2003	Gulf of Alaska groundfish richness (average number of species per survey haul)	Richness	Mueter 2004
BLKI Productivity	1983-2002	Black-legged kittiwake productivity (fledglings per egg) in Prince William Sound	Productivity	D.E. Dragoo, USFWS, personal communication
TBMU Productivity	1976-2002	Thick-billed murre productivity (fledglings per egg) at Chowiet	Productivity	D.E. Dragoo, USFWS, personal communication
COMU Productivity	1976-2002	Common murre productivity (fledglings per egg) at Chowiet	Productivity	D.E. Dragoo, USFWS, personal communication
Abiotic time series				
PDO	1901-2004	Pacific Decadal Oscillation	Winter sea surface temperature; physical forcing	http://jisao.washington.edu/pdo/PDO.latest
AOI	1951-2004	Arctic Oscillation Index	Sea level pressure; physical forcing	http://www.beringclimate.noaa.gov/index.html
MLD	1973-2001	Mixed layer depth at GAK1 (north GOA)	Water column conditioning; physical forcing	Sarkar and Royer 2003
Human time series				
Trophic level of catch	1956-2003	Gulf of Alaska trophic level of the catch	Ecological balance of fishing	Livingston 2004
Hook and Line Effort	1993-2002	Hook and line (longline) effort (number of hooks)	Fishing effort	Fitzgerald et al. 2003
Bottom Trawl Duration	1990-2002	Gulf of Alaska bottom trawl duration (24 hour days)	Fishing effort	Coon 2004

Table 4. The table on the next page displays standardized anomalies of 26 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 six divisions of anomalies. 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, and to minimize repeat information; however, there are some variables that will be added when those time-series become available. The time series included are: Trophic level of catch, PDO (Pacific Decadal Oscillation), Total GOA salmon catch, Thornyhead rockfish log-transformed recruit per spawning biomass, Sablefish log-transformed recruit per spawning biomass, MLD (Mixed Layer Depth at GAK 1, north GOA), AOI (Arctic Oscillation Index), Pollock log-transformed recruit per spawning biomass, POP (Pacific Ocean perch) mean log-transformed recruit per spawning biomass, COMU (Common murre at Chowiet) Productivity, Sandfish CPUE (ADFG small mesh survey), Herring recruits, Pandalid CPUE (ADFG small mesh survey), Eulachon CPUE (ADFG small mesh survey), Pricklebacks CPUE (ADFG small mesh survey), FHS (flathead sole) log-transformed recruit per spawning biomass, Northerns (rockfish) log-transformed recruit per spawning biomass, BLKI (Black-legged kittiwake in Prince William Sound) Productivity, Cod log-transformed recruit per spawning biomass, Hook and Line Effort, Bottom Trawl duration, Diversity, Total CPUE, TBMU (Thick-billed murre) Productivity, Richness, ATF (arrowtooth flouder) log-transformed recruit per spawning biomass. See Table 3 for a description of time series.

Gulf of Alaska

Year	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Normalized time series
Trophic level of catch	.	-	-	-	-	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	+		1956-2003
PDO	+	-	--	.	-	-	-	+	.	-	.	+	.	+	+	+	+	++	+	-	.	--	.	.	+	-	.	.	+	.	-	.	.	++	.	1901-2004
Total salmon catch	.	-	-	-	-	-	-	.	.	.	.	.	.	+	+	+	+	.	.	+	+	++	+	++	++	++	++	+	++	+++	+	+++	+	+++		1900-2003
Thornyheads (R/S)	-	-	-	-	-	-	-	-	-	.	+	.	.	+	++	++	+	+	+	.	+	.	.	.												1967-1992
Sablefish (R/S)	-	-	--	-	+	-	-	++	+	.	++	+	-	.	+	.	-	-	.	-	+	.	.	.	+	+	.	+	-	.						1960-1999
MLD				--	.	+	-	.	-	.	--	.	+	-	-	++	.	+	.	-	.	.	+	-	.	+	.	-	+	.	+	+				1973-2001
AOI	-	.	.	+	.	+	+	--	-	-	.	.	.	.	.	-	-	-	.	++	+	+	+	++	.	+	-	.	.	+	+	-	+	.	-	1951-2004
Pollock (R/S)	+	+	++	+	.	+	+	+	+	+	-	-	-	-	.	-	--	-	+	.	-	-	-	-	.	.	-	-	.	+	+	-				1969-2001
POP mean (R/S)								-	.	-	-	+	.	+	+	+	+	++	++	.	.	-	-	.	-	.	-	-	-							1977-1998
COMU Productivity										-	+	+								+	.	-		.		-			-				+			1976-2002
Sandfish cpue			-	-	.	-	.	.	.	+	++	++	-	.	.	.	.	.	-	.	-	-	+	-	-	+	-	-	.	-	-	++	+	++		1972-2003
Herring recruits											.	-	-	+	.	-	.	+++	-	-	-	+++	-	-	-	.	.	+	+	.	.	.	.	.		1980-2003
Pandalid cpue			+	++	++	++	++	+	+	+	.	.	.	.	.	-	-	-	-	-	-	-	.	-	-	-	-	-	-	-	-	.	.	-		1972-2003
Eulachon cpue			.	+	.	-	.	.	.	.	+	+	.	.	.	.	.	+	-	.	-	-	+	-	-	.	-	-	.	-	-	.	+++	+++		1972-2003
Pricklebacks cpue			+	+++	+++	.	.	.	+	.	.	+	.	.	.	-	-	.	-	.	-	-	.	-	.	-	.	-	-	.	-	.	.	.		1972-2003
FHS (R/S)															.	+	+	.	.	+	-	.	+	-	--	-	-	+								1984-1997
Northerns (R/S)								+	+	.	.	+	+	+	++	.	.	.	.	-	.	.	-	--	+	-										1977-1995
BLKI Productivity														--	.	.	+	+	+	+	-	.	--	-	.	-	+	.	.	--	.	++	+			1983-2002
Cod (R/S)								+++	+	+	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	-	-	.	.	.					1977-2001
Hook and Line Effort																								++	+	+	-	-	-	-	.	.	.			1993-2002
Bottom Trawl duration																					++	+	+	+	.	.	.	.	-	-	-	-	-			1990-2002
Diversity																					-			.			.			++		-		.		1990-2003
Total CPUE																					-			+			+			-		-		+		1990-2003
TBMU Productivity										.	.	++								.	.	.		.		.			--				-			1976-2002
Richness																					--			.			.			+		.		+		1990-2003
ATF (R/S)	+	++	++	+	++	+	+	+	+	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.								1961-1997

Legend

+++	X>2.6
++	2.6>X>1.6
+	1.6>X>0.5
.	0.5>X>-0.5
-	-0.5>X>-1.6
--	-1.6>X>-2.7
	no data

North Pacific Climate Assessment

This section addresses six questions that pertain to the role of climate variability on North Pacific ecosystems:

1. Has the North Pacific shifted to a different state or regime since the late 1980s?
2. What is the nature of the new state?
3. What are the ecosystem responses?
4. How long can the shift be expected to last?
5. Is it possible to predict when the regime will shift back and what indicators should be used to determine when it happens?
6. What are the implications for the management of marine resources?

1. Has the North Pacific shifted to a different state or regime since the late 1980s?

Based on basin-wide North Pacific climate-ocean indices, there appear to have been regime shifts in 1989 and in 1998. For previous regime shifts, such as in the mid-1940s and 1977, the pattern of sea surface temperature spatial variability implied a west-east dipole. Since 1989, the pattern of spatial variability has been dominated by a second pattern of sea surface temperature variability, which implies a north-south dipole. At regional scales the responses to these basin-scale changes may not be as coherent. It is important to note that regimes are defined as decadal scale periods, yet there are only 5 years of data available since 1998 with which to assess the new state. Given the variability in the indices since 1998 there is some uncertainty about the level of productivity of the new regime. However there is growing evidence that some ecosystems are responding to the shift in 1998. There is evidence that the California Current ecosystem is responding to the 1998 shift and weak evidence of some changes in the Gulf of Alaska since 1998.

2. What is the nature of the new state?

There are regional differences in the oceanographic and environmental responses to basin-wide climate regime shifts and as such the nature of the new regime varies from region to region. Specific regional responses to the 1998 shift are detailed in the Appendices. It appears that some regions are in a transition period since 1998. In addition a strong El Niño event in 2002/03 has produced a strong signal that has confounded characterization of the new state. In general, the nature of the new state by region is:

- The coastal Gulf of Alaska became slightly cooler after 1989, but has been variable since. Increased storm intensity from 1999-2001 in the central Gulf of Alaska resulted in a deepening of the mixed layer depth. Overall, dramatic changes have not been detected in the Gulf of Alaska, perhaps as a reflection of its location as a transition zone in the 1998 north-south dipole.

- The Bering Sea has been warm since 1977. Since 2000, the Bering Sea has been even warmer and there has been a lack of sea ice on the southeast Bering Sea shelf. Beginning in 1989 there was a decrease in the intensity of the cross shelf winds which shifted current patterns and reduced the intensity of mixing. Overall, dramatic changes have not been detected since 1998 in the Bering Sea and Aleutian Islands.

3. What are the ecosystem responses?

As with regional oceanographic or environmental conditions, the biota, or ecosystem communities, of different regions have variable responses to basin-wide climate regime shifts. Specific ecosystem responses to the 1998 shift are detailed in the Appendices. Overall:

- There is strong biological evidence of a 1989 regime shift in the Gulf of Alaska. After 1989, British Columbia salmon catches and survival declined. In addition, recruitment declined for some groundfish stocks in northern British Columbia. In the northern Gulf of Alaska recruits per spawning biomass and biomass of demersal fish declined. Pacific herring survival in the Queen Charlotte Islands (northern British Columbia) has been poor since the mid-1980s. Other stocks of herring in Alaska and northern British Columbia have varied without trend. Evidence for significant biological changes associated with the 1998 regime shift is less clear. Phytoplankton biomass (from satellite measured chlorophyll) from 1997-2001 show large interannual variability, but the highest concentration in 1999 and 2000. Unfortunately, the chlorophyll record is too short to attribute changes to a long-term climate shift. After 1998 primary production and coho marine survival in British Columbia increased. In the northern Gulf of Alaska there was an increase in shrimp catches. There was a strong year class in pollock and Pacific cod in 1999. Catches of Alaskan salmon have remained high since 1977. There has been a long term decline in abundance of harbor seals and the western population of Steller sea lions since the late-1970s.

• Since the late 1970s Bering Sea pollock abundance has been high and stable, representing over 50% of the groundfish biomass. Since the late 1980s there has been low recruitment of winter spawning flatfish. There has been a northward shift of coldwater species since the late-1980s and the warm water species have expanded their range northward at the expense of ice dependent coldwater species. Jellyfish species increased in biomass after the 1989 regime shift, but declined after the 1998 shift. The abundance of Bristol Bay sockeye salmon was high in the 1980s and 1990s, but has been more variable since 1997. There has been a decline in fur seal pup production and Steller sea lion abundance since the late-1970s.

4. How long can the shift be expected to last?

It is uncertain how long this regime will last. Because we currently lack a good understanding of mechanisms of the multiple physical and biological processes involved in regime shifts, it is currently not possible to reliably predict when a regime will end. Historical data show regimes of different durations. Climate indicators from the North Pacific, such as sea level pressure and sea surface temperature, show a persistence (sequential high or low values), when interannual variability is removed, and sharp regime-like structures. Regime lengths vary; longer regimes were 20 years (1926-1947) and 30 years (1947-1977) with shorter regimes (10 years) beginning in 1977 and 1989.

5. Is it possible to predict when the regime will shift back and what indicators should be used to determine when it happens?

It is important to note that regimes cannot be characterized by only two possible states. As such, a regime shift will not necessarily imply a shift ‘back’ to a previously observed state. As noted above it is currently not possible to reliably predict when a regime shift will occur. There are multiple physical and ecological processes underlying regime shifts that are currently not well understood. Different statistical models fitted to data provide divergent predictions of future conditions.

However, it is possible to monitor and detect abrupt changes in climate and oceanic conditions soon after they have occurred. Because they have proven to be reasonable indicators of past regime shifts, existing climate-ocean indices (e.g., Pacific Decadal Oscillation index, Victoria pattern of sea surface temperature, Northern Oscillation index) should continue to be monitored, and used as indicators of changes in climate and North Pacific Ocean conditions. However, research should also continue on developing and testing the utility of new indicators. Sea surface height and ocean color from satellites may be very reliable indicators, because they integrate many processes of ecological importance (thermal structure, circulation, primary production), and satellite technology makes these fields consistently and regularly available. It is important to monitor additional physical changes at regional scales, and to use indices that represent fields or processes that directly affect fishery populations (e.g., coastal upwelling, circulation, stratification) rather than a broad-scale index that may be integrating a number of different signals in different regions.

Monitoring programs to develop and maintain indices that are more directly and intimately related to the productivity of a fish population or ecosystem should be a high priority. These types of indices will be consistent in explaining biological variability and can supplement the common indicators available now that are proxies of the biological changes we seek to track. Research should continue on identifying the mechanisms by which climate change leads to ecosystem response. This research is critical if we are to efficiently recognize the signals that produce shifts in marine populations of interest to resource managers.

6. What are the implications for the management of marine resources?

Inclusion of the effects of regime shifts in the management of marine resources is critical to sustainable productivity. There are numerous examples globally of fishery examples of the undesirable consequences of failing to detect or acknowledge climate impacts on fish populations. Agencies need to develop policies that explicitly specify decision rules and subsequent actions to be taken in response to preliminary indications that a regime shift has occurred. These decision rules need to be included in long-range policies and plans. Stock assessment advice should provide an indication of the likely consequences to stock viability of alternate harvest strategies under various recruitment assumptions expected in different regime periods.

Reorganization of ecosystems in response to natural disturbance provides opportunities for some species to persist when there is competition for limited resources. In managed systems, where harvest is controlled, systems may continue to shift and evolve in response to environmental disturbance. The key responsibility for managers is the recognition that human exploitation may not shift in a manner consistent with natural disturbances. Managers should also recognize that the longevity of species may have evolved in response to decadal patterns of variability. Shortlived species exhibit the ability to rapidly expand and re-colonize regions when favorable environmental conditions are present. In contrast long-lived species may rely on the storage of reproductive potential in the age distribution of the population. This strategy banks reproductive potential for decades to ensure some probability of recruitment success when favorable conditions occur. These survival strategies require different management responses.

In the case of short-lived species that exhibit highly auto-correlated recruitment responses to climate shifts, such as walleye pollock, stock assessment scientists have a high probability of detecting the processes or indices thereof that influence production. Assessment scientists should be directed to incorporate these processes into their assessment advice. Stock projections can be conducted using best estimates of 5-10 year climate regimes to directly incorporate environmental forcing in advice to managers. It should be noted that preservation of spawning stock biomass at levels consistent with MSY for a productive period will probably be impossible when the stock shifts to a less productive regime. Minimum stock size thresholds may be the best protection for species with this type of life history strategy. Imposing this type of stock protection may result in prolonged periods when no directed harvest is possible.

In the case of long-lived species, such as Pacific Ocean perch, the response of the spawning stock biomass to regime shifts will be slower or lagged by the age of recruitment to the regime shift year. For these species, annual recruitment is only a fraction of the spawning stock biomass, and longevity ensures a relatively long reproductive cycle, enabling populations to endure prolonged periods of unfavorable environmental conditions. Maintaining a diverse age-structure in spawning stock biomass should be a paramount management goal for long-lived, late maturing species.

It is also important to recognize that management actions may be out of phase with productivity levels in consecutive regimes. In view of regime effects on productivity, management of long-lived species may require lower fishing mortality than would be required under a constant environment with no regime effects.

Table 5. Indicator summary of most indicators in the Ecosystem Considerations chapter.

INDICATOR		

INDICATOR		

INDICATOR		

INDICATOR		

INDICATOR		

Advances in Developing Predictive Models

Multispecies and ecosystem models provide the tools for prediction of possible future effects of fishing on the status of marine ecosystems. Multispecies bycatch model predictions of catch, bycatch, and characteristics of various fishing strategies provide future predictions of realistic fishing mortalities expected for groundfish stocks and the bycatch of nontarget species in groundfish fisheries given the present bycatch and OY constraints of the groundfish fisheries of the BSAI and GOA. Fishing mortalities from the multispecies bycatch model can be used to drive multispecies and ecosystem predator/prey simulations to evaluate the predator/prey implications of these fishing strategies. These predator-prey models are not used for year-to-year management advice but provide a method for assessing the possible medium and long-term implications of fishing strategies on predator/prey relationships and energy flow in these systems. Incorporating climate and lower trophic-level models into this framework is an important next step.

Due to changes in the catch accounting system, the multispecies bycatch model and its predictions could not be updated for this year. Some progress in advancing multispecies predator/prey and ecosystem food web models as predictive tools has been made. This progress is documented below.

Multispecies statistical model: incorporating predation interactions into a statistical catch-at-age model.

Contributed by Jesús Jurado-Molina, Patricia A. Livingston, and James Ianelli

<u>Introduction</u>

One weakness of MSVPA is its lack of statistical assumptions that impede the inclusion of uncertainty into multispecies model parameter estimation. MSVPA is based on Gulland's method (1965), which is a deterministic backward nonlinear sequential method. Including statistical assumptions in multispecies models requires the inclusion of the separable fishing mortality assumption (Doubleday 1976), which allows for common statistical estimation procedures. This could provide new insights for fisheries management in a multispecies context, a task that is not possible with the current available MSVPA-MSFOR technology. In this work we show how the predation equations from MSVPA can be introduced into a statistical catch-at-age model and we also discuss some advantages of this approach.

<u>Methods</u>

We reduced the number of species used in previous work (Jurado-Molina and Livingston 2002), to include only walleye pollock and Pacific cod. To assess the dynamics of these two species we applied the MSVPA and the MSM. We compared the results from these models with the single-species statistical stock assessments carried out by scientists from the Alaska Fisheries Science Center (AFSC) and also with the results from the MSVPA base-run that includes all predator species and a complete predator stomach content data. A brief description of the models used in this work is presented below.

Models

MSVPA uses catch-at-age data, predator ration and predator diet information to estimate fishing mortality, recruitment, stock size, suitability coefficients and predation mortality. Some of the model's principles with regard to predation are based on the work of Anderson and Ursin (1977) on predator-prey preferences. In addition to the standard equations from VPA, MSVPA uses three additional predation equations. The first is the assumption of the separation of natural mortality M in two components:

(1) $$M = M1 + M2,$$

where $M1$ is the residual mortality and $M2$ is the predation mortality. The second equation estimates the predation mortality:

(2) $$M2_{p,a} = \sum_i \sum_j \frac{\overline{N}_{i,j} R_{i,j} S_{p,a,i,j}}{\sum_{p,a} \overline{N}_{p,a} W_{p,a} S_{p,a,i,j}}.$$

Where $\overline{N}_{i,j}$ represents the average stock size of the predator i of age j. $R_{i,j}$ is the annual ration of the predator and $S_{p,a,i,j}$ is the suitability coefficient for each combination of predator-prey-age. The denominator of (2) represents the total suitable biomass available to the predator. In the denominator, $\overline{N}_{p,a}$ represents the average stock size of the prey p of age a and $W_{p,a}$ represents the weight at age of the prey in the stomach of the predator. The third equation estimates the suitability coefficients:

(3) $$S_{p,a,i,j} = \frac{U_{p,a,i,j} / \left(\overline{N}_{p,a} W_{p,a}\right)}{\sum_p \sum_a U_{p,a,i,j} / \left(\overline{N}_{p,a} W_{p,a}\right)}$$

where $U_{p,a,i,j}$ represents the fraction of prey p of age a found in the stomach of the predator. Equations (1- 3) are set up in a quarterly form and are solved iteratively (Gislason 1991).

In addition to equations (1 - 3), the MSM uses the following equations from single-species statistical catch-at-age models:

(4) $$N_{a+1,t+1} = N_{a,t} e^{-(F_{a,t} + M_a)}$$

(5) $$C_{a,t} = \frac{F_{a,t} N_{a,t} (1 - e^{-(F_{a,t} + M_a)})}{F_{a,t} + M_a}$$

(6) $$F_{a,t} = s_a F_t$$

(7) $$s_a = \frac{1}{1 + e^{u - va}}$$

(8) $\hat{I}_t = q\hat{B}_t$

where $N_{a,t}$ is the number of individuals of age *a* in year *t*, $F_{a,t}$ the fishing mortality at age, $C_{a,t}$ the catch-at-age, s_a the age-dependent gear selectivity (*u* and *v* are its parameters), F_t the full fishing mortality, $\hat{I}_t$ is the estimated relative index of abundance, $\hat{B}_t$ the estimated biomass (or population $N_{a,t}$) and *q* the catchability coefficient.

Different indices of relative abundance and the catch at age data were used to fit the model. In the case of walleye pollock the bottom trawl survey (BTS) and the echo integration trawl (EIT) survey were used. For Pacific cod the biomass estimate from the EBS bottom trawl survey was used. In MSM we assumed observation error in the catch-at-age and the relative indices of abundance. The log-likelihood function for each index was defined as:

(9) $$\ln L = \frac{\sum\left(\ln I_{obs} - \ln I_{pred}\right)^2}{2CV^2},$$

where *CV* is the coefficient of variation. The catchability was estimated algebraically.

The sum of the log-likelihood components associated with each species was used as the objective function. In the estimation process, the Solver subroutine from EXCEL and the Sample-Importance-Resample SIR method (Mcallister and Ianelli 1997) were used. In particular, in the SIR method we used uniform priors for all parameters except the recruitment whose priors were assumed log-normal with the mean and the standard deviation calculated from recruitment estimates from MSVPA.

The stomach content was assumed to be measured without error. The MSM was set up in a quarterly fashion. We assumed recruitment of age-0 fish takes place in the third quarter of the year.

The MSM is a complex model involving the estimation procedures for the statistical part and the predation mortality. Given a set of parameters ($N_{a,0}$, R_t,F_t and selectivity coefficients) the MSM starts a forward procedure where the current population depends on the population from the previous year, the natural and fishing mortality. The fishing mortality is fixed due to its dependency on the parameters. However, the predation mortality, a component of the natural mortality, is estimated by MSM. As shown in equations (1-3) this variable and the suitability coefficients depend on the average population, therefore to solve this circular reference problem iterative algorithms are used (Sparre 1991). The first algorithm starts with an initial guess for M2 that allows a first estimation of the population. These estimates together with given values of the suitability coefficients (a similar algorithm is used for these variables) allows the estimation of the predation mortality, which in turn can be used to estimate new values of the population. The process is repeated until two consecutive iterations converge to marginally different

M2 values according to established criteria (Sparre 1991). Once the criteria are reached and the estimates of predation mortality, suitability coefficients and population have converged, the estimated likelihood can be used for minimization (Solver) or to estimate the joint or marginal posterior distribution (SIR algorithm).

We compare results from the MSVPA, the MSM and the single-species statistical age-structured stock assessments from the AFSC. Details about the models used in the single-species stock assessment of walleye pollock and Pacific cod can be found in the 2002 North Pacific Groundfish Stock Assessment and Fishery Evaluation Reports (Ianelli et al. 2002; Thompson and Dorn. 2002).

Data

Common input data for all models included catch-at-age data, maturity-at-age and weight-at-age. The common input data for MSVPA and the MSM model included stomach content data, prey weight-at-age in the predator stomach contents, predator annual ration and residual natural mortality. Stomach content data and estimates of weight-at-age in the stomach contents of the predator from 1985 and 1987 were used because those years had complete quarterly information for the two species. The same annual ration was used as previously described in Livingston and Jurado-Molina (2000).

A particular input for MSVPA is the terminal fishing mortalities that were tuned to minimize the differences between single-species cohort analysis estimates and the estimates from stock assessments models used by NMFS scientists (Livingston and Jurado-Molina 2000). Finally, relative indices of abundance (BTS and EIT) also used in the 2002 single-species stock assessment (Ianelli et al. 2000; Thompson et al. 2000) were incorporated into the MSM.

Results

The fit of the MSM model to the walleye pollock and Pacific cod abundance indices is shown below (Figures 1, 2 and 3). The estimates of the suitability coefficients from both models (MSVPA and MSM) for both species were similar (Figure 4). Percent deviations of suitability coefficients between the two modes were mostly small (Figure 5). Out of 146 average suitability estimates, only 25 had a percentage deviation greater than 30%. Most of these (18) corresponded to Pacific cod as predator.

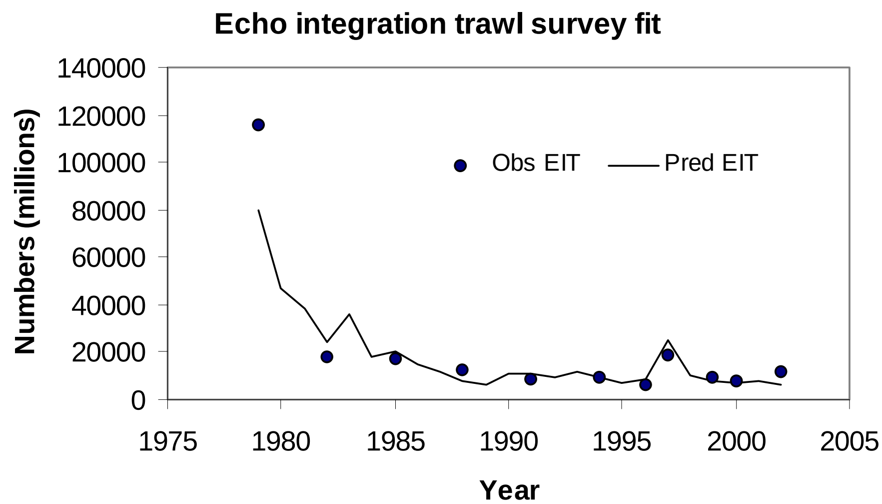


Figure 1. MSM fit to the walleye pollock 2002 echo integration survey in the eastern Bering Sea. Obs EIT – observed values of the echo integration trawl survey; pred EIT – predicted values of EIT.

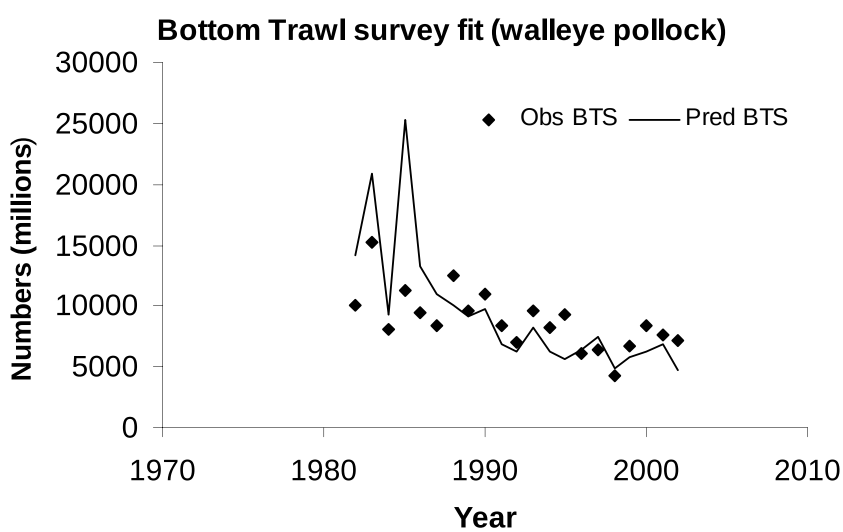


Figure 2. MSM fit to the walleye pollock 2002 biomass trawl survey in the eastern Bering Sea. Obs BTS – observed values of the bottom-trawl survey; pred BTS – predicted BTS values.

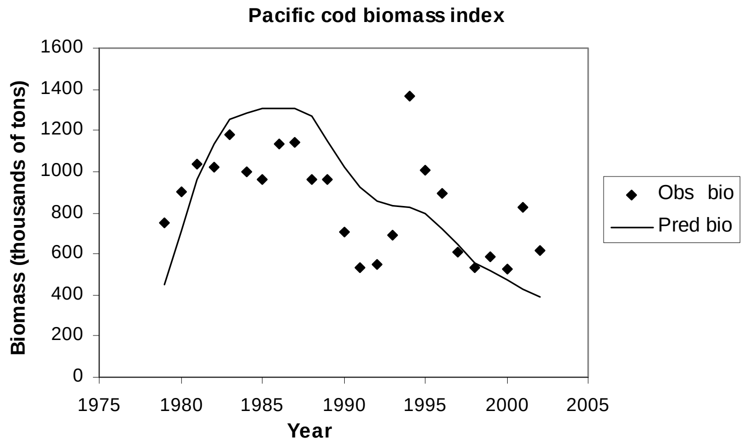


Figure 3. MSM fit to the Pacific cod 2002 biomass index in the eastern Bering Sea. Obs bio – observed values of the biomass index; Pred bio – predicted biomass index

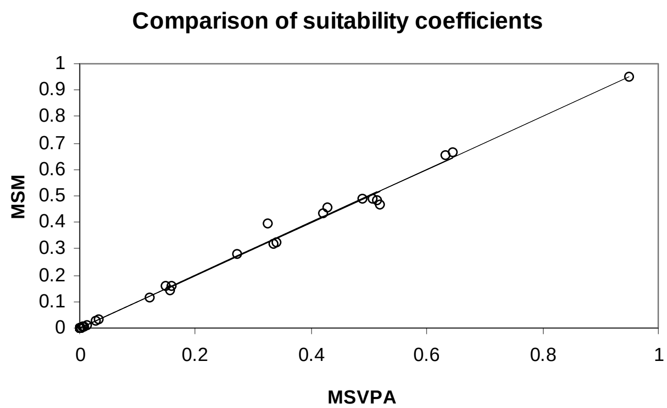


Figure 4. Comparison of estimates of average suitability coefficients for walleye pollock as predator from the multispecies virtual population analysis and the multispecies statistical model.

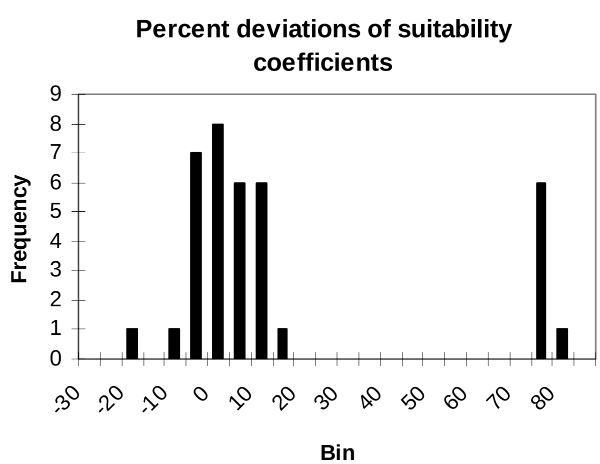


Figure 5. Percentage deviations between estimates of suitability coefficients from the multispecies virtual population analysis and the multispecies statistical model.

The estimates of the average predation mortality from both models for age-0 walleye pollock (Figure 6) and age-1 pollock (Figure 7) show that the estimates from MSVPA and MSM followed the same trend with similar values. Similar results were found for the predation mortality of age-2 walleye pollock. For the rest of the age classes, the estimates were similar up to 1984, after that year the estimates from MSM were larger than the estimates from MSVPA. The estimates of predation mortality of Pacific cod were not as similar as the pollock case (Figure 8). For age-0 cod, although both estimates follow the same trend, the estimates from MSM were larger than the estimates from MSVPA from 1979 to 1989. For ages 1, 2 and 4 these differences were more substantial, with higher MSM estimates. Nonetheless, the MSM estimates always followed the same trend as the MSVPA estimates.

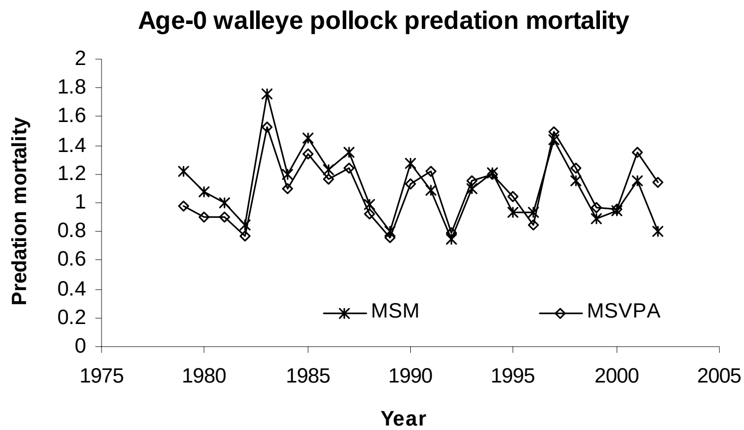


Figure 6. Temporal trend of the predation mortality of age-0 walleye pollock in the eastern Bering Sea. MSM – multispecies statistical model, MSVPA – multispecies virtual population analysis model (two species).

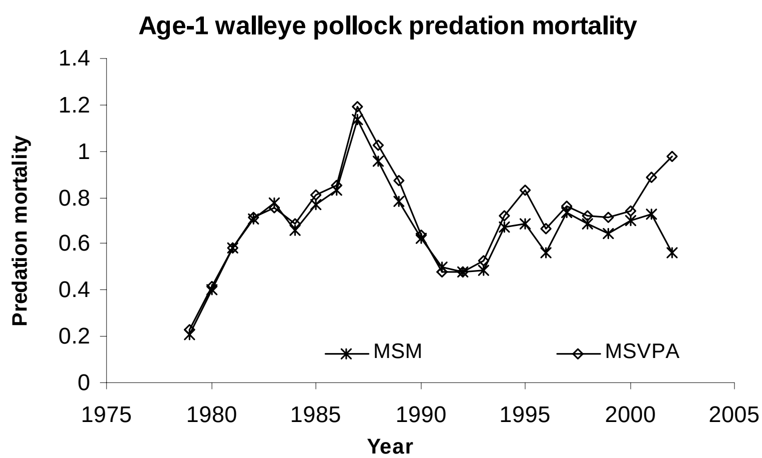


Figure 7. Temporal trend of the predation mortality of age-1 walleye pollock in the eastern Bering Sea. MSM – multispecies statistical model, MSVPA – multispecies virtual population analysis model (two species).

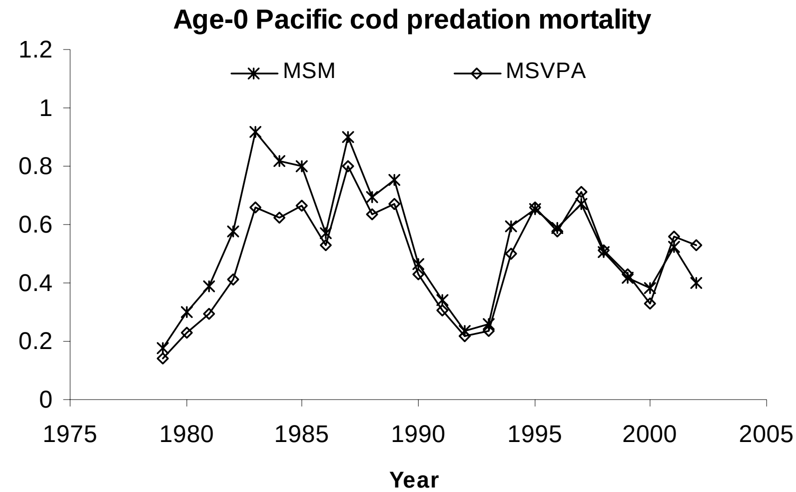


Figure 8. Temporal trend of the predation mortality of age-0 Pacific cod in the eastern Bering Sea. MSM – multispecies statistical model, MSVPA – multispecies virtual population analysis model (two species).

The comparison of the estimates of the number of age 3+ (N3+) walleye pollock from the multispecies statistical model, the singles-species stock assessment from AFSC, MSVPA (two species) and the MSVPA base-run is shown below (Figure 9). In general, the majority of *N3+* estimates produced by all the multispecies models are larger than the single-species AFSC stock assessment. In particular, the largest deviations with respect to the AFSC stock assessment model estimates corresponded to the MSM model from 1981 to 1985, with 1981 the highest at 27%. However, in latter years of the assessment, the MSVPA (base-run) and the MSM had smaller N3+ estimates than the ones from the AFSC assessment.

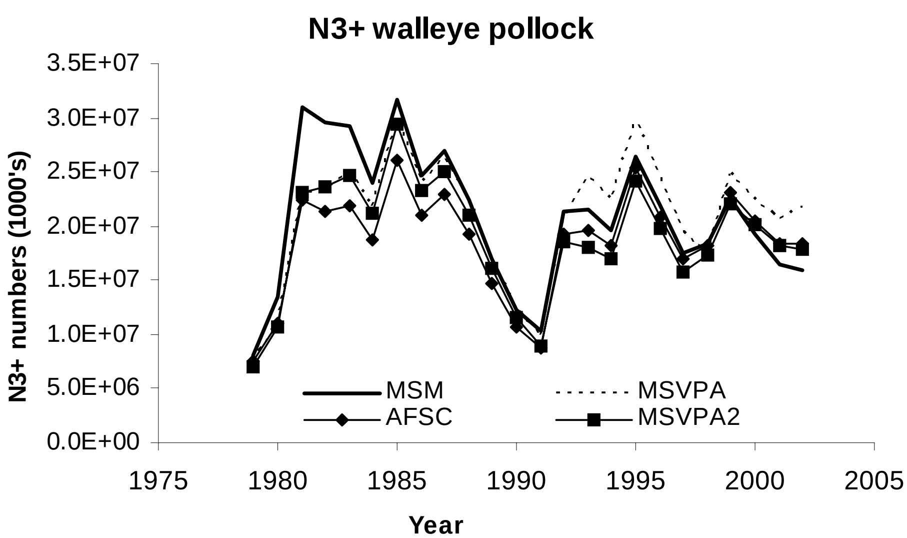


Figure 9. Comparison of walleye pollock estimates of N3+ in the eastern Bering Sea. AFSC – 2002 stock assessment single-species stock assessment, MSM – multispecies statistical model, MSVPA – multispecies virtual population analysis (two species), MSVPA2 – multispecies virtual population analysis (base-run, all predators included).

Discussion

This work presents preliminary results with an initial version of the model. Further refinements and validation of the model will be needed. However, some general conclusions can be stated from this analysis. In general, more similarities than differences between the estimates of suitability coefficients from the MSVPA and the MSM models were found. Most of the greatest percentage deviations corresponded to Pacific cod as predator. In the case of walleye pollock, some large percentage deviations were found for the first quarter. However, in terms of predation mortality the third and fourth quarter are the most important to determining the magnitude of this parameter for walleye pollock since rations are larger in these quarters. MSVPA provides a point estimate for the suitability coefficients with no measure of the uncertainty associated with those parameters. Due to the estimation procedure used in MSM, this model is capable of providing a measure of the uncertainty (posterior distribution) associated with the suitability coefficients.

The MSM model reproduced all temporal trends found in the estimates of walleye pollock predation mortality from the MSVPA model. The resulting temporal trend of predation mortality of walleye pollock as prey is the result of the additive consumption of predators of different age classes preying on walleye pollock. In particular the highest predation mortality of age-0 walleye pollock in 1983 is the result of the consumption of large adult walleye pollock population (*N3+*) and a large age-1 walleye pollock class. For the younger age classes where predation mortality of walleye pollock is high, the estimates of MSM and MSVPA were very similar. The greater differences were observed in older ages. For Pacific cod as predator, larger differences were found for two age classes of walleye pollock as prey (age-1 and age-4); however they followed the same trend. Discrepancies between estimates of suitability coefficients and predation mortality from both models might be due to the use of different estimation procedures. MSM uses a forward fitting process based on likelihood fitting algorithms while MSVPA uses a deterministic backward nonlinear sequential method. Therefore it is promising that both models provide similar estimates of suitability coefficients and predation mortality.

Although some differences were observed between the *N3+* estimates from MSM and the estimates of the single-species stock assessment, the majority of estimates and the temporal trend are similar. The difference between the estimates might be due to the type of data use to fit the models. The single-species stock assessment uses age composition data from surveys and fisheries. In particular catch-at-age data is allocated to particular fishing gear. For the MSM, age composition for catch-at-age was used but was aggregated over all fishing gears and survey age composition was not used. In general, the MSM model was able to reproduce the majority of estimates from MSVPA and the single-species stock assessment (N3+) and also provided a measure of the uncertainty of suitability coefficients and predation mortality, a task that it is not possible with the available MSVPA-MSFOR technology.

Another important aspect of this work is that results from the MSM suggest that if a good estimate of the residual mortality *M1* is included in the model, MSM with only two species was able to reproduce fairly the *N3+* estimates from the MSVPA model containing all species and all predator stomach content data (Jurado-Molina and Livingston 2002).

Similar to other multispecies models and ecosystem models, the multispecies statistical model has to be considered as work in progress. As with any multispecies model, the MSM could play an important role in describing the indirect effects of fishing but it may be wise to accept general rather than specific prediction (Hollowed et al. 2000). However, now comparisons between MSM and single-species stock assessment methods can be done within the same statistical framework. Several improvements could be made in future versions of the model including the addition of more predator species. In particular, the addition of Pacific herring and rock sole (prey), which seem to be the most sensitive species to indirect effects of fishing mortality (Jurado-Molina and Livingston 2002a). It is also necessary to include the complete set of predator stomach content data. It is also important to incorporate a statistical model for the diet composition data in the future. A formal evaluation of the model through simulation of the system (adding sampling error) given a known dynamics will be necessary to see if the model is able to generate good estimates of the parameters. The final goal would be to incorporate all the data sources used in the single-species stock assessments into the multispecies statistical model. Preliminary forward simulations to test management scenarios are being implemented. In those simulations future recruitment can be log-normal distributed or modeled as either a Ricker or Beverton and Holt spawner-recruit relationships to account for compensatory effects.

The main goal in the development of this model is to incorporate the predation equations into the actual stock assessment models used to provide groundfish management advice for the Bering Sea. The development of the multispecies statistical method is an important step in its adoption in providing advice to fisheries managers because it allows consideration of uncertainty in a multispecies predator-prey modeling context and it will help to establish useful scenarios for the management of groundfish resources in the Bering Sea.

Ecosystem modeling results

By Kerim Aydin, Sarah Gaichas, and Ivonne Ortiz (NMFS)

To aid in assessing the ecosystem effects of fishing relative to predation, stock-scale food web models of the Bering Sea, Gulf of Alaska, and Aleutian Islands management regions were parameterized as described in Aydin et al. 2003. Each of the three models consists of 130-140 functional (species) groups including lower trophic levels, fish, birds, and mammals. Example results for one species (walleye pollock) are shown here: full results for all modeled species are available from the author and shall be made accessible through the Alaska Fisheries Science Center website.

For each species, parameters for biomass, production rate, consumption rate, and diet composition were assembled from trawl survey data, age-weight keys, food habits data from the REEM fish food habits database, and from extended reviews of the literature.

Moreover, data quality for each input parameter was assessed on a qualitative scale including coverage and sample size: these qualitative rankings were converted into prior distributions for each parameter for each functional group.

The primary purpose of these results is to provide stock assessment authors with information and time trends to identify possible predator, prey or bottom-up forces that might be influencing stock growth or distribution patterns. For example, the initial results show the different proportioning of mortality for species in each of the three ecosystems, as shown for walleye pollock in Figure 10.

These prior distributions were used to generate a range of potential non-equilibrium ecosystems for the management regions in the mid-1990s: a species persistence criterion was used to reject simulated ecosystems in which species could not coexist (the "Bayesian Synthesis" approach described in Aydin et al. 2003 p. 328). Each modeled ecosystem showed an approximately 95-98% rejection rate of parameter sets, reflecting the range of uncertainty in the independent parameter estimates. The accepted ecosystem parameter sets, approximately 500 for each management region, thus contain covariance structure between parameters which represent potential "states of nature" in which all functional groups persist over time.

As an initial sensitivity analysis, each species group was increased in turn by simulating a decrease in that group's mortality rate by 10%, and allowing each simulated ecosystem to come to a new equilibrium using the nonlinear biomass dynamics equations initially developed in the software package Ecosim (Christensen and Walters 2004) and modified to account for differences in predator consumptions and growth rates that result from age structure (Aydin in press).

This resulted in a 140x140 matrix showing the modeled effects of a perturbation of each species on each other species, including confidence intervals showing the 95% range of predicted effect among the accepted ecosystems for each management region. The width of this confidence interval indicates the current uncertainty of each species' effect on others, given current data quality, and including indirect effects of competition and trophic cascades. These results have been summarized as shown in Figure 11 for walleye pollock, and are available for each modeled species group within the three management regions.

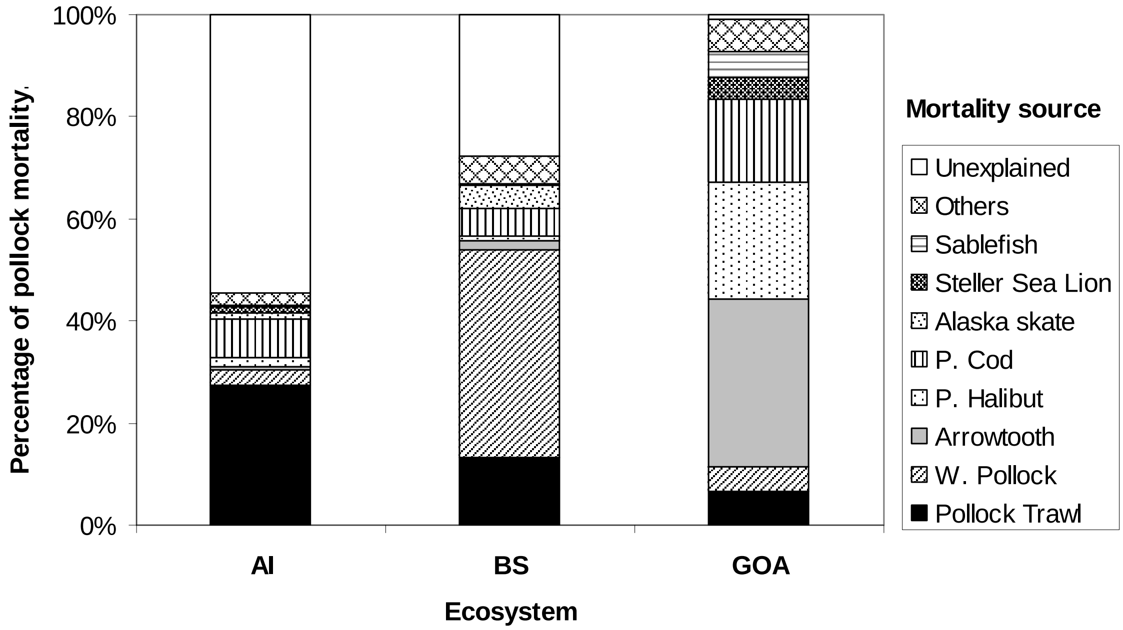


Figure 10. Sources of mortality for walleye pollock, from each of the modeled food webs (Aleutian Islands, Bering Sea, and Gulf of Alaska), averaged over the mid-1990s. Sources include fishing (black), various predators (grey shades) and "unexplained" mortality (white). "Unexplained" mortality represents the difference between the stock assessment mortality rates (weighted by age composition for all pollock age 2+) and sources of mortality identified within the food web.

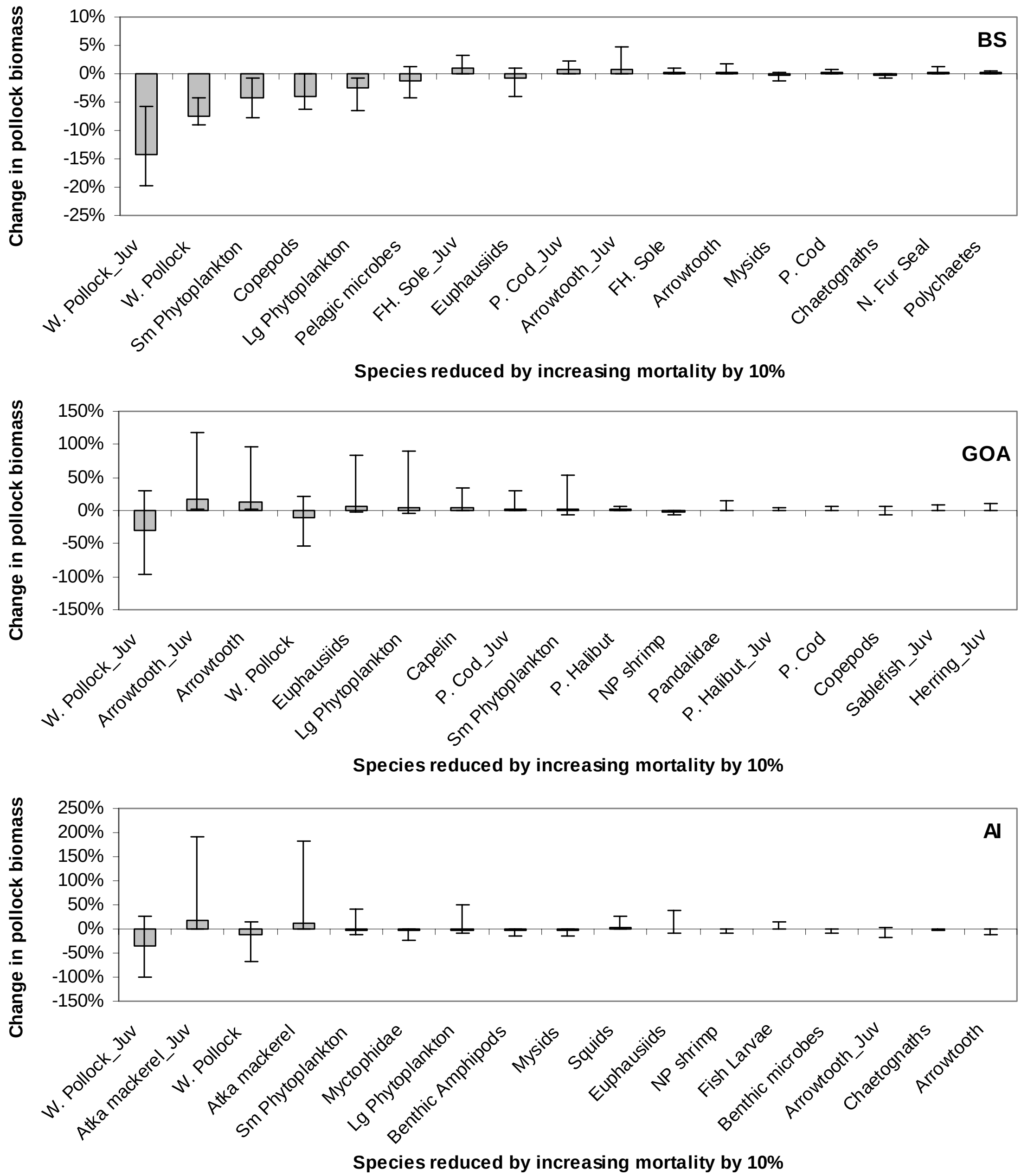


Figure 11. Perturbation experiments results. For each modeled ecosystem, each species was reduced in turn by increasing its mortality by 10% and allowing the ecosystem to reach a new equilibrium state. The resulting changes in walleye pollock biomass are shown for each ecosystem, sorted by magnitude of effect. Solid bars represent median effect while error bars show the 95% limits across the generated possible ecosystems. For the Bering Sea (top), the strongest effects on pollock come from reducing pollock, followed by bottom-up effects (phytoplankton and copepods), in which reducing plankton production reduces pollock biomass. For the Gulf of Alaska (middle) the strongest effects on pollock are top-down, whereby reducing arrowtooth flounder biomass increases walleye pollock. For the Aleutian Islands (bottom), the strongest effects appear to be competitive interactions with atka mackerel. Note the wide confidence intervals for the Gulf of Alaska and Aleutian Islands results, indicating the relatively high uncertainty in data from these regions.

ECOSYSTEM STATUS INDICATORS

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

Physical Environment

Empirical evidence for North Pacific Regime shifts from 1965-2003 (not updated for 2004)

Nathan Mantua, Climate Impacts Group, University of Washington
Steven Hare, International Pacific Halibut Commission

Background

In this short contribution we report on analyses of an updated version of the 100 time series matrix of North Pacific fishery and environmental data first analyzed and discussed by Hare and Mantua (2000) (HM2000 hereafter). Table 6 provides a complete listing of the elements in the 100 time series matrix, and Figure 12 provides a schematic representation of the spatial distribution of the observations. This contribution aims to provide a large scale context for the time variations in the two patterns of ecosystem variability identified and discussed by HM2000. The latest observations in our matrix are for 2001, although the PDO and NP indices through the winter of 2003 will also be discussed. Thus, the main contribution here is an extension of the HM2000 analysis to include observations from 1998-2001.

Results

The PC scores for the 1st and 2nd modes of variability in the full data matrix are shown in Figure 13. PC1 score for 1998 is strongly positive, then near zero for 1999, weakly positive for 2000, and weakly negative for 2001. Likewise PC2 scores for 1998-2001 also show strong negative values for 1997-2000, then a positive score for 2001. The PC/Loading patterns found in this analysis are nearly identical to the corresponding 1st and 2nd PC/Loading patterns reported on in HM2000, with the 1st pattern accounting for 23% of the variance and the 2nd pattern accounting for 11% of the variance for the 1965-2001 period of record.

This analysis shows that changes in the North Pacific climate and ecosystems in 1998-2001 led to a very weak projection onto the leading patterns of climate and ecosystem variations identified in the data from 1965-2001, and a switch from negative to positive scores for PC2 in 2001. These results do not identify compelling evidence for a strong regime shift that would amount to a reversal of the changes initiated in 1977 or in 1989. ***Stated another way, climate and marine ecosystem conditions in 2001 were quite unlike either phase of the two most prominent regime patterns identified in the data for 1965-1997.*** One important caveat in this statement is the fact that in the data examined here there are only 20 biotic observations for 2000 and just 3 biotic observations for 2001 (see Figure 14). This limited number of observations for 2000 and 2001 mean that the 2000 PC scores plotted in Figure 13 should be taken as rough estimates, while those for 2001 are not likely to accurately represent the ecosystem state, though it is based on a relatively complete set of climate indices.

One perspective on the large scale North Pacific SST state is provided by the annual PDO index (see Figure 15). Changes in North Pacific SSTs initiating in 1998 led to a relatively strong shift in the sign of the PDO index. Those SST changes included a substantial cooling of the coastal waters of the NE Pacific and a warming of central N. Pacific SSTs that persisted until fall 2002. From August 2002 to July 2003 PDO index values have been uniformly positive, indicating that the projection on the cool interior-warm coastal phase of the PDO pattern has dominated. In contrast to the strong 1998/1999 phase change in the PDO index, there was no clear shift in the wintertime Aleutian Low index (NP) during this period. The NP index was very weakly positive for the winter of 1999, but had relatively large negative values in 2000, 2001, and 2003. At this time, it is not clear how one might separate the *interdecadal signal* from the *interannual noise* in N. Pacific climate, and this situation makes it impossible to determine whether or not we have experienced a regime shift in the recent past.

The summer/fall 2002 change from cool to warm phase PDO SST anomalies in the N. Pacific coincided with a modest intensity El Niño episode in the equatorial Pacific, and the extratropical changes were perhaps related to tropical climate events. The latest observations from the tropical Pacific show a pattern of mostly above average SSTs and subsurface SSTs in the equatorial belt, suggesting that another weak warm episode (i.e. a weak El Niño) may return by fall 2003 through winter 2004. As of July 10, 2002, NOAA's climate prediction center favors "ENSO-neutral" conditions in the tropical Pacific for the coming fall and winter (for monthly updates, see the CPC diagnostic discussion at
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/index.html).

Taking all this information together, there is not a consistent suite of evidence in support of a recent regime shift since 1997. Instead, abiotic data from 1998-2003 indicate that the 3 year cooling of the NE Pacific from 1999 through 2001 has since faded dramatically, and even reversed itself, so that much of the past year has experienced a return to N. Pacific climate conditions like those that prevailed during the warm NE Pacific regime of 1977 – 1997.

Table 6. The 100 time series used in the analysis. The time series are plotted geographically in Figure 12. Means were computed for each time series for three periods: 1965-1976 (regime 1), 1977-1988 (regime 2), and 1989-1997 (regime 3). The 1977 change is the difference between regime 1 and regime 2, and the 1989 change is the difference between regime 3 and regime 2. No difference was computed if there were less than five years data in one of the regimes.

No.	Abbreviation	Full name	1977 change	1989 change
1	NPATMOS	Aleutian Low Pressure Index	1.18	-0.66
2	PDOWIN	Pacific Decadal Oscillation - winter index	1.60	-0.95
3	PDOSUM	Pacific Decadal Oscillation - summer index	1.11	0.27
4	SOI	Southern oscillation Index	-0.86	0.24
5	ENSOWIN	ENSO3.4 - winter index	0.50	-0.27
6	ENSOSUM	ENSO3.4 - summer index	0.10	0.44
7	AO	Arctic Oscillation index	-0.17	1.37
8	KSAT	King Salmon, AK air temperature	1.70	-0.61
9	CBAT	Cold Bay, AK air temperature	0.96	-0.40
10	KUSSTR	Kuskokwim River stream flow	-0.29	0.78
11	PISST	Pribilof Islands sea surface temperature	0.40	-1.33
12	BSICE	Bering Sea ice cover	1.64	-0.53
13	EBZOO	Eastern Bering Sea zooplankton biomass	-0.64	0.37
14	BSJELLY	Bering Sea jellyfish		1.50
15	EBSPOLL	Eastern Bering Sea walleye pollock recruitment	0.02	-0.16
16	EBSCOD	Eastern Bering Sea Pacific cod recruitment		-0.30
17	EBSYFS	Eastern Bering Sea yellowfin sole recruitment	-0.67	0.66
18	EBSTRBT	Eastern Bering Sea Greenland turbot recruitment	-0.99	-0.85
19	EBSATF	Eastern Bering Sea arrowtooth flounder recruitment	1.58	0.01
20	EBSRSOLE	Eastern Bering Sea rock sole recruitment		-0.69
21	EBSFSOLE	Eastern Bering Sea flathead sole recruitment		-1.32
22	EBSAKPLA	Eastern Bering Sea Alaska plaice recruitment	-0.15	-1.83
23	EBSPOP	Eastern Bering Sea Pacific Ocean perch recruitment	-0.26	0.50
24	EBSHERR	Eastern Bering Sea herring recruitment	1.14	
25	AIATKA	Aleutian Islands Atka mackerel recruitment		-0.70
26	AIPOP	Aleutian Islands Pacific Ocean perch recruitment	1.14	
27	WAK_CH	Western Alaska chinook salmon catch	1.08	-0.27
28	WAK_CM	Western Alaska chum salmon catch	1.11	-1.73
29	WAK_CO	Western Alaska coho salmon catch	1.73	0.03
30	WAK_PI	Western Alaska pink salmon catch	0.48	-0.04
31	WAK_SO	Western Alaska sockeye salmon catch	1.60	0.13
32	EP	East Pacific teleconnection index	-0.85	-0.72
33	KODAT	Kodiak, AK air temperature	1.72	-0.96
34	KENSTR	Kenai River stream flow	0.97	-0.45
35	PAPA	Ocean Station Papa trajectory index	1.05	-0.19
36	GAK1SST	GAK 1 sea surface temperature		-0.47
37	U60N149W	Upwelling at 60N, 149W	-0.59	-0.23
38	U57N137W	Upwelling at 57N, 137W	-0.99	0.69
39	CPZOO	Central Pacific zooplankton biomass	0.63	-0.97
40	EPZOO	Eastern Pacific zooplankton biomass		-0.53
41	GOASHR	Gulf of Alaska shrimp catch	-1.61	-0.78
42	GOASAB	Gulf of Alaska sablefish recruitment		-1.10
43	GOAHAL	Gulf of Alaska halibut recruitment	1.72	
44	GOAPOP	Gulf of Alaska Pacific Ocean perch recruitment	0.28	
45	GOATHORN	Gulf of Alaska shortspine thornyhead recruitment	0.33	-0.83
46	GOAPOLL	Gulf of Alaska walleye pollock recruitment	0.09	-0.87
47	GOACOD	Gulf of Alaska Pacific cod recruitment		-0.50
48	GOAATF	Gulf of Alaska arrowtooth flounder recruitment	1.29	0.14
49	PWSHERR	Prince William Sound herring recruitment	0.07	
50	SITHERR	Sitka herring recruitment	0.79	0.01
51	CAK_CH	Central Alaska chinook catch	1.48	0.68
52	CAK_CM	Central Alaska chum catch	1.43	-0.46
53	CAK_CO	Central Alaska coho catch	1.71	0.12
54	CAK_PI	Central Alaska pink catch	1.49	0.37
55	CAK_SO	Central Alaska sockeye catch	1.49	0.55
56	SAK_CH	Southeast Alaska chinook catch	-0.41	-0.56

Table 6. continued.

No.	Abbreviation	Full name	1977 change	1989 change
57	SAK_CM	Southeast Alaska chum catch	0.54	1.65
58	SAK_CO	Southeast Alaska coho catch	1.09	0.97
59	SAK_PI	Southeast Alaska pink catch	1.16	0.76
60	SAK_SO	Southeast Alaska sockeye catch	1.26	0.81
61	SKEESTR	Skeena River stream flow	-0.77	0.54
62	KISST	Kains Island sea surface temperature	1.24	-0.24
63	U51N131W	Upwelling at 51N, 131W	-0.43	0.01
64	NDR	Northern diversion rate	0.94	0.66
65	BC_CH	British Columbia chinook salmon catch	-0.53	-1.61
66	BC_CM	British Columbia chum salmon catch	0.37	0.19
67	BC_CO	British Columbia coho salmon catch	0.05	-1.19
68	BC_PI	British Columbia pink salmon catch	0.58	-0.72
69	BC_SO	British Columbia sockeye salmon catch	0.70	-0.01
70	FORAT	Forks, WA air temperature	0.41	-0.02
71	NEWAT	Newport, OR air temperature	0.66	0.22
72	EURAT	Eureka, CA air temperature	1.22	-0.51
73	COLSTR	Columbia River stream flow	-0.61	0.29
74	8RIVSTR	8 Rivers index	-0.09	-0.54
75	SCRSST	Scripps' pier sea surface temperature	1.21	0.03
76	U48N125W	Upwelling at 48N, 125W	0.26	-1.14
77	U42N125W	Upwelling at 42N, 125W	-1.47	0.24
78	U36N122W	Upwelling at 36N, 122W	-0.72	-0.50
79	CCZOO	CalCOFI Region 2 zooplankton biomass	-0.81	-1.04
80	OCI	Oyster Condition Index	-1.32	-0.45
81	WCMACK	West Coast mackerel recruitment	1.97	-0.42
82	WCSAB	West Coast sablefish recruitment	0.00	-1.22
83	WCDSOLE	West Coast dover sole recruitment	-1.16	
84	WCWIDOW	West Coast widow rockfish recruitment	0.47	-0.89
85	WCCHILI	West Coast chilipepper recruitment	-0.74	-0.01
86	WCBOCACC	West Coast bocaccio recruitment	-0.19	-0.57
87	WCCANARY	West Coast canary rockfish recruitment	-0.56	-0.97
88	WCYTROCK	West Coast yellowtail rockfish recruitment	-0.12	-0.21
89	WCHAKE	West Coast Pacific hake recruitment	0.16	-0.04
90	WCANCHOV	West Coast anchovy recruitment	-0.09	-0.89
91	WCPOP	West Coast Pacific Ocean perch recruitment	0.03	0.30
92	WA_CH	Washington chinook catch	-0.75	-1.62
93	WA_CM	Washington chum catch	1.37	-0.06
94	WA_CO	Washington coho catch	-0.19	-1.65
95	WA_PI	Washington pink catch	-0.13	-0.19
96	WA_SO	Washington sockeye catch	-0.15	-0.84
97	OR_CH	Oregon chinook catch	-0.23	-0.84
98	OR_CO	Oregon coho catch	-0.47	-1.54
99	CA_CH	California chinook catch	-0.12	-0.94
100	CA_CO	California coho catch	-0.82	-1.16

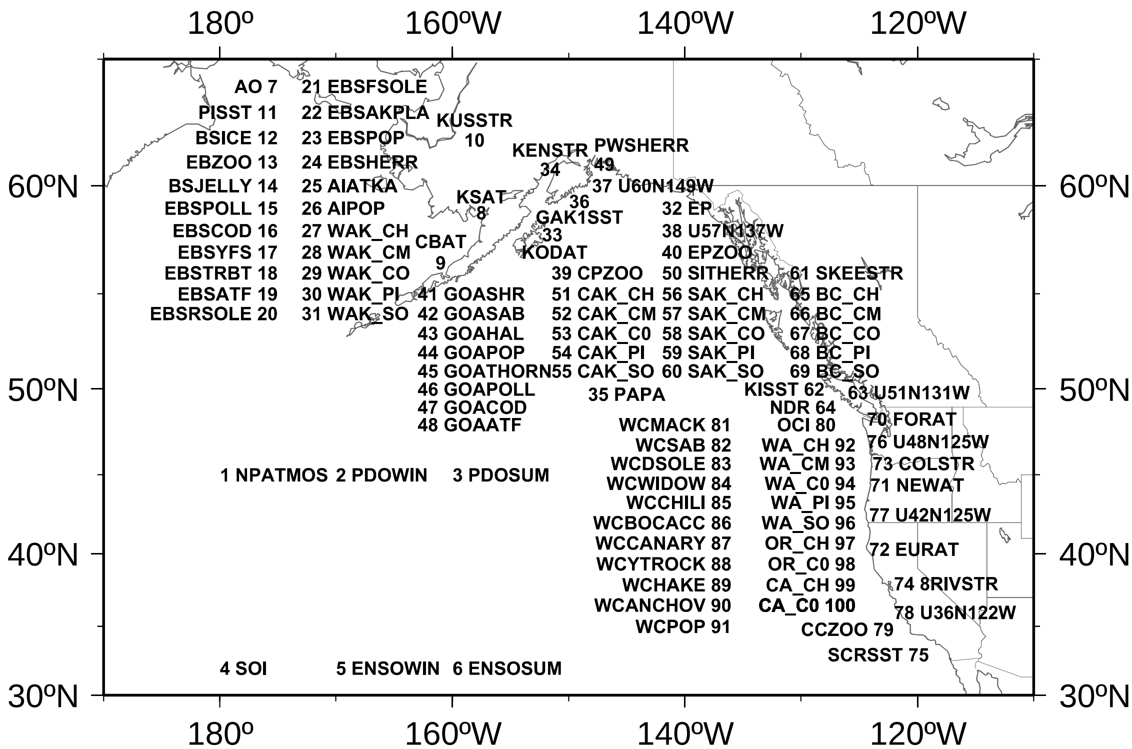


Figure 12. Numeric and alphabetic abbreviations for the 100 time series (reproduced from HM2000). Geographical arrangement gives a general indication of where each variable is measured or has influence. See Table 6 for a definition of each abbreviation.

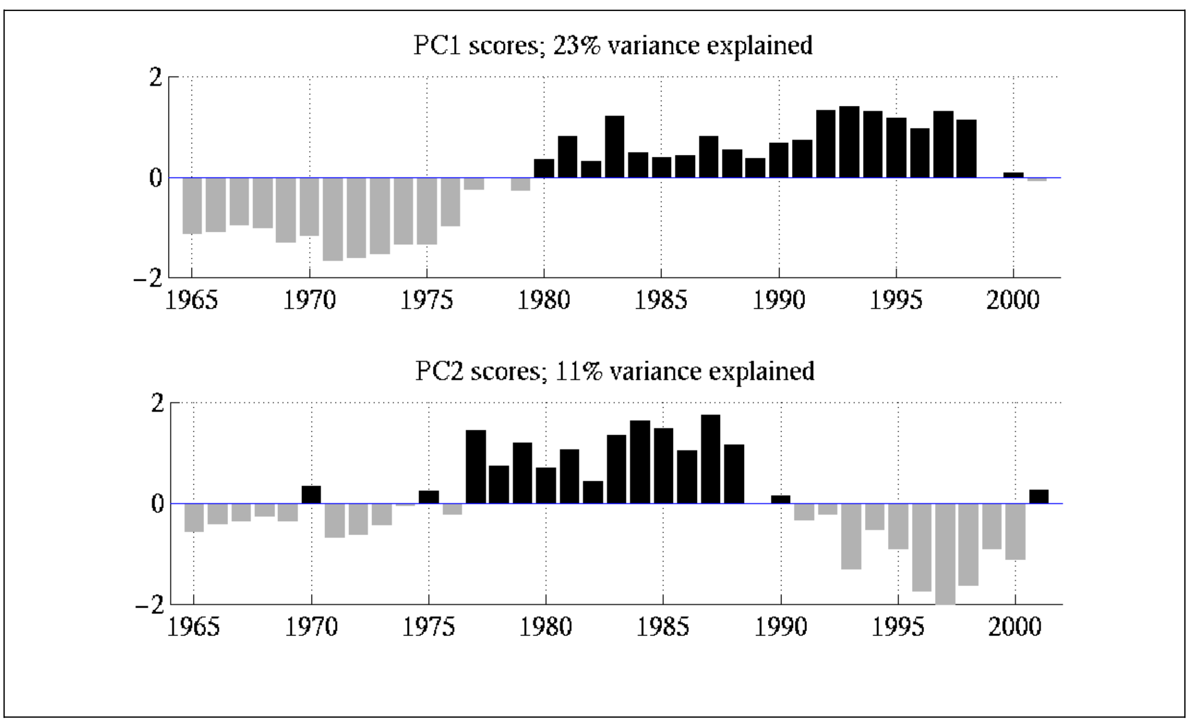


Figure 13. The first two principal component scores from a principal component analysis of the 100 environmental time series for 1965-2001, updated from HM2000.

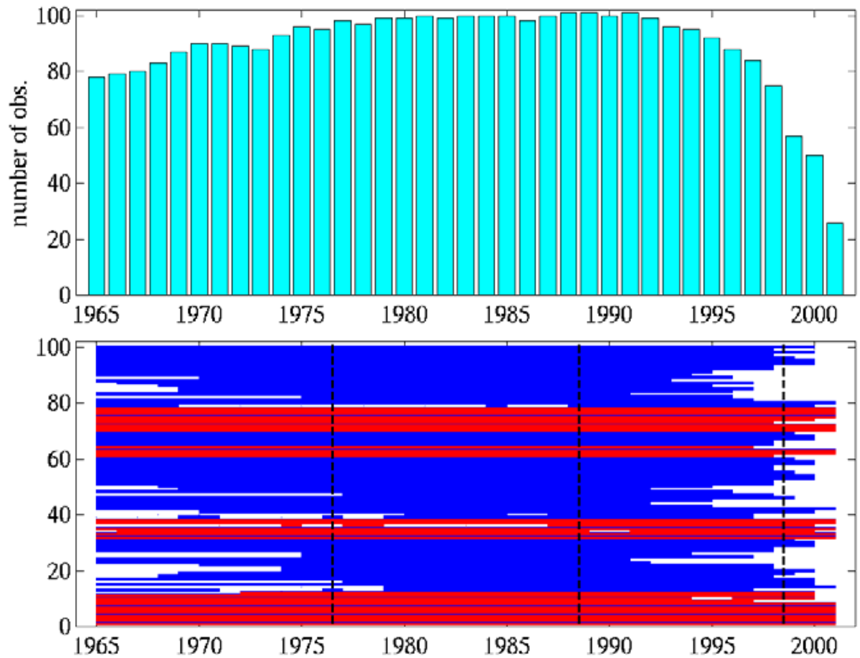


Figure 14. Data coverage for each of the 100 time series. The top panel shows the number of observations for each year, while shading in the bottom panel indicates years with observations (white areas have no observations). The blue (dark) shading indicates a biotic time series observation, the red (light) shading indicates an abiotic observation. Note that there are 20 biotic observations for 2000 but just 3 biotic observations for 2001.

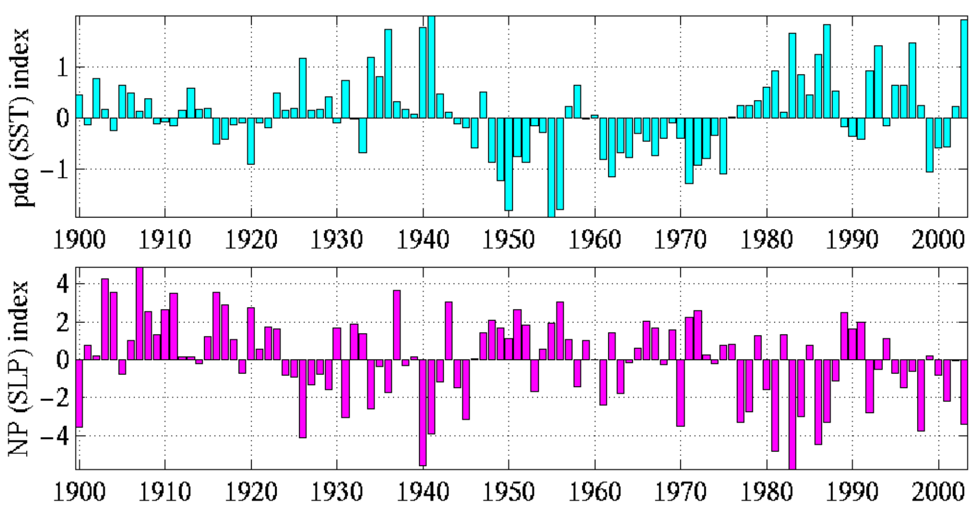


Figure 15. Annual PDO index (top) and Nov-Mar NP index, a measure of the intensity of the Aleutian Low. Both indices are plotted as anomalies from the 1900-2003 means. The 2003 value for the PDO index is based on data for January-June only.

Ecosystem Indicators and Trends Used by FOCI
Edited by S. Allen Macklin, NOAA/PMEL

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

North Pacific Climate Overview – FOCI
S. Rodionov, J. Overland, and N. Bond (NOAA/PMEL)

Summary. *The purpose of this report is to provide a summary of recent atmosphere-ocean conditions in the North Pacific in the context of its primary modes of variability. The first part of this report is focused on decadal-scale variability after the major climate shift in the late 1970s, and the second part describes the climate conditions in 2004. It is shown that in the past three decades the North Pacific climate system experienced two minor regime shifts. The first of these shifts occurred in 1989, primarily in the winter Pacific Decadal Oscillation (PDO) index, which represents the leading mode of North Pacific sea surface temperature (SST) variability and is related to the strength of the Aleutian low. The second shift was in 1998, and was associated with a change in the sign of the second principal mode of North Pacific SST variability, the so-called Victoria pattern, in winter and the PDO index in summer. The atmospheric expression of the Victoria pattern is a north-south pressure dipole, with the negative 500-hPa height anomaly center over the eastern Aleutian Islands and the positive center over the east-central North Pacific (positive mode of the pattern). During the period 1989-1997, atmospheric pressure tended to be above normal in the high latitudes and below normal in the mid-latitudes, which translated to a relative cooling in the Bering Sea. Since 1998, the polarity of the winter north-south pressure dipole reversed. The SST field in the eastern Bering Sea became anomalously warm, whereas colder-than-normal conditions were established along the U.S. West Coast. During the summer season, the 1998 shift exhibited itself in a transition from the north-south pressure dipole to a monopole characteristic of the negative PDO pattern. It is unclear whether this shift in the summer PDO index to significantly negative values from 1999 through 2001 represents just a temporary reprieve from positive PDO conditions, or heralds the onset of an extended period featuring negative PDO conditions throughout the year.*

Recent Regime Shifts on the Decadal Time Scale

The climate shift that occurred in the late 1970s was associated with an abrupt transition from a negative to a positive phase of the Pacific Decadal Oscillation (PDO). The PDO index tracks major, multidecadal changes in the North Pacific climate, often referred to as regimes (Mantua et al. 1997). In addition to these multidecadal regimes, the climate experiences minor, decadal-scale regimes. Minobe (1999) discusses a possible resonance between the regimes on these two time scales, which may lead to an amplification of the magnitude of a shift as in the mid-1940s and late 1970s.

A question critically important for fisheries is whether a string of negative values of the PDO index in the late 1990s and early 2000s signifies the end of the positive PDO regime established in the late 1970s, or if it was just a temporary deviation from that regime, possibly associated with the prolonged La Niña event of 1998-2001. If this is a climate regime shift, is it on the decadal or longer time scale? It is also possible that recent changes in the North Pacific climate have little to do with the PDO, which is the first principal mode of sea surface temperature (SST) variability, but rather with the Victoria pattern, which is its second principal mode (Overland et al. 2004).

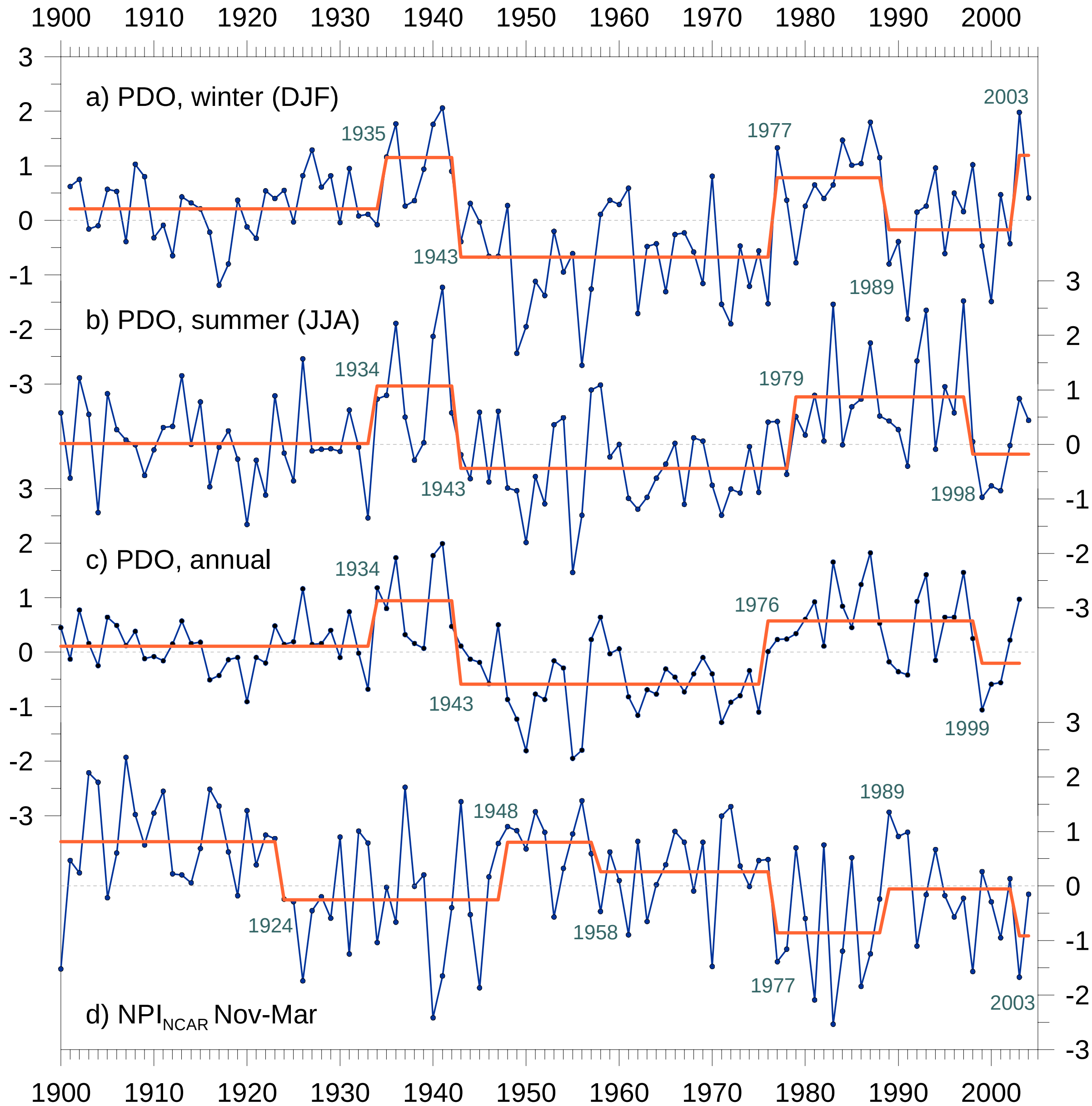


Figure 16. a) Mean winter (DJF) PDO index, 1901-2004, b) mean summer (JJA) PDO index, 1900-2004, c) Annual (Jan-Dec) PDO index, 1900-2003, and d) North Pacific index (Nov-Mar) from the National Center for Atmospheric Research (Trenberth and Hurrell 1994), 1900-2004. The stepwise functions (orange lines) characterize regime shifts in the level of fluctuations of the indices. Shift points were calculated using the STARS method (Rodionov 2004), with the cutoff length of 10 years and significance levels of 0.05 for the PDO indices and 0.2 for the NPI$_{NCAR}$ index.

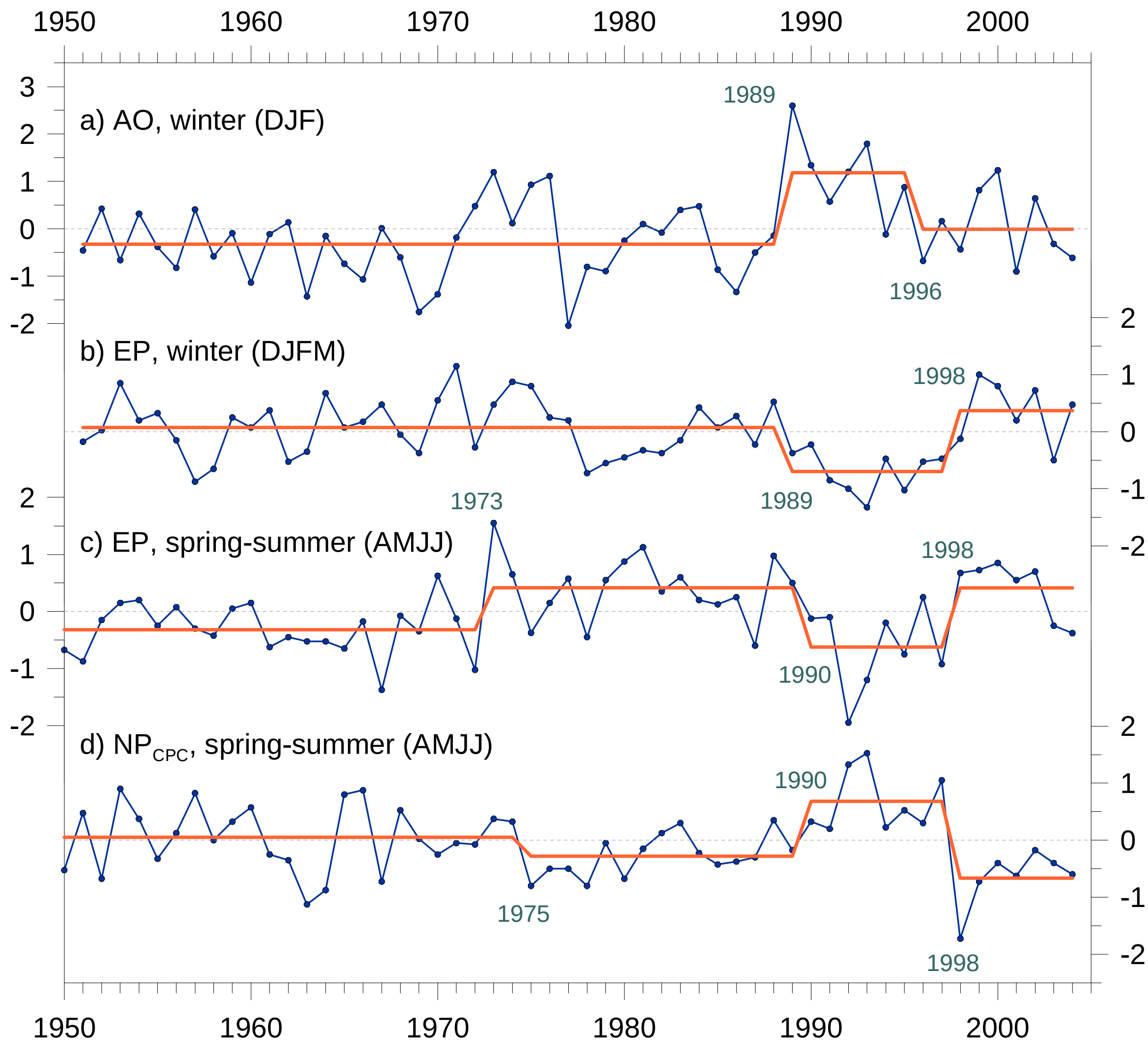


Figure 17. a) Mean winter (DJF) Arctic Oscillation index, 1951-2004, b) mean winter (DJFM) East Pacific index, 1951-2004, c) Mean spring-summer (AMJJ) East Pacific index, 1950-2004, and d) mean spring-summer (AMJJ) North Pacific index from the Climate Prediction Center, 1950-2003. The stepwise functions (orange lines) characterize regime shifts in the level of fluctuations of the indices. Shift points were calculated using the STARS method (Rodionov 2004), with the cutoff length of 10 years and significance levels of 0.1 for the NPI$_{CPC}$ index and 0.05 for other indices.

A regime shift analysis of the mean winter (DJF) PDO time series using the STARS method (Rodionov 2004) reveals only two regime shifts that are significant at the 0.01 level, one in 1943 and the other one in 1977. At the 0.05 level, however, the shift in 1989 is also detected (Figure 16). The magnitude of the 1989 shift was not as large as the one in 1977. Nevertheless, it survived the test, despite a series of positive PDO values in the mid-1990s. Having analyzed 100 physical and biological time series, Hare and Mantua (2000) came to conclusion that the regime shift of 1989 was not as persuasive as the 1977 shift; it was more prominent in biological records than in indices of Pacific climate (McFarlane 2000). In 2003, the winter PDO index was the highest since 1941. This suggests a possibility of a new regime shift; however, it may be just a reaction to the El Niño event of 2002-2003. The shift of 1989 and a possible shift in 2003 can also be seen in the North Pacific (NP) index (Trenberth and Harrell 1994), albeit at the less strict significance level (0.2) due to strong interannual variability in the index (Figure 16d).

The pattern of temporal variability for the summer (Figure 16b) and annual (Figure 16c) PDO indices is different from that for the winter PDO index. The negative index values in the late 1980s and early 1990s were not large enough to qualify as a regime shift. Instead, a regime shift was detected in the late 1990s. During the past 7 years (1998-2004), the values of the summer PDO index were lower than the average value of the index for the regime of 1979-1997.

The shifts of 1989 and 1998 can be found in other climatic indices as well. One of the most noticeable manifestations of the 1989 shift was an abrupt transition from a negative phase of the Arctic Oscillation (AO) index to its positive phase (Figure 17a). When the AO index is in its positive phase, it usually translates into positive sea level pressure (SLP) anomalies over the North Pacific and the Bering Sea. In fact, the mean winter Bering Sea pressure index (see the Bering Sea section of this report) shows a marked increase in SLP during the period 1989-1997. At the same time, the 1990s were characterized by frequent El Niño events and an elevated SST background in the equatorial Pacific. The period 1990-1995 has been considered as one continuous El Niño event (Trenberth and Hoar 1995), which was soon followed by the extremely strong El Niño event of 1997-1998. During El Niño events, the Aleutian low typically is stronger (deeper) than normal and is displaced south-east of its normal position (Niebauer 1998). The result of this combined effect of the AO and ENSO was a north-south pressure dipole over the eastern North Pacific, both in SLP (not shown) and 500-hPa height anomalies (Figure 18a). This dipole is the atmospheric expression of what Overland et al. (2004) call the Victoria pattern. The oceanic part of the pattern is the second principal mode of SST variability in the North Pacific that will be described below.

The Victoria pattern is related to a teleconnection mode previously identified by correlation and principal component analyses, the East Pacific (EP) pattern. The EP pattern is a north-south dipole which in its positive phase has a negative 500-hPa height anomaly center in the Gulf of Alaska and a positive center in the east-central North Pacific. During the period 1990-1997, the EP index was persistently negative (Figure 17b). The distribution of correlation coefficients between the EP index and SSTs (Figure 19a) clearly resembles the second principal mode of the North Pacific SST variability described by Bond et al. (2003). Unlike the PDO pattern (Figure 19b), for which SST anomalies have the same sign along the entire west coast of North America, the second SST mode features anomalies of one sign along the U.S. West Coast and of opposite sign in the Gulf of Alaska and eastern Bering Sea. For the latter region, the 1990s were a relatively cold period.

Starting with the winter of 1998, the EP became predominantly positive (Figure 17b), i.e., the polarity of the north-south pressure dipole switched (Figure 18b). As a whole, the period 1998-2004 was characterized by an increased cyclonic activity in the Bering Sea and anomalously strong Subtropical high. The only exception from this pattern was the El Niño winter of 2003 when the EP index was negative due to a strongly negative 500-hPa height anomaly in the east-central North Pacific. The SST response to these atmospheric changes, as it can be inferred from Figure 18a, was a switch toward notably colder winters in the California Current region (Peterson and Schwing 2003) and a string of anomalously mild winters in the Bering Sea (Bond et al. 2003).

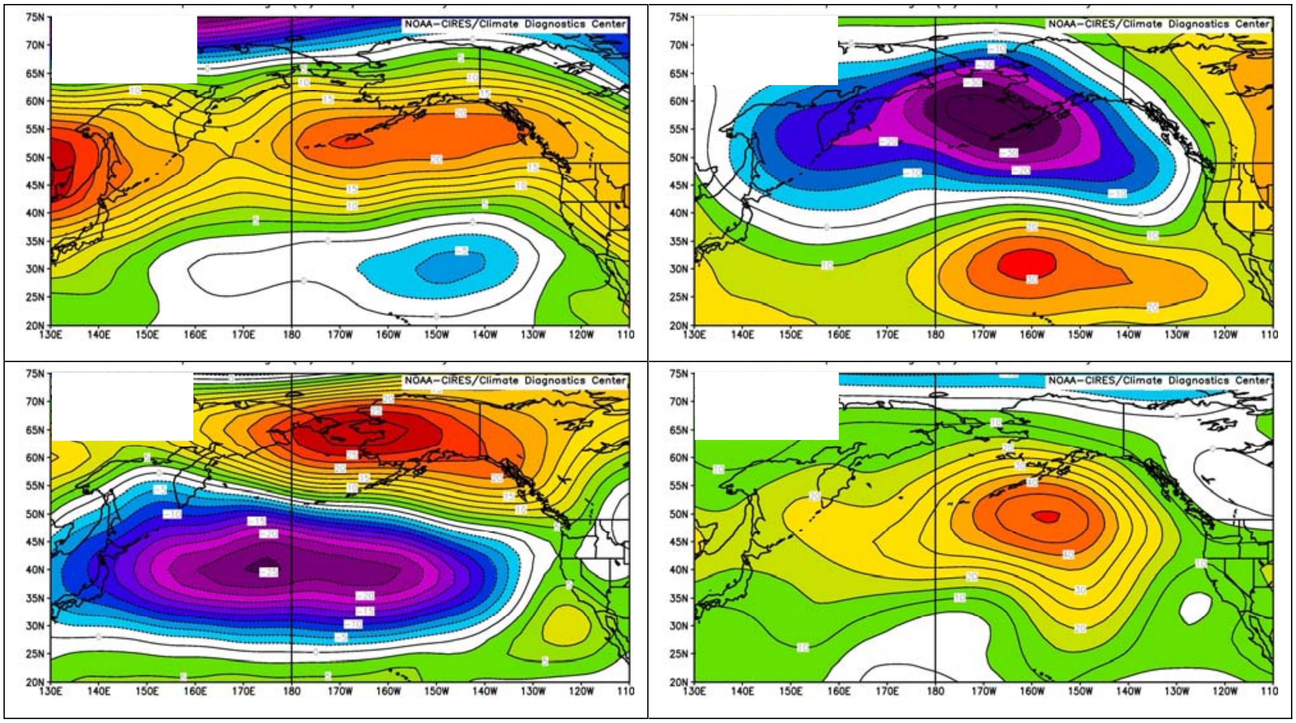


Figure 18. 500-hPa height composite anomalies in winter (DJFM) of a) 1989-1997 and b) 1998-2004 and spring-summer (AMJJ) of c) 1990-1997 and d) 1998-2004. The base period for calculating anomalies is 1968-1996.

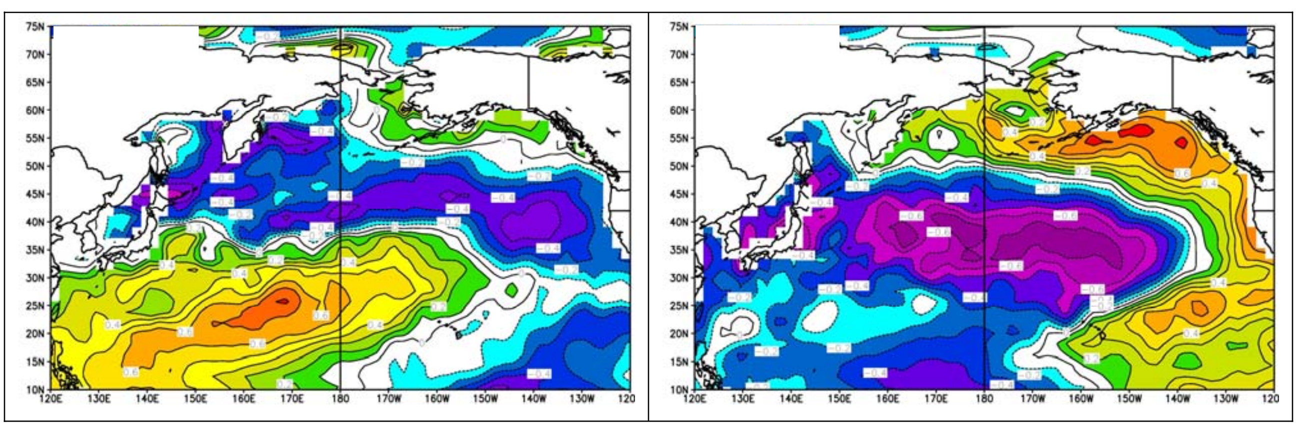


Figure 19. The distribution of the correlation coefficients between a) the EP index and b) the PDO index and SST anomalies for the winter (DJFM) season, 1982-2004.

The 1998 regime shift exhibited itself strongly in spring-summer months as well, as evidenced by the EP index and North Pacific (NP_{CPC}) indices for April-July (Figures 17c and 17d, respectively). Positive values of the NP_{CPC} index correspond to higher 500-hPa heights over the Bering Sea and lower heights for the region south of the Aleutian Islands. Therefore, during the period 1990-1997, the north-south pressure dipole was basin wide (Figure 18c) and not limited to the eastern North Pacific as in winter (Figure 18a). In spring-summer, the shift of 1998 was characterized not by a shift in the polarity of the north-south pressure dipole as in winter, but by a transition to a monopole with a high pressure center south of the Alaska Peninsula (Figure 18d). This distribution of 500-hPa height anomalies is associated with a weak Aleutian low and a negative phase of the PDO.

In summary, the climate regime of positive PDO phase established in the late 1970s appears to have mostly continued, at least in the winter season. On the background of this multidecadal climate regime, there were two minor regime shifts on the decadal time scale. The first shift occurred in 1989 and the second one in 1998, the former being more prominent in winter, whereas the latter in spring-summer. The period 1977-1988 represents a classical positive PDO regime, with a stronger-than-normal Aleutian low and anomalously warm waters along the west coast of North America stretching as far north as the eastern Bering Sea. Variations in the North Pacific climate since 1989 have to do with the north-south pressure dipole in the atmosphere and the second principal SST mode in the ocean, rather than with the PDO phase. During the period 1989-1997, atmospheric pressure tended to be above normal in the high latitudes and below normal in the mid-latitudes, a pattern observed in both winter and spring-summer seasons. This resulted in a relative cooling in the Bering Sea, but no apparent changes in SST variations along the U.S. West Coast were reported. Since 1998, the polarity of the winter north-south pressure dipole reversed. The SST field responded in the way that positive SST anomalies dominated in the eastern Bering Sea, whereas negative SST anomalies were observed along the U.S. West Coast. During the spring-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. While there is no strong correlation between winter and summer PDO indices on the year-to-year scale, the two variables experienced similar regime shifts in the past. It is unclear whether the shift in the summer PDO index to significantly negative values from 1999 through 2001 represents just a temporary reprieve from positive PDO conditions, or heralds the onset of an extended period featuring negative PDO conditions throughout the year.

Climate in 2004

After the 2002-2003 El Niño event, El Niño-Southern Oscillation (ENSO) conditions in the equatorial Pacific Ocean remained near-neutral during the first six month of 2004. The Southern Oscillation Index (SOI) shows pronounced month-to-month variability with no persistent positive or negative trend (Figure 20), which suggests a weakening of air-sea coupling in the equatorial Pacific. SST anomalies off the coast of South America (Nino 1+2 region) remain predominantly negative, while in the central equatorial Pacific (region 3.4, which is considered to be a better indicator of ENSO events) SST anomalies are positive (Figure 21). Based on the latest observations and forecasts from the Climate Prediction Center, it is likely that weak El Nino conditions (with SST anomalies more prominent in the central tropical Pacific) will develop over the rest of 2004 and persist into early 2005.

The mean winter (DJFM) Aleutian low was about 5 hPa deeper than its average value during the 1968-1996 base period. It was also shifted to the northwest of its normal position, a situation conducive to milder than normal winters in the Bering Sea (Rodionov at al. 2004). Cyclonic activity was somewhat enhanced in the Gulf of Alaska. The mean winter 500-hPa anomaly map (not shown) features a north-south dipole over the eastern North Pacific characteristic of positive phases of the EP and Victoria patterns. At the sea level, however, the north-south dipole is much less pronounced.

During the winter of 2004, the SST anomaly pattern in the North Pacific (Figure 22) resembled neither the PDO, nor the Victoria patterns. Winter temperatures were above the 1971-2000 average in the Bering Sea and near the average in the Gulf of Alaska and the U.S. West Coast. The lack of any significant ENSO event in 2004 increases the uncertainty of what major SST pattern should be expected in the winter of 2005.

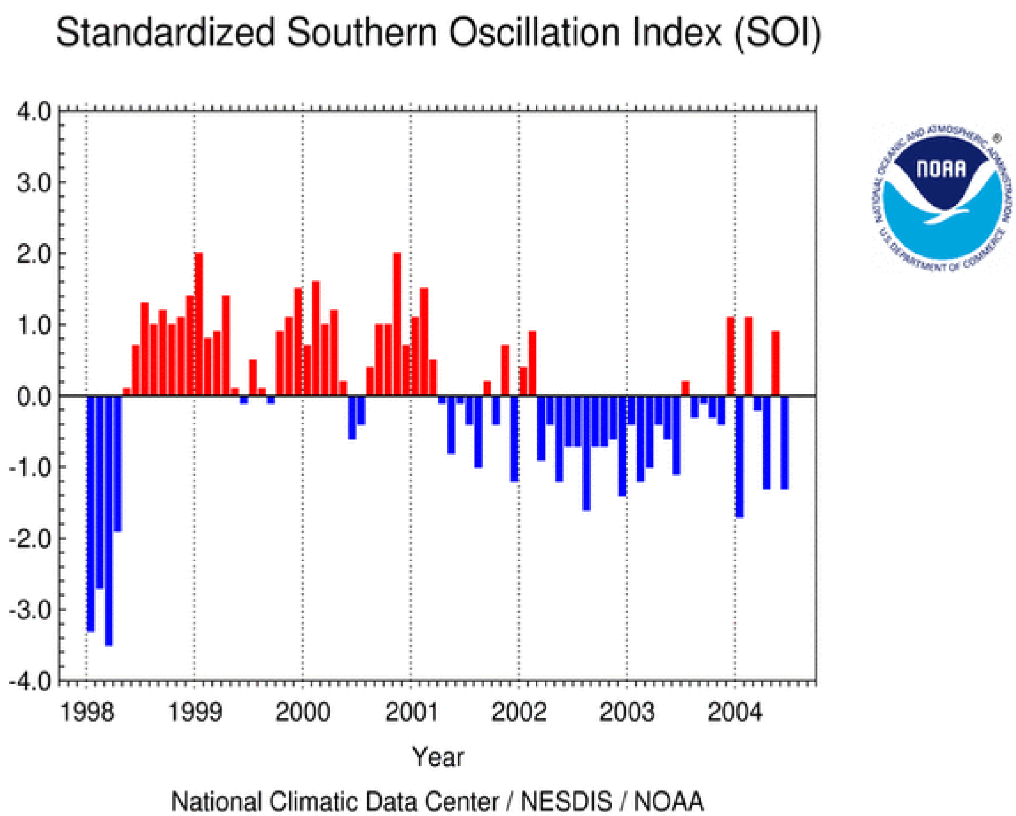


Figure 20. Mean monthly values of the Southern Oscillation Index, January 1998 through June 2004.

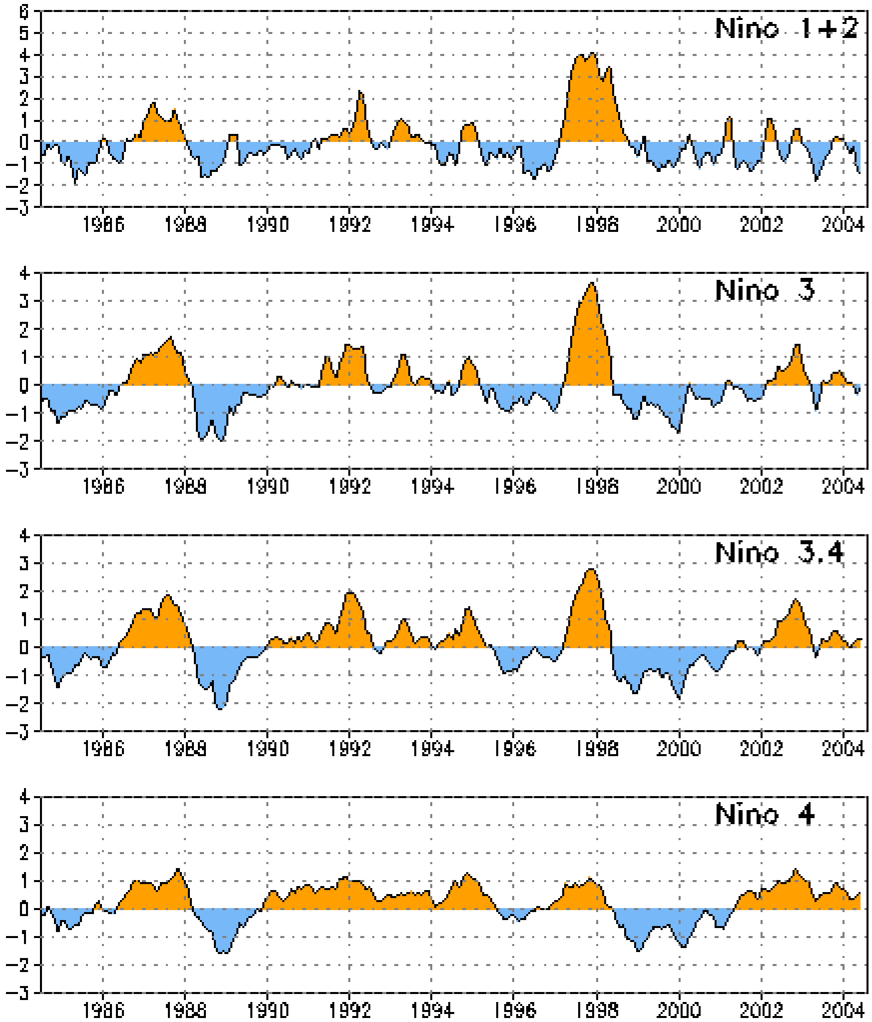


Figure 21. SST anomalies (deg. C) along the west coast of South America (Nino 1+2 region) and central parts of the equatorial belt (Nino 3, 3.4, and 4 regions).

Figure 22. Mean seasonal SST anomalies in the winter (DJFM) of 2004. Anomalies are relative to the 1971-2000 base period. Source data: NOAA OI.v2 SST monthly fields.

GULF OF ALASKA

Pollock Survival Indices –FOCI

Contributed by S. A. Macklin, NOAA/PMEL

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

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

Seasonal rainfall at Kodiak

FOCI uses measured Kodiak rainfall as a proxy for freshwater discharge that promotes formation of baroclinic instabilities (eddies) in the Alaska Coastal Current (ACC) flowing through Shelikof Strait (Megrey et al. 1996). 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 23. Although there is large interannual variability, a trend toward increased survival potential is apparent from 1962 (the start of the time series) until the mid 1980s. Since then, the survival potential has been more level. Survival potential increased in 2003 and 2004 because almost all winter and spring months experienced average or greater rainfall than their respective 30-year averages. 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.

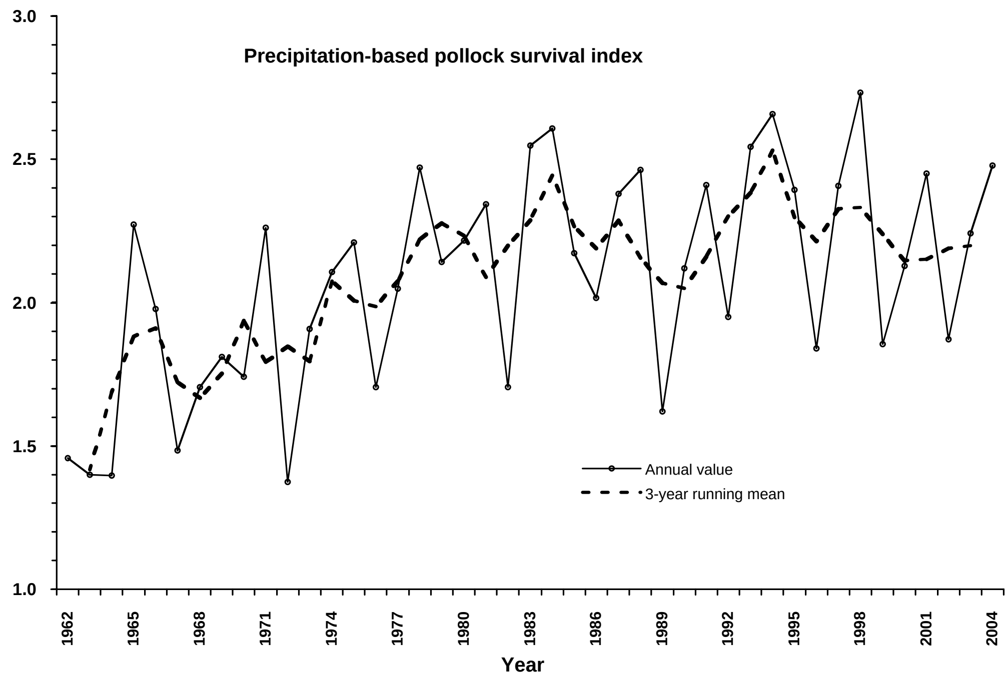


Figure 23. Index of pollock survival potential based on measured precipitation at Kodiak from 1962 through 2004. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Wind mixing at the southwestern end of Shelikof Strait

Of course, rainfall is only one indicator of early-life-stage pollock survival. FOCI hypothesizes that a series of indices (proxies for environmental conditions, processes and relationships), assembled into a predictive model, provides a method for predicting recruitment of walleye pollock. A time series of wind mixing energy (W m^{-2}) at [57°N, 156°W] near the southern end of Shelikof Strait is the basis for a survival index wherein stronger than average mixing before spawning and weaker than average mixing after spawning favor survival of pollock (Megrey et al. 1996). The wind-mixing index is produced from twice-daily surface winds created from a model (Overland et al. 1980) using NCEP reanalyzed sea-level-pressure fields. The model is tuned to the region using information determined by Macklin et al. (1993). A time series of the wind-mixing index is shown in Figure 24. 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. Monthly averaged wind mixing in Shelikof Strait generally has been below the 30-year (1962-1991) mean for the last seven January through June periods (1998-2004). This may be further evidence that the North Pacific climate regime has shifted in the past decade.

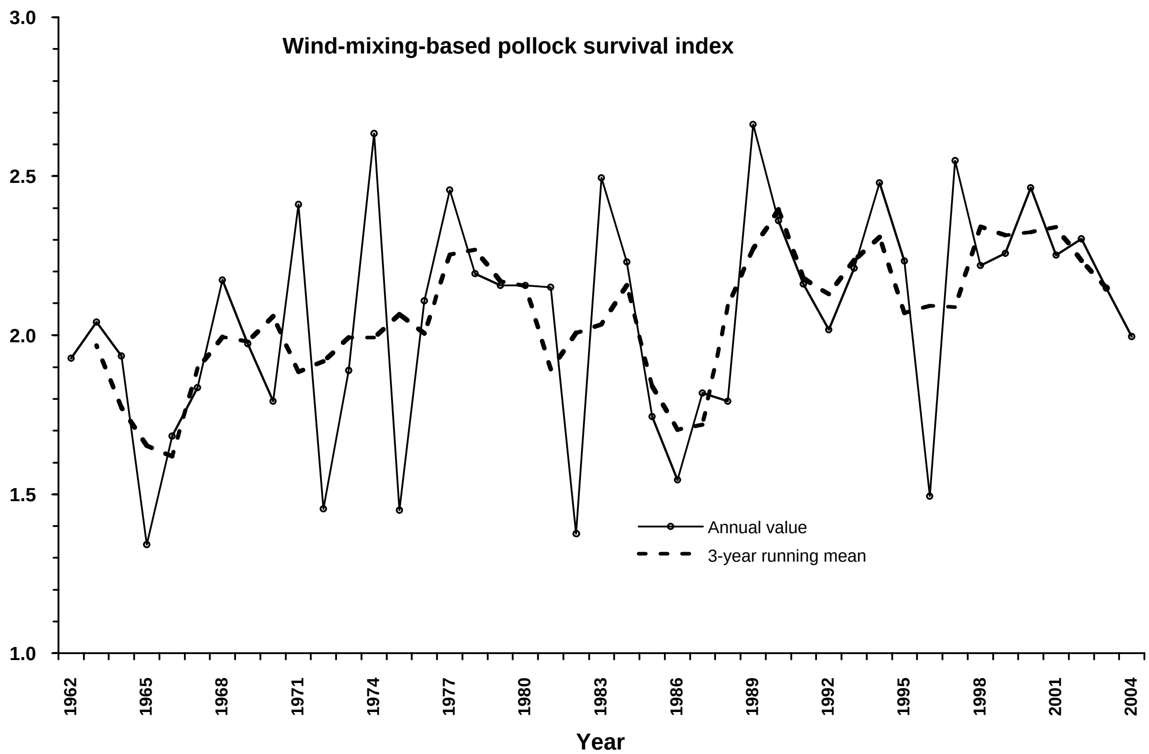


Figure 24. Index of pollock survival potential based on modeled wind mixing energy at [57°N, 156°W] near the southwestern end of Shelikof Strait from 1962 through 2004. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Ocean transport in the western Gulf of Alaska –FOCI (not updated for 2004)
Contributed by P. J. Stabeno, NOAA/PMEL

The spring and summer seasonal strength of the Alaskan Stream and Alaska Coastal Current (ACC) is an important factor for overall productivity on the shelf of the Gulf of Alaska. FOCI uses satellite-tracked drift buoys, drogued at mid mixed-layer depths (~45 m), to measure ocean currents as a function of time and space. Animations of drifter trajectories from deployments during 2001-2003 can be found at *http://www.pmel.noaa.gov/steller/ssl_drifters.shtml*. There is a strong seasonal signal in the ACC. During late spring and summer, the flow on the Gulf of Alaska shelf between Prince William Sound and the Shumigan Islands is weak. The many bathymetric features such as troughs and banks interact with the currents. This results in flow up the eastern side of such troughs as Amatouli, Chiniak and Barnabas. Flow over banks such as Portlock, is often recirculating, and satellite-tracked drifters can be retained in closed circulation for weeks to months. ACC flow in the western Gulf of Alaska during 2001 and 2002 was particularly weak. Later in the summer or fall, with the intensification of regional winds, the ACC becomes stronger, and the flow down Shelikof Strait becomes more organized, as shown by the animations for September of 2001 and 2002. During 2003 (Figure 25), ACC flow was more organized and stronger. Specifically, the flow in Shelikof Strait appeared more complex with more meanders and eddies than have been evident in previous years. This year, more than the typical number of drifters went aground along the Alaska Peninsula and the Kenai Peninsula west of Gore Point.

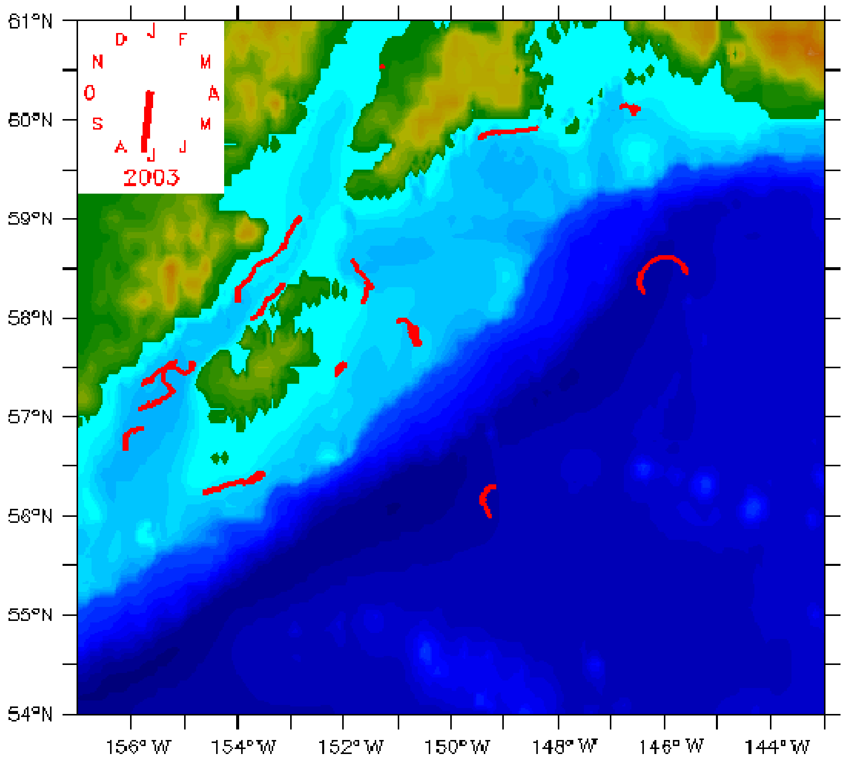


Figure 25. Tracks of satellite-tracked drifters for the period October 14-18, 2001, show sluggish flow on the shelf, except for within Shelikof Strait.

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

Eddies in the Gulf of Alaska – FOCI
Contributed by Carol Ladd, NOAA/PMEL

Because the Gulf of Alaska is predominantly a downwelling system, cross-shelf exchange of nutrients is particularly important for productivity on the shelf. Eddies have been implicated as an important mechanism for cross-shelf exchange in the western Gulf of Alaska (Musgrave et al. 1992, Niebauer et al. 1981, Stabeno et al. 2004). The influence of eddies on biological processes has been confirmed with data from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) showing elevated chlorophyll associated with eddies.

Eddies propagating along the slope in the northern and western Gulf of Alaska are generally formed in the eastern gulf in the autumn or early winter (Okkonen et al. 2001). In most years, these eddies impinge on the shelf east of Kodiak Island in the spring. Using altimetry data from 1993 to 2001, Okkonen et al. (2003) find an eddy in that location in the spring of every year except 1998. They find that strong, persistent Yakutat eddies occur more often after 1997 than in the period from 1993 to 1997.

In the spring/summer of 2004, two eddies were located near the Kodiak Island shelf: one northeast of Kodiak Island and one south of the island near the exit of Shelikof Strait (Figure 26). The southernmost eddy was formed in the winter of 2003, while its more northern counterpart was formed in winter of 2004. In situ observations of water properties within these eddies suggest that the eddies trap shelf water in their interior and transport it off-shelf into the basin. This eddy core is likely to contain shelf-derived species of zooplankton and concentrations of iron and other nutrients, as has been found for Haida eddies, found farther south in the Gulf of Alaska (Mackas and Galbraith 2002, Whitney and Robert 2002). The eddy core of the 2003 eddy was observed to maintain its coastal signature through at least May 2004.

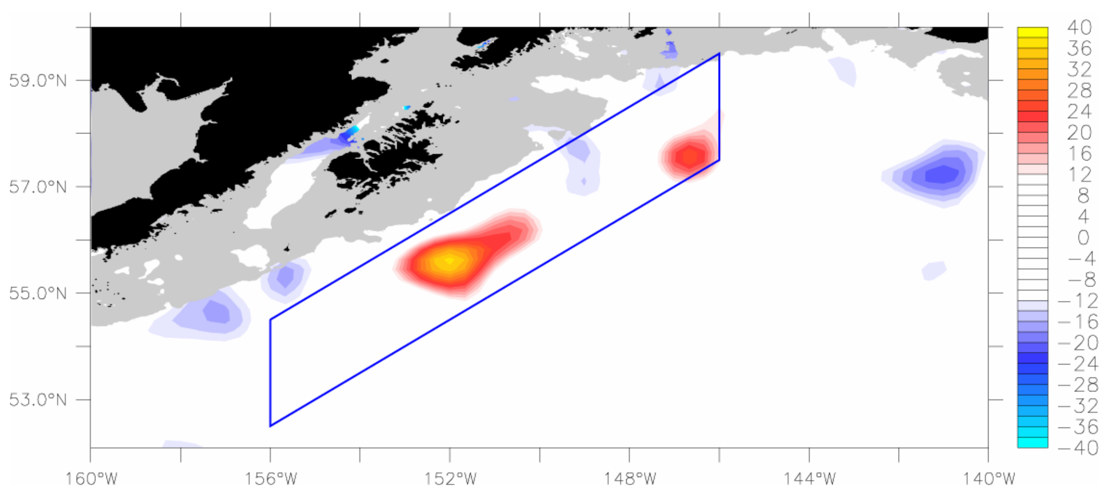


Figure 26. Sea surface height anomaly from TOPEX/Poseidon, ERS-1/2 and Jason merged altimetry. Positive anomalies imply anticyclonic circulation. Blue line outlines region over which EKE was averaged for Figure 27.

Since 1992, the Topex/Poseidon satellite altimetry system has been monitoring sea surface height (SSH). Gridded altimetry data (merged TOPEX/Poseidon, ERS-1/2 and Jason at 1/3 degree resolution; Ducet et al. 2000) was used to obtain an index of energy associated with eddies in the Gulf of Alaska. Figure 27 shows a time series of eddy kinetic energy (EKE) in the region where eddies often impinge on the shelf near Kodiak Island (see Figure 26 for region over which EKE was averaged). EKE during the first half of 2004 was high compared to the rest of the record, probably because two eddies were active in the region. Prior to 2000, EKE was generally lower than the ~11-year average, although 1993 and 1997 both showed periods of high EKE. In addition, the amplitude of the quasi-seasonal cycle also appears to have increased later in the record. Research is ongoing on the causes and implications of these patterns. (The altimeter products were produced by the CLS Space Oceanography Division as part of the Environment and Climate EU ENACT project [EVK2-CT2001-00117] and with support from CNES; downloaded from http://www.aviso.oceanobs.com/).

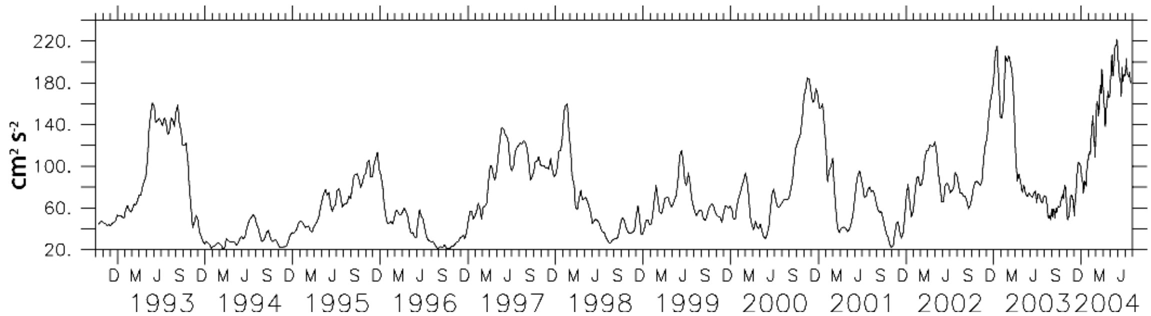


Figure 27. Eddy kinetic energy averaged over the region shown in Figure 26 calculated from TOPEX/Poseidon, ERS-1/2 and Jason-merged altimetry.

Ocean Surface Currents – Papa Trajectory Index 2004

Contributed by W. James Ingraham, Jr., Alaska Fisheries Science Center (Retired)

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

The Papa Trajectory Index (PTI) is an example of long-term time-series data computed from a single location in the Gulf of Alaska. OSCURS was run 100 times starting at

Ocean Station Papa (50º N, 145º W) on each December first for 90 days for each year from 1901 to 2003 (ending February 28 in the following year). The trajectories fan out northeastwardly toward the North American continent and show a predominately bimodal pattern of separations to the north and south. The plot of just the latitudes of the end points versus time (Figure 28) illustrates the features of the data series.

To reveal decadal fluctuations in the oceanic current structure relative to the long-term mean latitude (green horizontal line at 54.74º N), the trajectories were smoothed in time with a 5-year running mean boxcar filter. Values above the mean indicate winters with anomalous northward surface water circulation in the eastern Gulf of Alaska; values below the mean indicate winters with anomalous southward surface water circulation. The 5-year running mean shows four complete oscillations but the time intervals were not constant; 26 years (1904-1930), 17 years (1930-1947), 17 years (1947-1964), and 31-40 years and continuing (1964-1995 or 2004). The drift from Ocean Weather Station Papa has fluctuated between north and south modes about every 23 years over the last century and the shift from north to south modes appeared to be long overdue since we are in at least the longest oscillation this century. The time-series has been updated with winter 2004 calculations and shows a return to normal conditions despite the beginning of the possible southward shift last year. The 5-year running mean has fallen to the mean value twice (1995, 2001, and 2002), the possible start of a zero crossing. Once the 5-year running mean crosses the zero line it usually stays there for several years. In further support for the coming decadal change, Murphree et al. (2003) has reported unusual ocean circulation in the eastern North Pacific Ocean driven by large scale atmospheric anomalies in 2002.

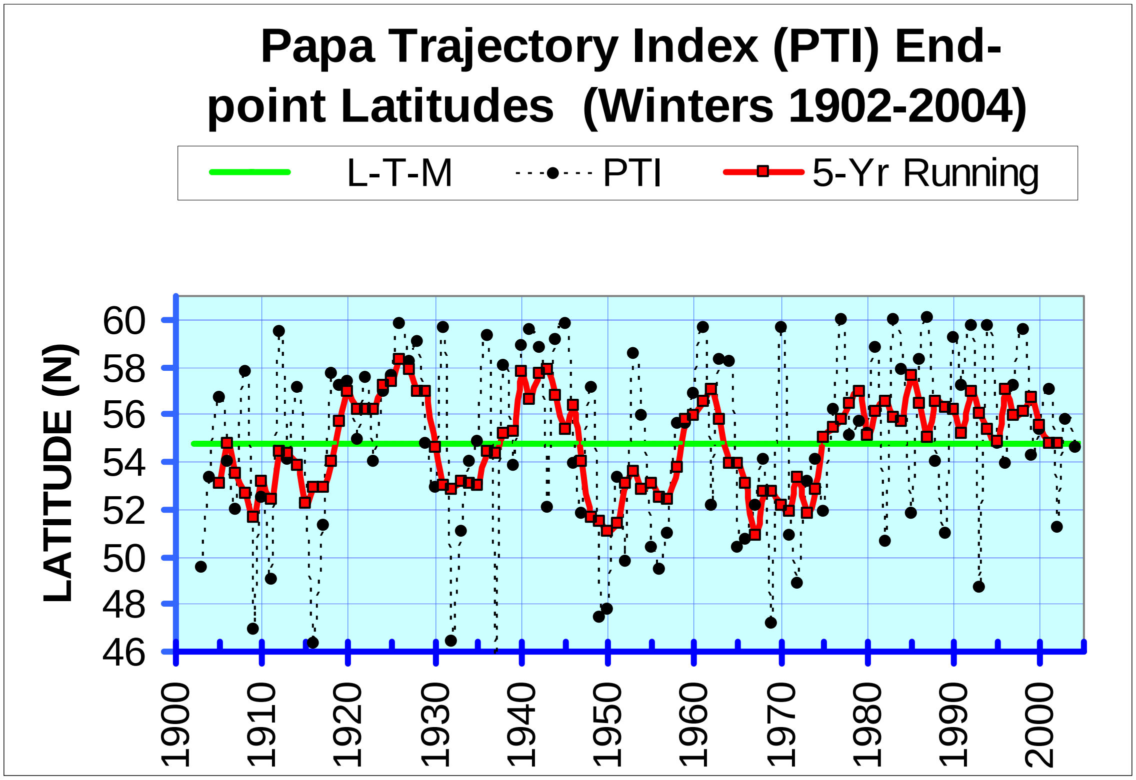


Figure 28. Annual, long-term mean, and 5-year running mean values of the PAPA Trajectory Index (PTI) time-series from winter 1902-2004. Large black dots are annual values of latitude of the end points of 90-day trajectories started at Ocean Weather Station PAPA (50º N, 145º W) each December 1, 1901-2004. The straight green line at 54º 44' N is the mean latitude of the series. The thick red oscillating line connecting the red squares is the 5-year running mean. This shows the variations in the onshore (eastward) flow, eras when winter mixed-layer water drifting from PAPA ended farther north or south after 90 days.

Gulf of Alaska Survey Bottom Temperature Analysis (not updated for 2004)

Contributed by Michael Martin, AFSC, RACE Division (michael.martin@noaa.gov)

Groundfish assessment surveys in the Gulf of Alaska have been conducted every two or three years since 1984 between Islands of Four Mountains (170°W) and Dixon Entrance (132°30'W) at depths between 15 and 1000 m. The area surveyed and timing of the survey has been inconsistent from year to year (Figure 29). The maximum depth of sampling has also varied from 1000 m (1984, 1987, 1999), to 750 m (2003) to 500 m (1990, 1993, 1996, 2001). These inter-annual differences complicate the comparison of bottom temperature data and require that the analysis consider date of collection, latitude and longitude for the results to be meaningful.

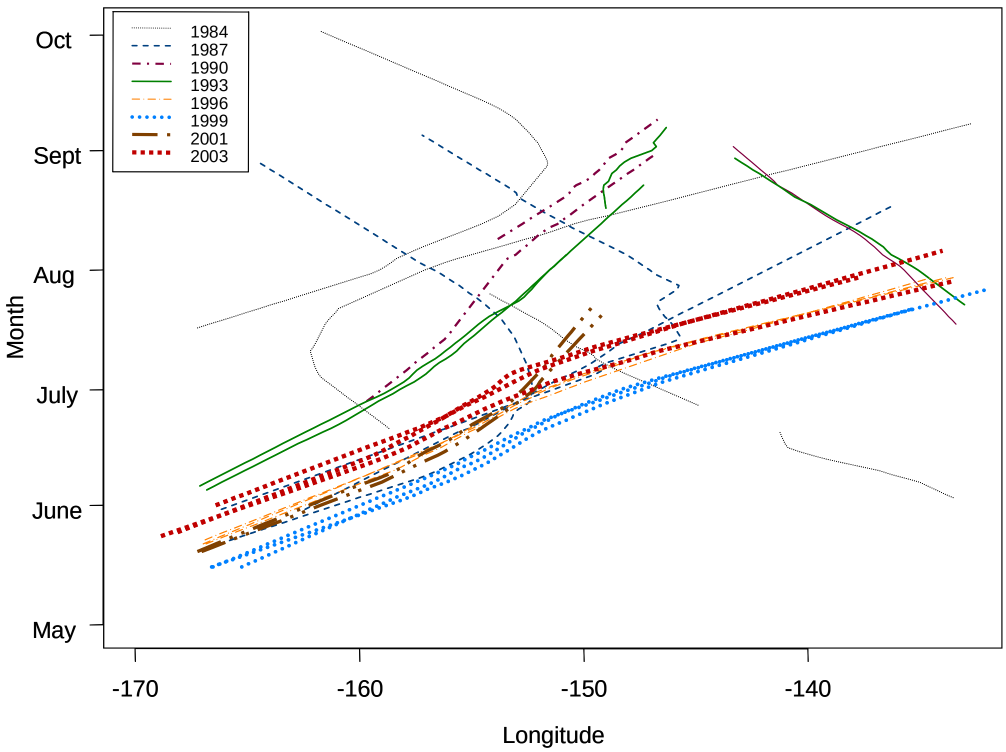


Figure 29. GOA survey temperature data collection by date and longitude.

The method of temperature data collection has also changed over time. Prior to 1993, bottom temperature data were collected with expendable bathythermographs (XBT's) when available, usually after completion of the tow. Since 1993, data have been collected using micro-bathythermographs (MBT's) attached to the headrope of the trawl during each tow.

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

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

Data from each survey year was given equal weight in the analysis to account for different sample sizes between years. The mean and standard error of the residuals were then calculated by year to examine inter-annual differences in bottom temperature. The results are presented in Figures 30 and 31. Figure 30 shows the results plotted by depth with year on the x-axis, while Figure 31 presents the same information by year with depth plotted on the x-axis. Values appearing above the horizontal line can be considered as being warmer than normal, and those below, cooler.

The data indicate that water temperatures in 1984, 1987, 2001 and 2003 were above normal for this period with 1984 and 2003 representing the warmest years of the period for all depths combined. Temperatures during the 2003 survey were the warmest yet recorded in depths less than 150 m. Temperatures were also quite warm in 1984 between 51 and 200 meters, with unusually cool temperatures in the shallowest waters, similar to the pattern seen in1987. Temperatures throughout the 1990's appear to have been generally cooler than normal, with 1999 being the coolest year. In water depths between 51 and 150 meters the coolest years were in 1990 and 1999. The pattern of temperature changes in these depths seems to generally follow the pattern exhibited by the Pacific decadal oscillation index based on sea-surface temperature anomalies in the north Pacific (plotted as a dotted line in Figure 30). The data also suggest a general warming pattern in depths less than 50 meters over the entire time series (Figure 30).

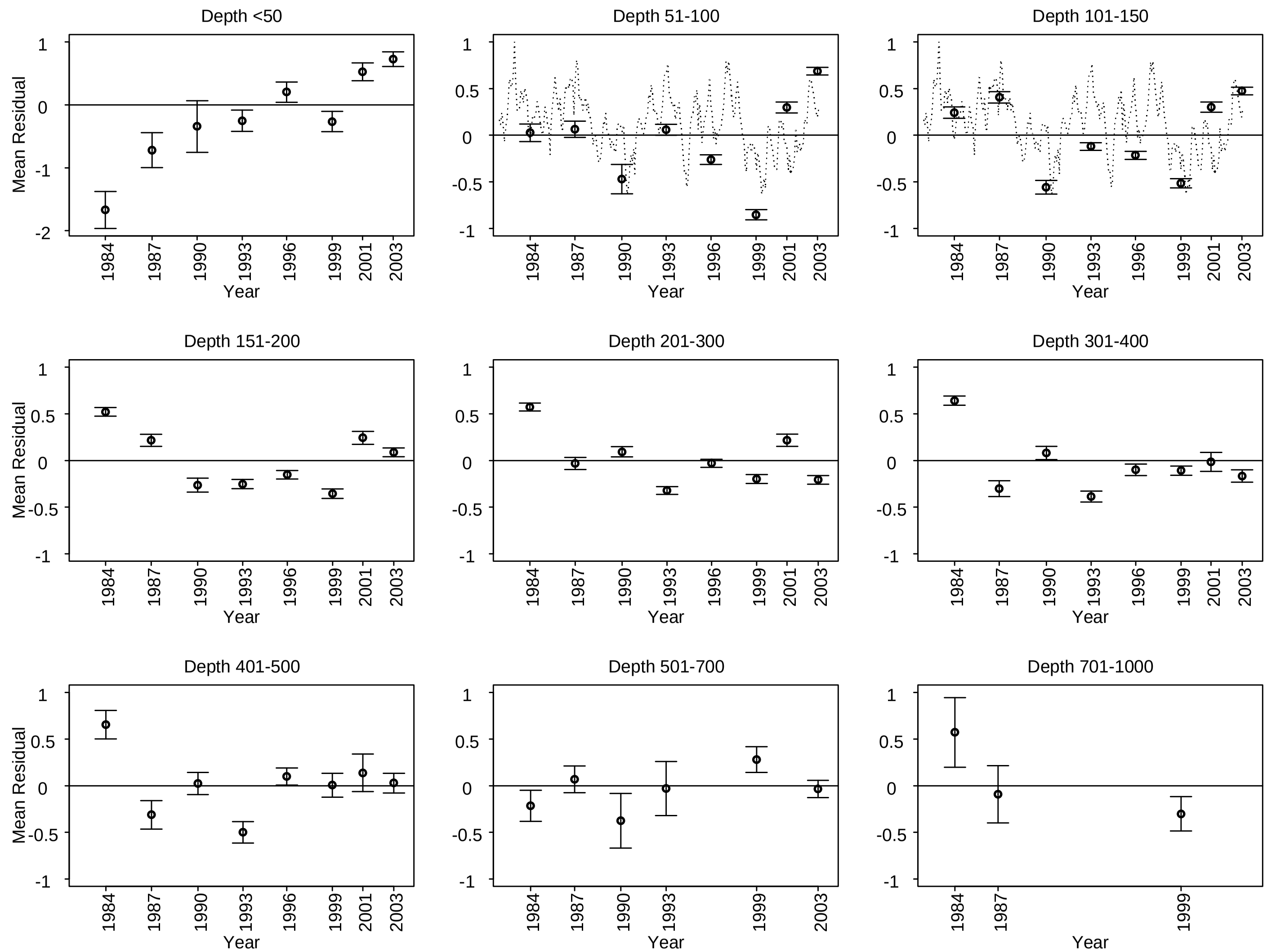


Figure 30. Mean temperature anomalies plotted by year within each depth stratum. Dotted line represents Pacific Decadal Oscillation index. Note expanded scale in < 50 m plot.

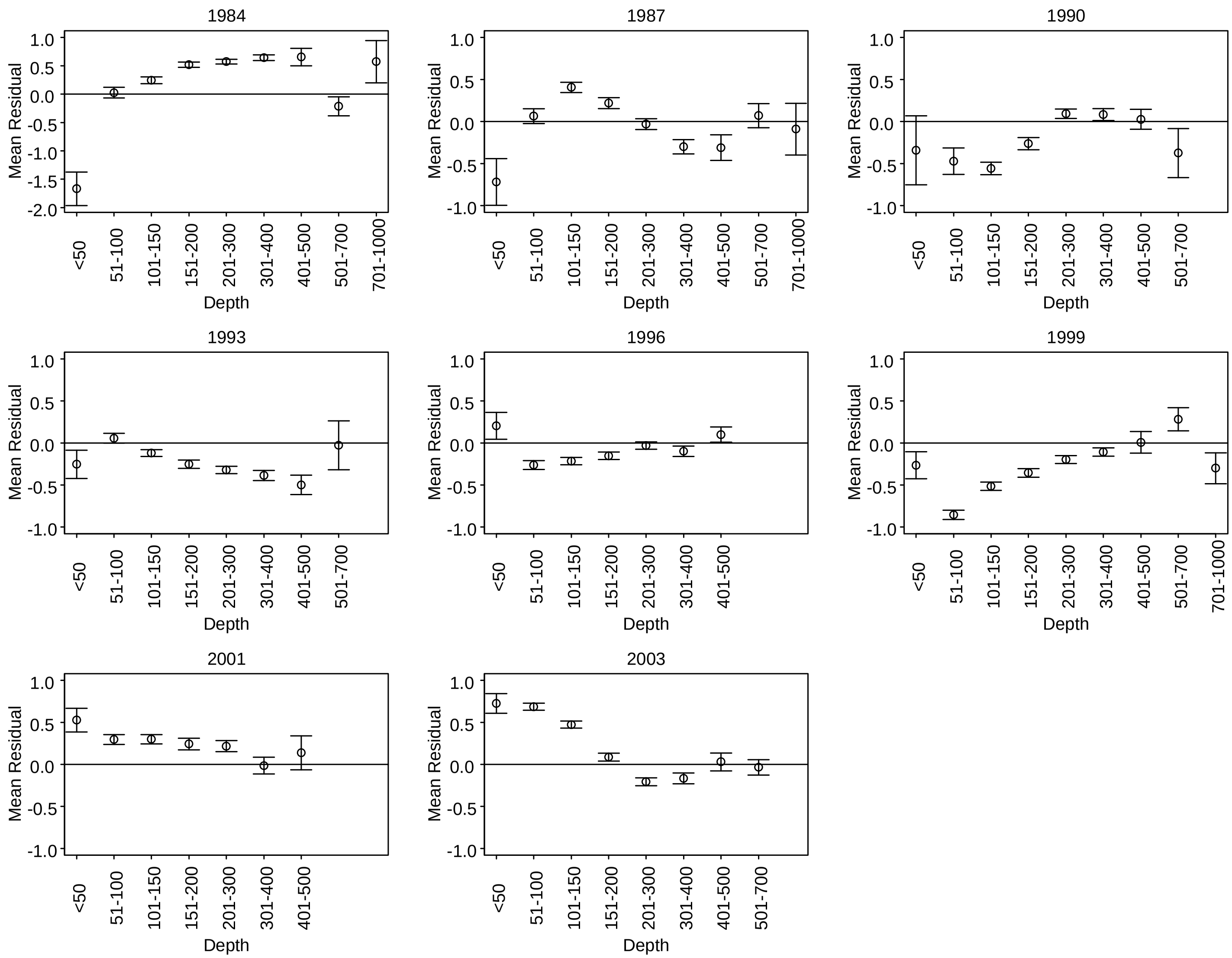


Figure 31. Mean temperature anomalies plotted by depth stratum within each year. Note expanded scale in 1984 plot.

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

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

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

Hydrographic station GAK 1 is located at 60˚ N, 149˚ W, at the mouth of Resurrection Bay in the Northern Gulf of Alaska. Temperature and salinity measurements have been made at various times of the year at this location since 1973. We have estimated the deepest winter mixed layer depths (MLDs) using the Freeland et al. (1997) algorithm. This algorithm performs well at estimating winter MLDs (winter is defined here as days 1 to 59 and 335 to 365 of any given 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.

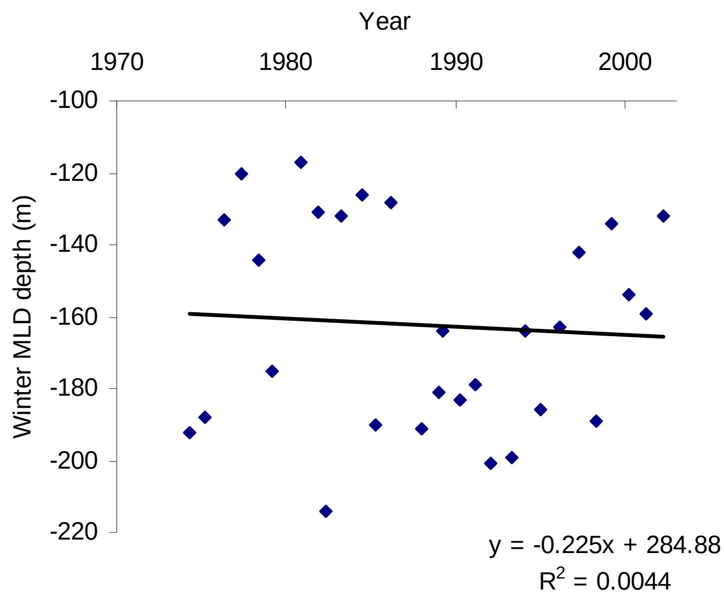


Figure 32. Winter mixed layer depth (m) at GAK 1 from 1974-2002.

The deepest winter MLDs at GAK 1 from 1974 to 2002 (Figure 32) range from a minimum of 117 m to a maximum of 214 m. The mean value is 162 m, with a standard deviation of 28 m. In 2002, the deepest winter MLD was 132 m, which is shallower than the deepest winter MLDs of the previous two years. The deepest winter MLDs from 1974 to 2002 show a deepening linear trend. However, this trend is not statistically significant. The non-significance of the trend maybe due to the short length of the time series, nevertheless the only conclusion is that during 1974-2002, 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. This dissimilarity of trends at the center and edge of the gyre may indicate that the gyre is spinning up.

EASTERN BERING SEA - 2004

Temperature and Ice Cover –FOCI

S. Rodionov, J. Overland, P. Stabeno, N. Bond, and S. Salo, NOAA/PMEL

Summary. *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 winter of 2004 was anomalously warm (although somewhat colder than the winter of 2003), with temperatures typical of the first decade after the 1977 regime shift. Ice cover in the vicinity of Mooring 2 was below the 1989-2004 average almost all season long, except during a cold spell in late March-early April. Spring air and sea surface temperatures were much above normal.*

The winter of 2004 in the Bering Sea was mild, with mean winter (DJFM) surface air temperature (SAT) at St. Paul of 1.34°C above the 1961-2000 average. Such mild winters are typical for the post-1977 climate regime, particularly during its first decade (Figure 33a). The shift of 1977 was very sharp, from the near record cold winters of 1975 and 1976 to the near record warm winter of 1979. This shift to a warmer climate and the previous shift to a colder climate in the late 1930s can be detected using the STARS change detection method (Rodionov 2004) at the confidence level $p < 0.01$. At the less strict confidence level of 0.2, the relatively cold period 1990-2000 can be singled out (Figure 33a). Of these 11 winters, only one winter (1996) was anomalously warm; all other winters were either near or below the 1961-2000 average. This cooling is a manifestation of the decadal-scale climatic variations that occur on the background of multi-decadal climatic regimes (see climate overview for the North Pacific).

The SAT at St. Paul during spring has been generally warm since the late 1970s regime shift (Figure 33b). During the last three spring seasons (2002-2004), SAT anomalies at St. Paul were greater than 1.7˚C (relatively to the 1961-2000 base period), which is anomalously warm even for the post-1977 regime. Note that apart from a relatively short warm period in the late 1930s, spring SAT anomalies were predominantly negative from the beginning of the record in 1916 until the regime shift in 1977.

Warm (cold) winter climatic regimes in the eastern Bering Sea tend to be associated with the periods of anomalous low (high) SLP, as expressed by the Bering Sea pressure index (BSPI), although the timing of the shifts in the winter SAT and BSPI may not be exactly in the same years (cf. Figures 33a and 33c). The BSPI is a measure of an overall cyclonic activity in the region and is closely linked with the strength of the Aleutian low. It is important to note that on the year-to-year scale the correlation between the BSPI and winter SAT at St. Paul is week ($r = -0.16$ for the 1978-2004 period). The reason is that winter climatic conditions in the Bering Sea depend not as much on the strength of the Aleutian low, as on its geographical position (Rodionov et al. 2004). On the multidecadal time scale, anticyclonic anomalies over the Bering Sea reflect the increased Arctic influence on the sea, whereas cyclonic anomalies characterize the increased Pacific influence. Thus a shift of 1977 from a cold to warm multidecadal regime was associated with an abrupt intensification of cyclonic activity over the North Pacific in general and the Bering Sea in particular. During the relatively cold period in the 1990s the BSPI was mostly near or above the 1961-2000 average (Figure 33c). Since 1998, cyclonic activity in the region intensified again. There was no winter during this later period (1998-2004) when the BSPI was positive. The average BSPI value for this 7-year period was the lowest for any consecutive 7-year period since the record began in 1900.

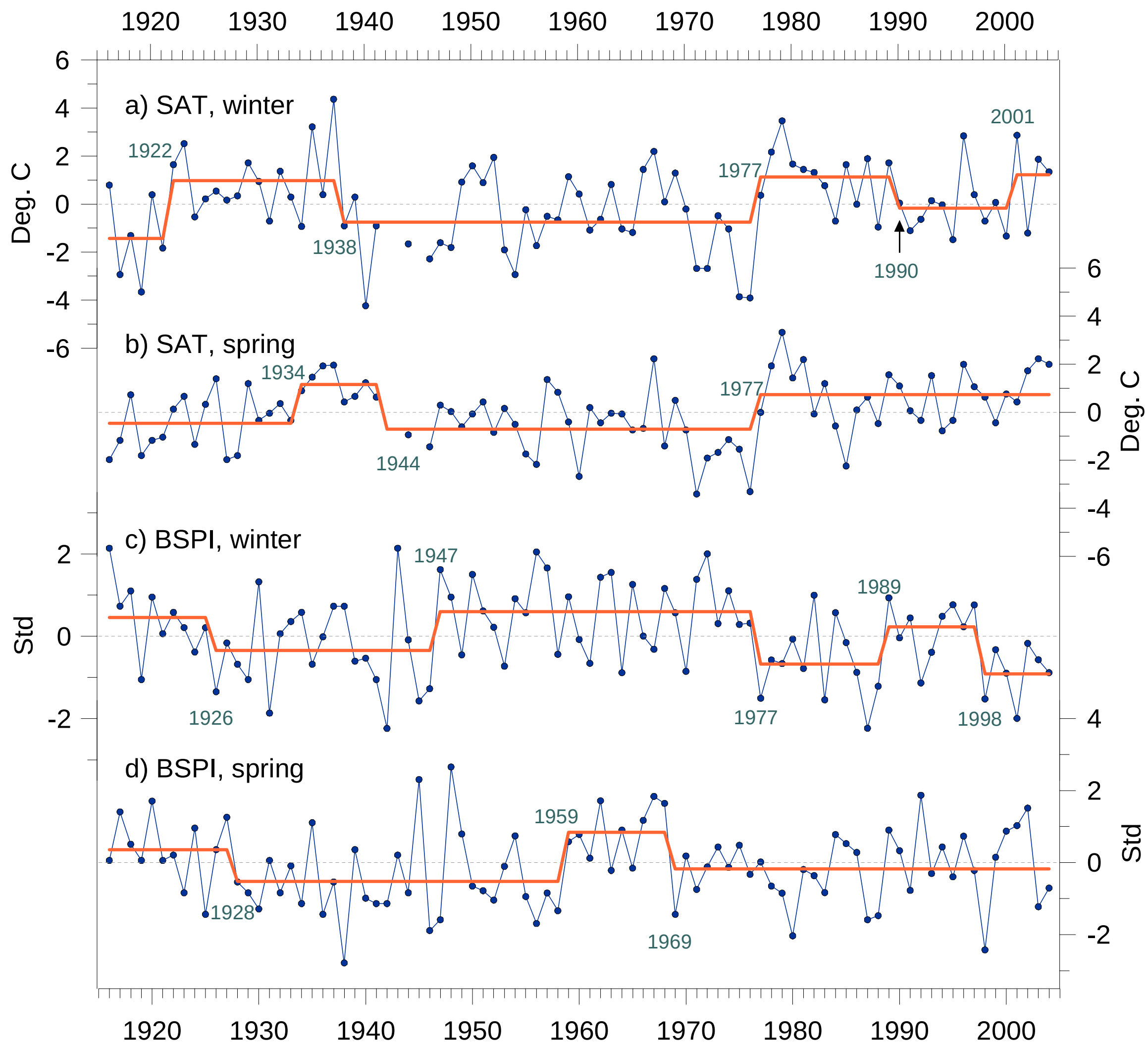


Figure 33. a) Mean winter and b) spring surface air temperature anomalies in St. Paul, Pribilof Islands, c) winter and d) spring Bering Sea pressure index. The winter months are December through March and spring months are April through June. The base period for calculating anomalies is 1961-2000. The stepwise functions (orange lines) characterize regime shifts in the level of fluctuations of the variables. Shift points were calculated using the STARS method (Rodionov 2004), with the cutoff length of 10 years and significance level of 0.2.

The spring BSPI (Figure 33d) tended to be negative during the period 1978-1989 and positive since 1990, but the difference between these two periods was not significant enough to qualify as a regime shift. There is no strong correlation between the BSPI and SAT at St. Paul in spring on the interannual time scale. Nor there are any similarities between these two variables in terms of regime shifts. The relationship between atmospheric pressure and thermal conditions in the Bering Sea is more complex in spring than in winter because the dynamic and radiative factors become comparable. When higher-pressure is present over the Bering Sea, there is often also a relatively cold low-level air mass. But it also means lighter winds, less cloud cover, more solar insolation, and hence, greater radiative heating of the ocean. Similarly, anomalously low SLP implies a trade-off between the advection of warm Pacific air and more clouds and hence less solar insolation.

Variability in ice cover in the Bering Sea depends on both temperature and atmospheric circulation. In turn, sea ice has a profound influence on the physical and biological ocean environment. Prior the climate shift in the late 1970s, the ice cover index (ICI) was predominantly positive (Figure 34a). After the regime shift, the winters from 1978 through 1989 were particularly mild. During this 12-year period there were only three winters when the ICI was slightly positive. During a relative cooling in the 1990s, the frequency of winters with above normal ice cover increased (8 winters with positive versus only 3 winters with negative ICI values during the period 1990-2000). The more recent winters were very mild again, particularly in 2001, 2003, and 2004 (Overland and Stabeno 2004).

As Figure 34b illustrates, there is a clear overall downward trend in the ice retreat index (IRI). Since the early 1970s, the index is declining at an average rate of almost 1 day per year, a trend significant at the 95% level. The IRI represents the number of days with ice cover after March 15 in the 2˚ x 2˚ box (56-58°N, 163-165°W) that includes Mooring 2 (57^{o}N, 164^{o}W). Based on the 1973-2004 statistics, the ice usually retreats from this area in the second week of April. During the period 1996-2004, there was only one year (1999) when ice stayed in the vicinity of Mooring 2 after that date. In the late 1990s, the early ice retreat was compensated by its early arrival, and the length of the ice season was near its average value of 85 days. In more recent years, the length of the ice season significantly shortened. Based on ice melt and changes in atmospheric circulation patterns, Stabeno and Overland (2001) report the Bering Sea is shifting to an earlier spring transition. In the winter of 2004, ice cover in the vicinity of Mooring 2 was below the 1989-2004 average almost the entire season, except for a brief cold spell in the end of March and early April (Figure 35).

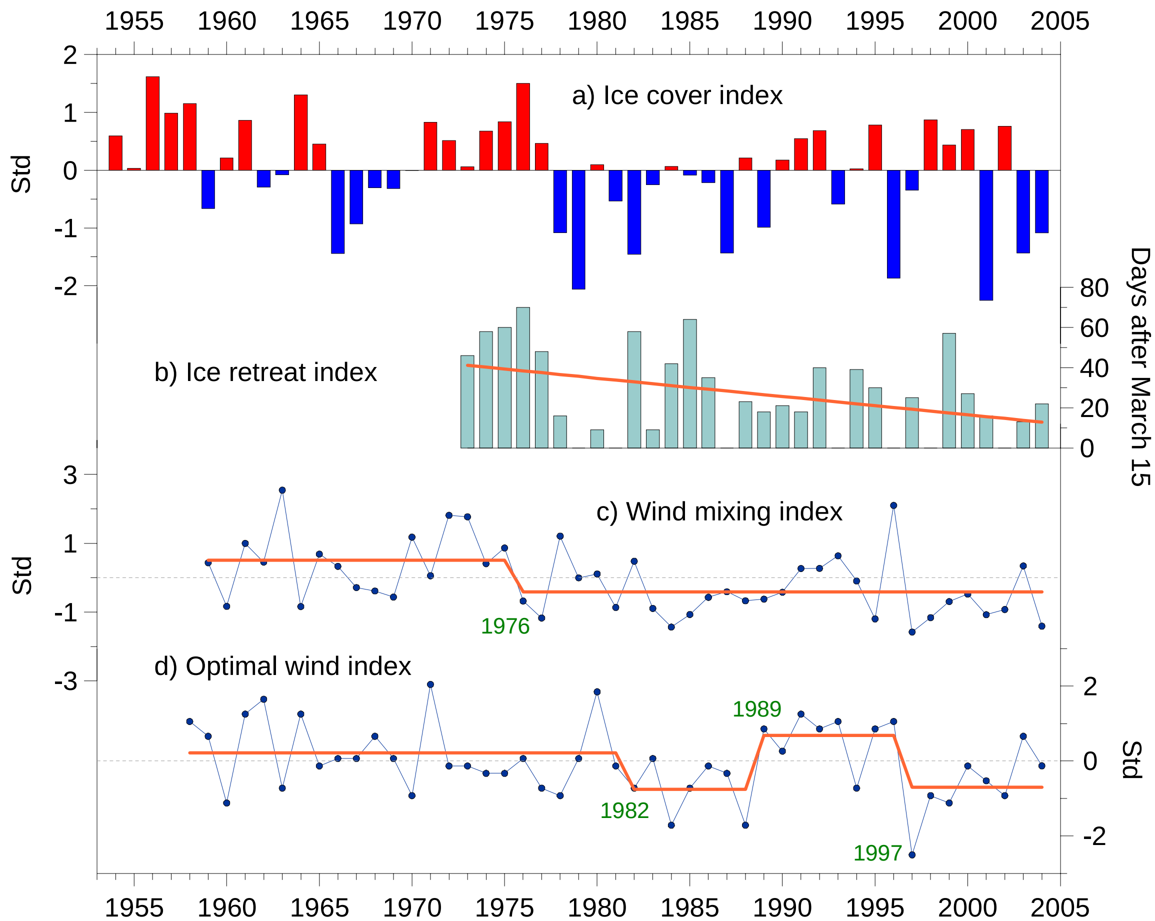


Figure 34. a) Ice cover index, 1954-2004, b) ice retreat index and its linear trend (orange line), 1973-2004, c) wind mixing index (June-July) at Mooring 2, 1959-2004, and d) optimal wind index for successful larval feeding (1 May – 15 July), 1958-2004. The stepwise functions (orange lines) characterize regime shifts in the level of fluctuations of the variables. Shift points were calculated using the STARS method (Rodionov 2004), with the cutoff length of 7 years and significance level of 0.2.

Sea surface temperatures in May, after ice has retreated from the southeastern Bering Sea, appears to be, to a large extent, a product of processes operating during the previous winter. For example, the MaySST index (average SST over the SE Bering Sea) is significantly correlated with winter indices such as the ICI, $r = 0.50$ ($P < 0.05$), and winter surface air temperature in St. Paul, $r = 0.59$ ($P < 0.01$), for the period 1970-2003. The MaySST index is also a good predictor for the summer bottom temperature as illustrated in Figure 36. The correlation coefficient between these two variables is $r = 0.82$ ($P < 0.001$) for the period 1982-2003. In 1999, the MaySST index reached the record low value since the beginning of observations in 1970. Since then this index has increased steadily. Due to the very mild winter and spring of 2003, the MaySST index in that year reached the highest value since 1981. Mean May SST in 2004 remained well above normal.

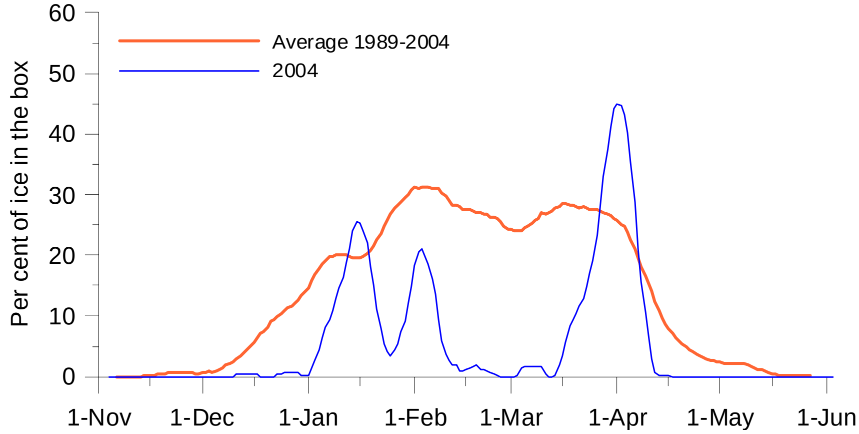


Figure 35. Percentage of ice cover in the 2˚ x 2˚ box (56-58°N, 163-165°W) during the winter of 2004.

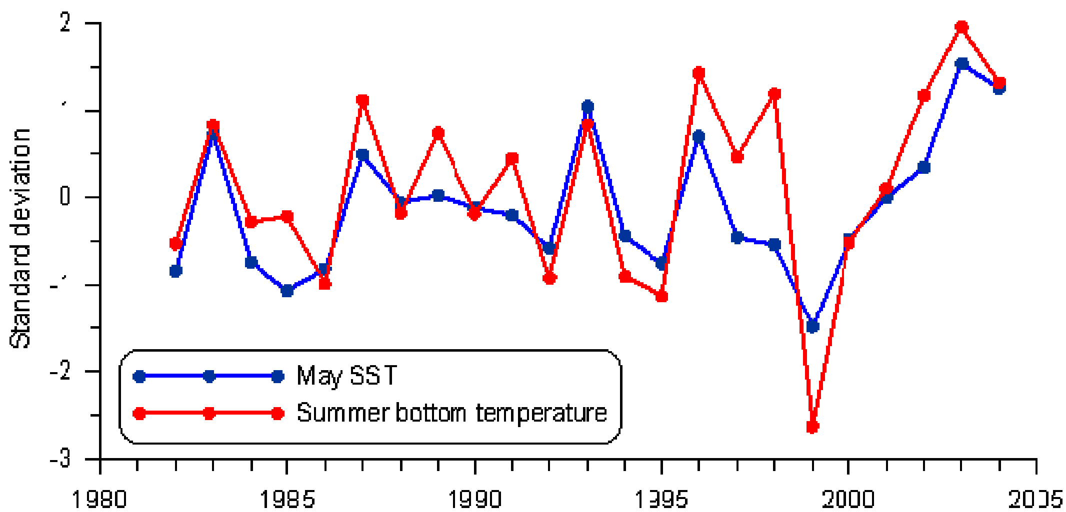


Figure 36. The May SST index (derived from NCEP/NCAR Reanalysis project) and mean summer bottom temperature (from bottom trawl surveys) in the southeastern Bering Sea.

Two indices were chosen to characterize wind conditions in the Bering Sea. The wind mixing $u*^3$ at Mooring 2 provides a good measure of warm season storminess. The quantity $u*^3$ represents the rate at which turbulent energy is supplied to the ocean by the winds, and ultimately relates to the rate of mixing at the base of the upper mixed layer. This exchange can be important to the ecosystem because it represents a mechanism for the transfer of nutrients from water below the pycnocline into the euphotic zone. This mechanism appears to be important in early summer over the Bering Sea shelf, through its role in sustaining primary production after the spring bloom. Figure 34c shows that during the warm climate regime since the late 1970s (and particularly since 1983) the wind mixing index tends to be negative. One prominent exception was the summer of 1996, which was very windy. As the observations at Mooring 2 indicate, that summer featured a thicker upper mixed layer, a weaker thermocline, and sustained primary productivity relative to the other years (Stabeno et al. 2001). It should be noted that

The second wind-related index tracks wind speeds favorable for successful larval feeding. Formally, it refers to the number of days each year during the period 1 May through 15 July in which the daily average wind speed was in the range 4.8 to 9.5 ms^{-1} at the location of Mooring 2. It is based on the study of Megrey and Hinckley (2001), which used a process oriented individual-based model (IBM) of walleye pollock larvae to evaluate the influence of wind-generated turbulence on feeding. Feeding success depends on turbulence through the latter's effects on the rate at which pollock larvae would encounter prey. The time series of the optimal wind index (Figure 34d) shows that there were relatively high number of optimal wind speed days during the period 1989-1996, while the periods 1982-1988 and 1997-2002 stand out as having low frequencies of wind speeds in this optimal range.

In summary, the main characteristic of the Bering Sea climatic conditions in the last 4 years is a year-to-year persistence in lack of sea ice, warm bottom temperatures, and warm air temperature anomalies in late winter through summer, even though the Arctic Oscillation and Pacific Decadal Oscillation indices have shown large interannual variability. Bering Sea indicators should be watched closely over the next 5 years to see whether the ecosystem is experiencing a substantial biogeographical shift northward in response to changing temperature and atmospheric forcing (Overland and Stabeno 2004). If this shift continues over the next decade, it will have major impacts on commercial and subsistence harvests as Arctic species are displaced by sub-Arctic species.

Simulated Drift Trajectories in the Southeast Bering Sea –FOCI
Contributed by Dylan Righi, FOCI, NOAA/PMEL

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

We have used the northeastern Pacific Regional Ocean Model System (ROMS) to simulate trajectories in the southeastern Bering Sea. Drifter tracking in ROMS is done using a fourth order predictor-corrector scheme and allows vertical movement. We currently have results for the years 1996-2003. The simulated drifters are initialized in the Bering Sea just north of Unimak Island and to the northeast of Unimak Pass. This is known to be an area of spawning for walleye pollock (Hinckley 1987). The initial drifter positions fill out a seven by seven grid with horizontal separations of about 10 km (Figure 37). Vertically, there are 15 drifters initialized at each grid point with maximum depths just over 40 m. The drifter initial positions are denser near the surface, replicating vertical egg distribution data collected in the Bering Sea (Kendall et al. 1994). Drifters are released on April 1 of each year and are tracked for 90 days.

Endpoints after 90 days for drifter trajectories from the 1998-2003 runs are shown in Figure 38 (this plot shows all drifters at all depths). In all years there is a strong tendency for trajectories to move to the northeast up the Alaskan peninsula. The other common path is movement to the northwest along the 100-m isobath. The split between these two paths is seen clearly in the 1998, 1999, 2001 and 2003 drifter endpoints. The full trajectory plots (not shown here) show that the endpoints in 2000 are the result of a strong turning to the northwest of trajectories that had been moving up the Alaskan peninsula. In 2002 the drifters initialized at deeper points follow the common paths along the peninsula and the 100-m isobath. But drifters nearer the surface seem influenced by local winds and first move to the northeast, then turn to the northwest, resulting in endpoints spread evenly across the entire shelf. Further study of possible forcing mechanisms is needed to understand what leads to these years departing from the archetypal two-limbed flow.

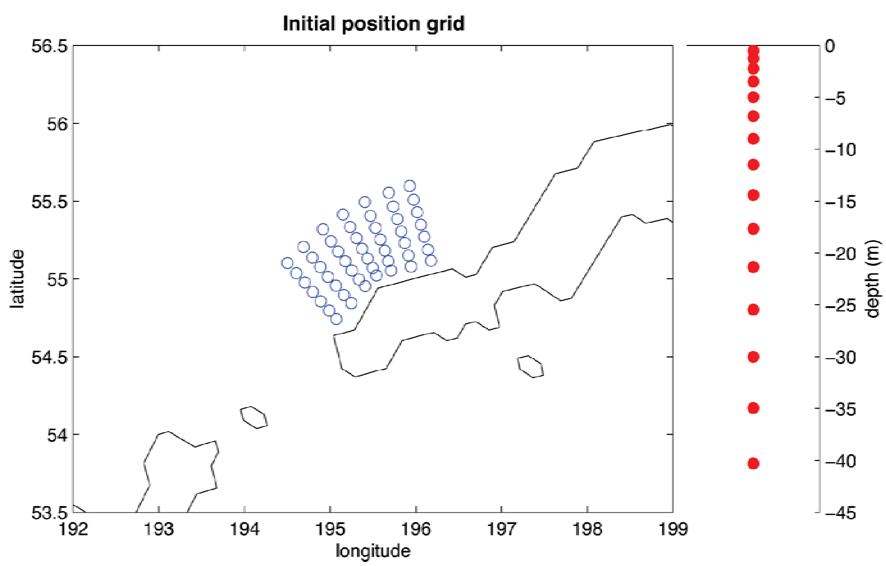


Figure 37. Simulated drifter initial horizontal (left) and vertical (right) positions.

The initial goal of this work was to compare simulated trajectories from a full primitive equation model with those from the Ocean Surface Current Simulations (OSCURS) numerical model. OSCURS computes daily surface current fields using daily sea level pressure and long-term mean geostrophic current data. As such, it is a simpler model in terms of the physics involved but is much more computationally inexpensive. Wespestad et. al. (2000) used OSCURS to create simulated trajectories in the Bering Sea. The initial grid used here was centered on the initial release point they used. Our trajectories for drifters released near the surface (0 to 5 m depth) show good agreement with the OSCURS results. But our results show variation of trajectory endpoints with changes in both horizontal and vertical initial position. Figure 39 shows the full trajectories for the 2001 simulated drifters. The upper left panel shows the tracks of all the drifters released, while the upper right and the bottom panels show drifter tracks as a function of their release depth. Within each depth bin it is evident that there is a large dependence of drifter endpoints on initial vertical placement with each bin showing, to relative degrees, the two-limbed split flow.

There is also a strong dependence on release depth. The OSCURS 2001 trajectory (not presented here) moves a short distance to the northeast up the Alaskan peninsula as do the majority of the NEPROMS drifters released in the upper 5 m of the water column (upper right panel of Figure 39). But with deeper release points comes a stronger divergence of the trajectory fates. In the 5-20 m and 20-40 m release bins there are significant numbers of drifters that join the 100-m isobath flow to the northwest, with some even moving through Unimak Pass before turning back. OSCURS results would completely miss this variation in particle fates.

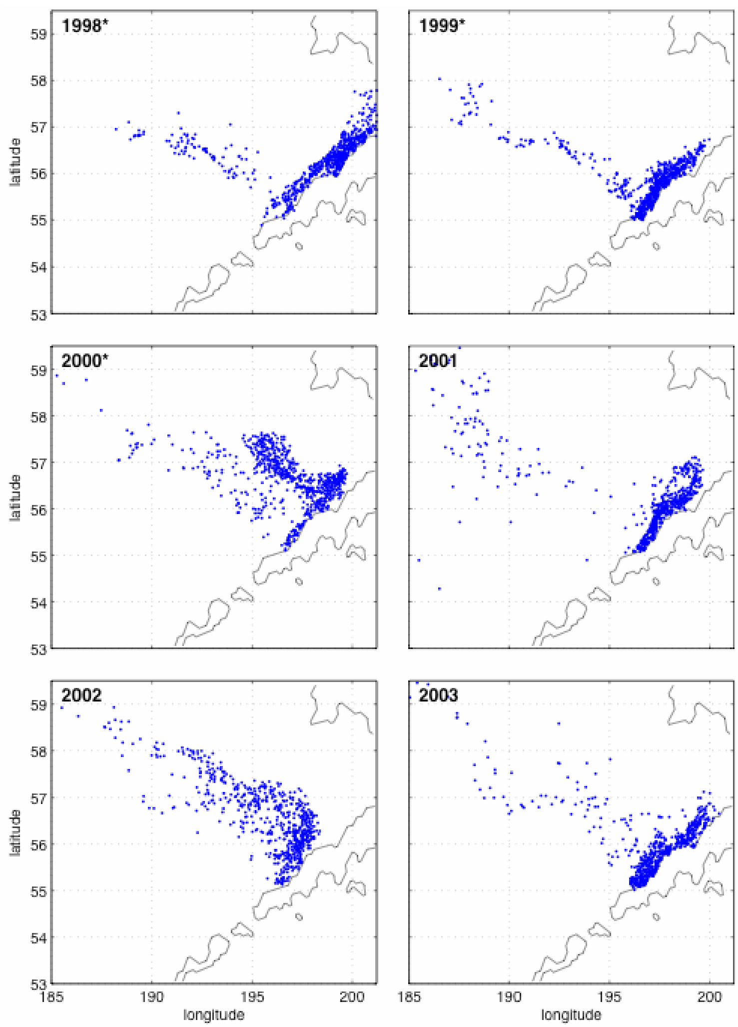


Figure 38. Endpoints for 90-day drifter trajectories for 1998-2003.

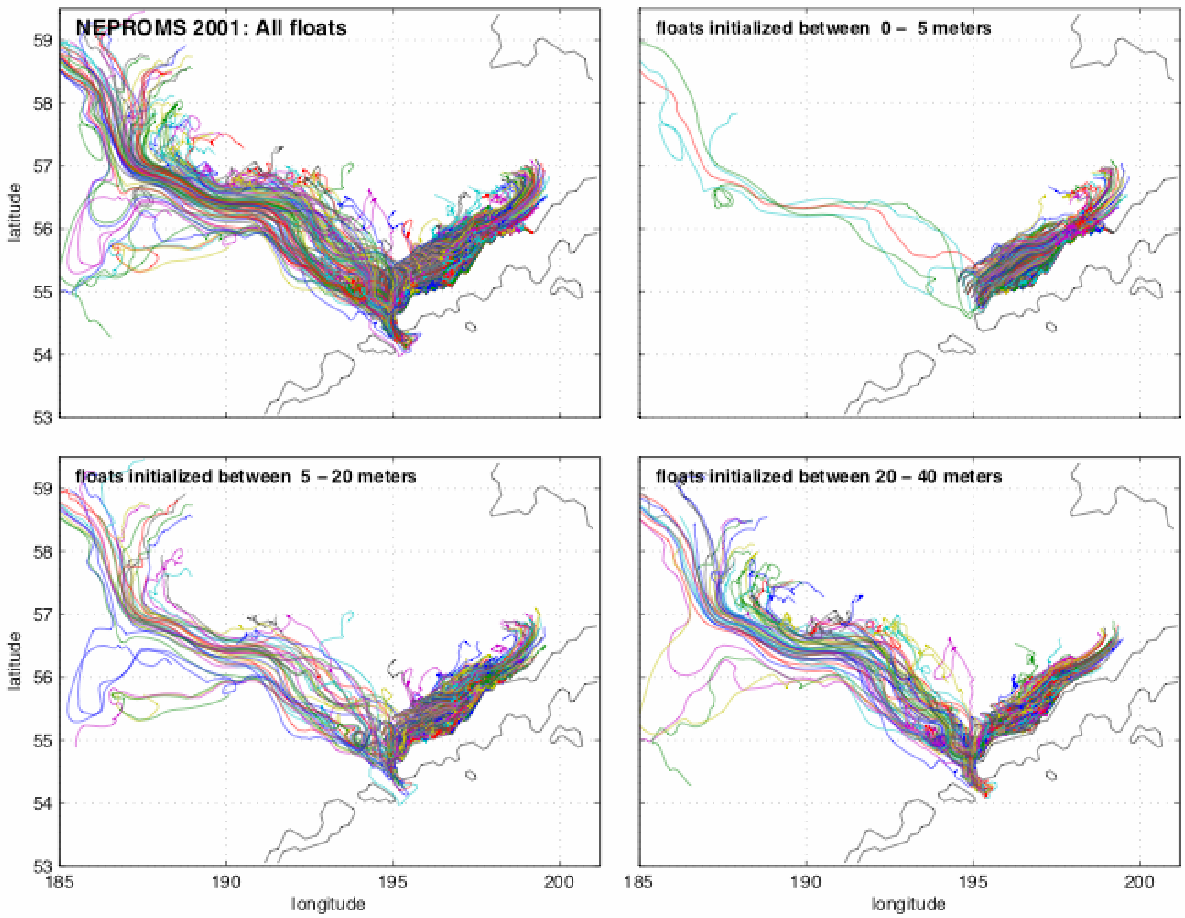


Figure 39. Full trajectories for the 2001 90-day simulated drifters. Upper left panel shows all drifters, while the upper left and bottom panels show drifters divided as a function of initial release depth.

Summer bottom and surface temperatures – Eastern Bering Sea
Contributed by Gary Walters, Alaska Fisheries Science Center

The annual AFSC bottom trawl survey for 2004 was started on June 5 and finished on July 25. For the first time in several years there was some ice cover in the southeast Bering Sea during the winter. However it came late, and left early, which is reflected in the small change in temperatures from 2003. The average bottom temperature was 3.39 ^{o}C, well above the 1982-2003 mean of 2.54 ^{o}C (Figure 40). Slight decreases in bottom temperature from those recorded in 2003, however, were evident in almost all major areas of the standard survey. Bottom temperature anomalies from the long term station means were positive over virtually the entire shelf (Figure 41). Maximum anomalies occurred in the inner and middle domain with several stations over +2 degrees Celsius. The 'Cold Pool', usually defined as an area with temperatures less than 2 degrees Celsius, surrounded St. Matthew Island and extended south to about 58^{o} N.

The average surface temperature, 8.29 ^{o}C, was actually higher than in 2003 (long term mean 6.66 ^{o}C). Surface temperature anomalies reflected the increases seen in 2004. Almost a third of the stations had temperatures over 2 ^{o}C above station long term means (Figure 41). The largest differences were in the inner and middle domains.

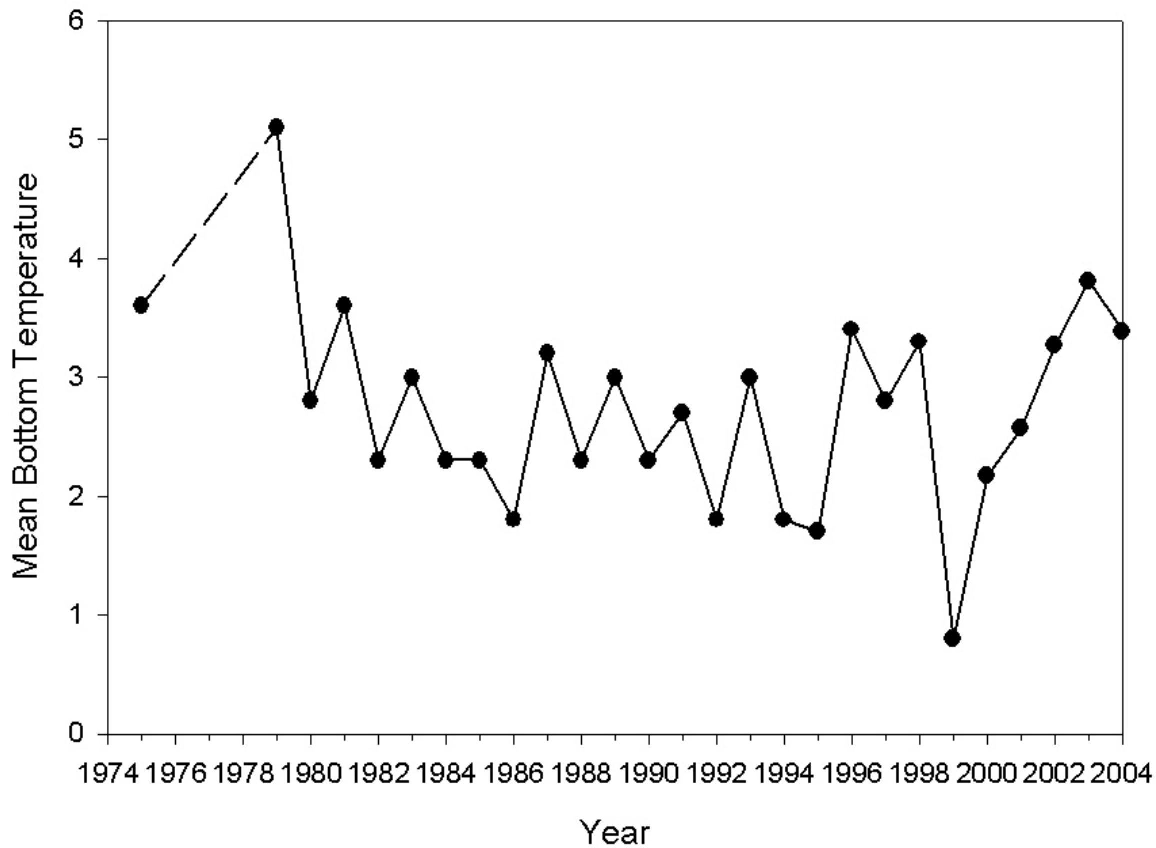
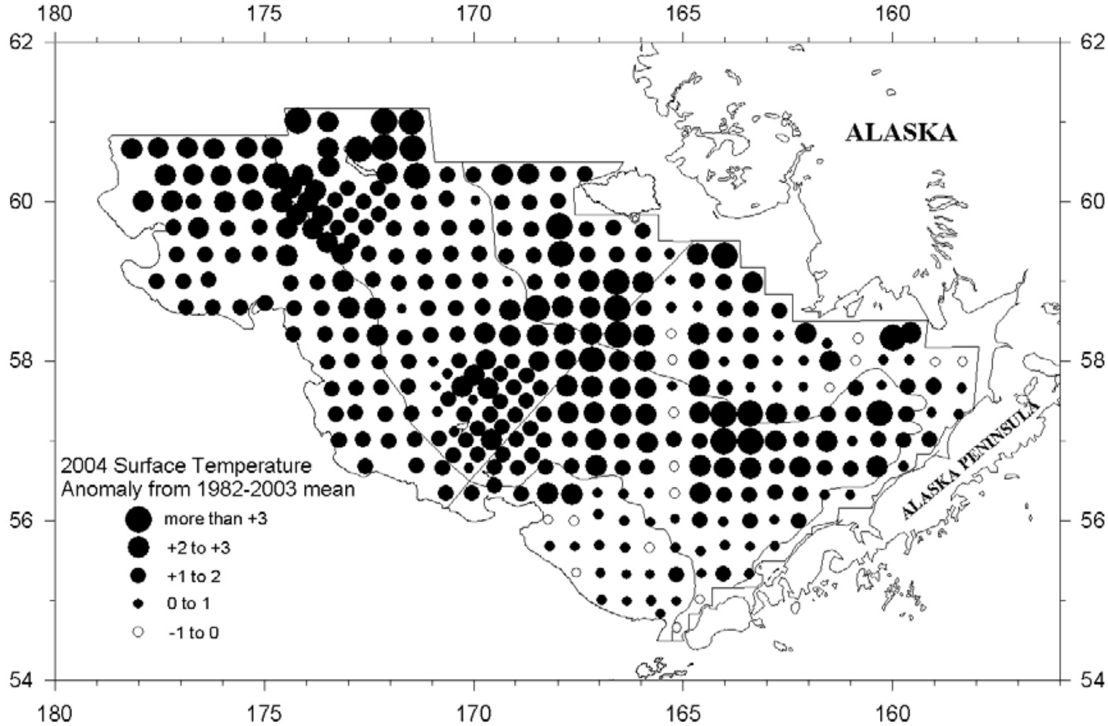


Figure 40. Mean summer bottom temperature (^{o}C) in the standard bottom trawl survey area of the eastern Bering Sea Shelf, 1975-2004.



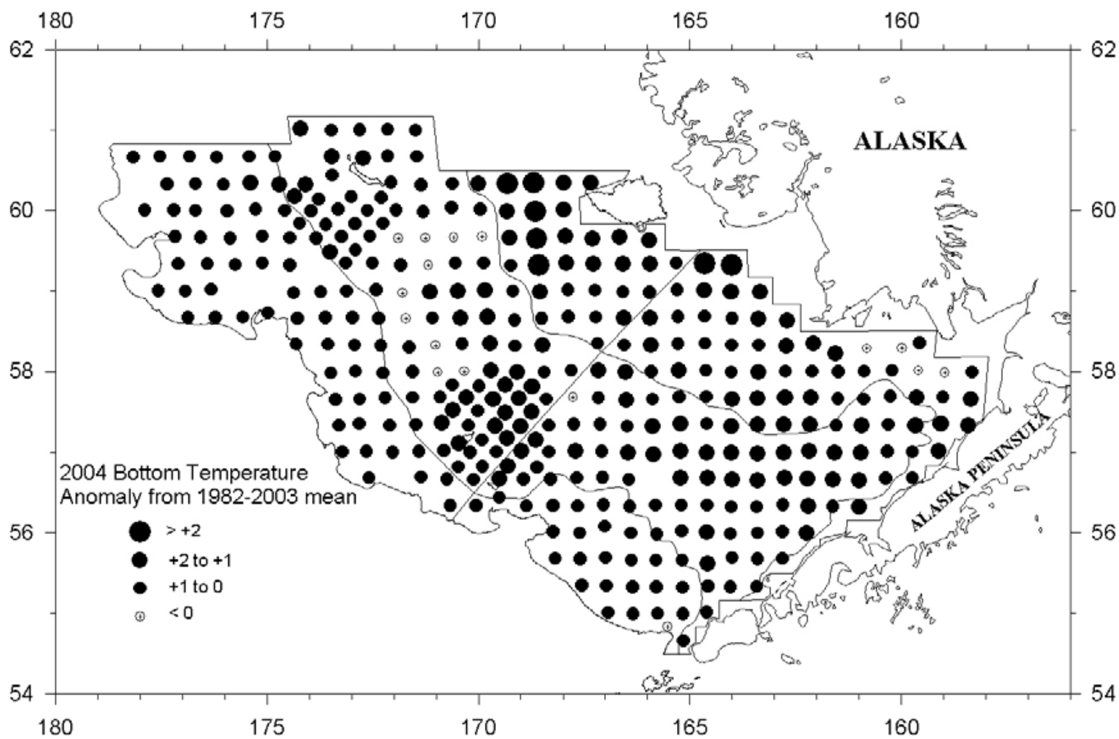


Figure 41. Summer bottom (bottom panel) and surface (top panel) temperature anomalies in 2004 from the 1982-2003 means at standard bottom trawl survey stations in the eastern Bering Sea.

ALEUTIAN ISLANDS

Water temperature data collections – Aleutian Islands Trawl Surveys
Contributed by Harold Zenger, Alaska Fisheries Science Center

A Brief Description of Water Flow in the Aleutian Islands

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

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

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

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

Implications for Groundfish Reproduction and Recruitment

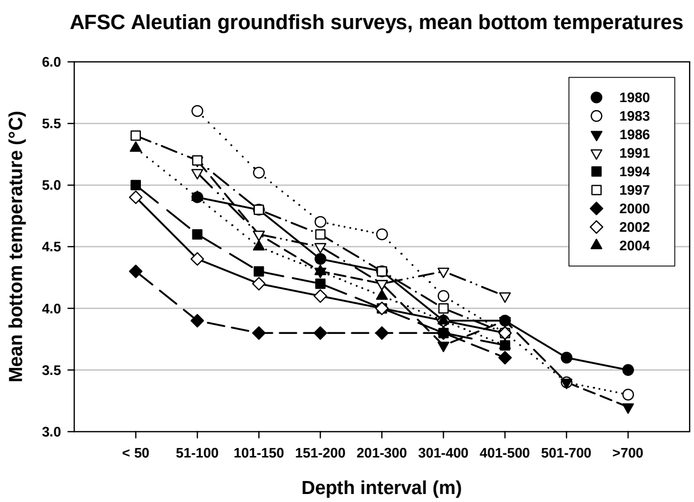
Although representing a relatively small volume of water, eddies that re-circulate water over or near the shelf might be important to concentrate primary production. They may also contribute to successful reproduction and recruitment of the major Aleutian semi-pelagic species such as Atka mackerel, Pacific Ocean perch, northern rockfish, and walleye pollock. For example

Seguam Pass is a known area of Atka mackerel spawning off Seguam and Amlia Islands and at probable locations on offshore rock outcrops south of Seguam Island (personal video observations of typical male nest guarding behavior). The implications of clockwise movement of water flowing past spawning grounds and then westward over the southern shelf, or within the northern margin of the Alaskan Stream, to ultimately deposit post-larval or young-of-the-year fish in favorable feeding and protective habitat should be investigated.

Trawl Survey Temperature Profiles – What They Can Show

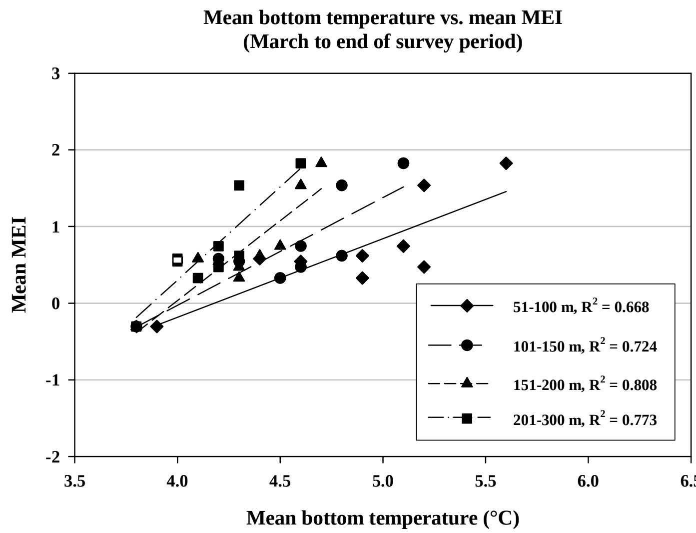
Stabeno *et al*. (1999) report on two vertical sections of temperatures across Amukta Pass between Amukta I. and Seguam I. collected in August. The 1994 data reflect a vertically mixed temperature distribution during a period of strong south to north flow through the pass. Relatively warm Alaskan Stream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

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



Wolter and Timlin (1993, 1998) produced a multivariate El Niño/Southern Oscillation (ENSO) index (MEI) that is presented graphically and regularly updated at the following website: Klaus Wolter (kew@cdc.noaa.gov). Comments on the timing of ENSO events cited herein reference that graph. The year 2000 produced the coldest bottom temperatures yet detected during summer AFSC groundfish surveys (Figure 42). The warmest years tend to be associated with El Niño events. The three coldest years thus far detected (1994, 2000, and 2002) have occurred within the last eight years, with one of the warmest (1997) occurring in their midst (Figure 42). Those colder years were associated with La

Niña events (2000 and 2002) or a strongly decreasing El Niño event (1994). The warm 1997 temperatures were associated with a very strong El Niño event. Generally mean temperatures at depth intervals shallower than 300m vary more than those deeper than 300m. Perhaps the year 2000 temperatures are not as anomalous as they appear, but many individual fish weighed and measured during the survey were notably lighter than during other surveys. Unfortunately, we have no data to compare for the intervening years. The 2004 data fall in the middle of the year-specific bottom temperatures and correspond to a moderate, increasing MEI.



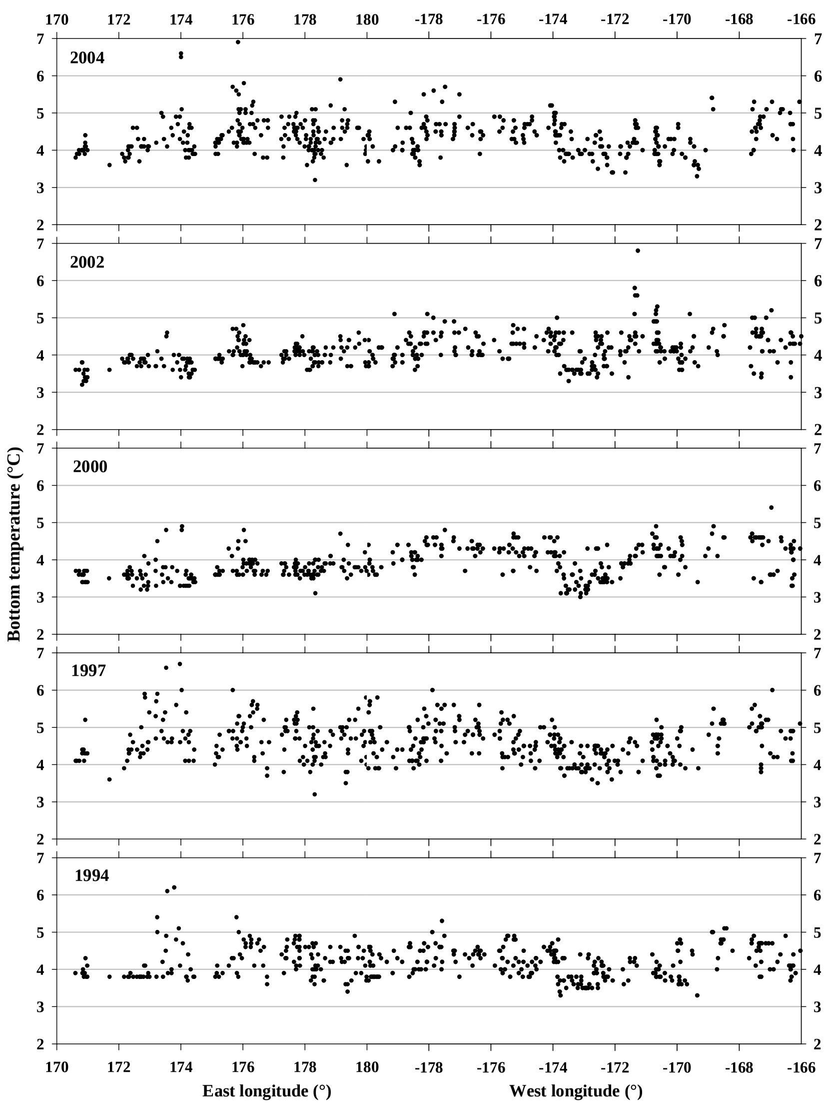
ENSO events are monitored using the Multivariate ENSO Index (MEI) which is based on six observed variables over the tropical Pacific: sea-level pressure (P), zonal (U) and meridional (V) components of the surface wind, sea surface temperature (S), surface air temperature (A), and total cloudiness fraction of the sky (C). Given the apparent correlation between the within-year MEI trends and summer mean bottom temperatures in the Aleutian archipelago, further investigation seems promising. If a correlation exists between the MEI and oceanographic events controlling Aleutian survey bottom temperatures, it might be demonstrated graphically as a linear relationship between mean MEI for the period from slightly before the start to the end of the groundfish survey period. Low MEI should correspond to low bottom temperatures and high mean MEI should correspond to higher bottom temperatures. Mean MEIs for the period from March to the end of each survey period were plotted against mean bottom temperature for four depth intervals (Figure 43). March was used as a starting point because most of the ENSO events began in spring or early summer (Hollowed *et al*. 2001). Correlation coefficients are included for each trend line and range from 0.67 and 0.81 suggesting that mean MEI and bottom temperatures to a depth of 300 m are somehow related (Figure 43). The weakest correlation is in the shallowest depth interval, where one might expect to find the most influence of seasonally warmed surface water and storm-caused mixing. Such short term, within-year effects are likely the result of atmospheric forcing and the position and strength of the Aleutian low-pressure phenomenon (Hollowed *et al*. 2001).

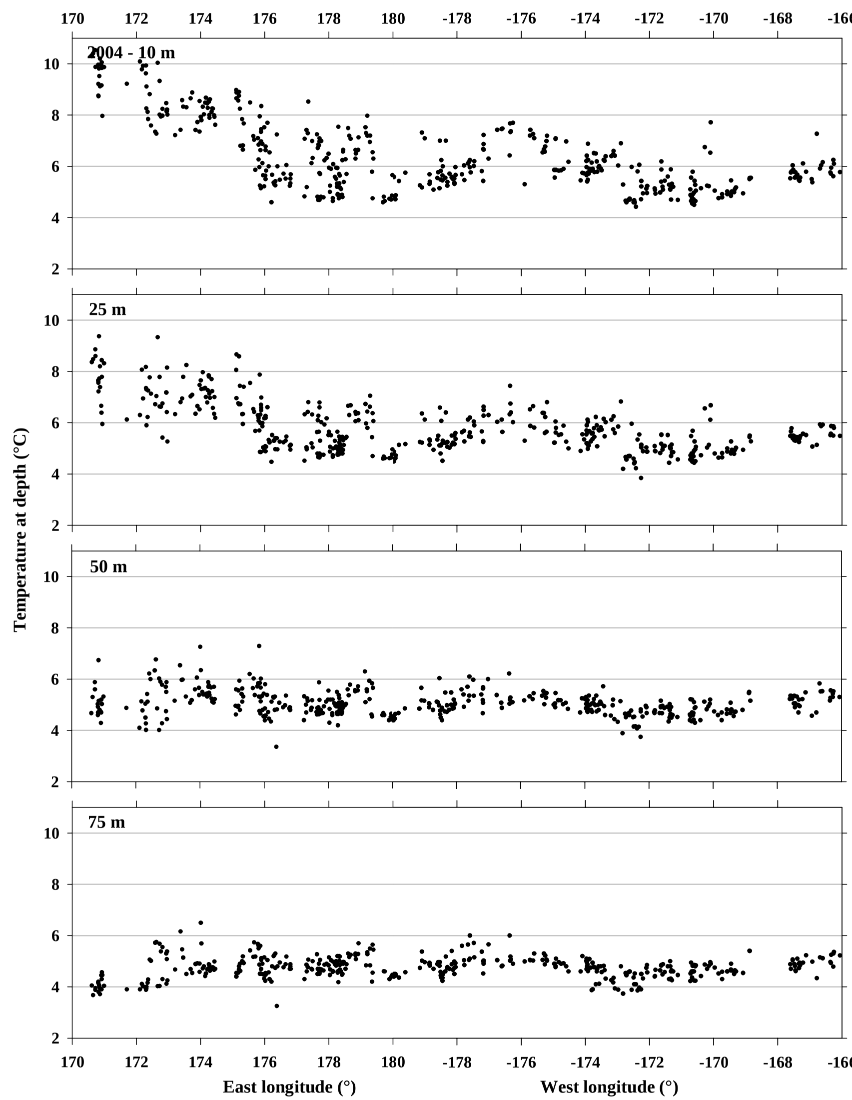
Water Temperatures Across the Survey Area

Figure 44 summarizes station-specific bottom temperature distributions by longitude for the 1994, 1997, 2000, 2002, and 2004 Aleutian Islands bottom trawl surveys. Several features appear to reoccur and warrant further comment along with some exceptions. Relatively warm bottom temperatures appear between 173°E and 176°E longitudes probably resulting from Alaskan Stream water washing over Tahoma Bank and Walls Plateau. Relatively cold temperatures found between 172°W and 174°W longitudes were probably the result of Bering Sea water flowing along the northern slope and onto the lower shelf. While the mean temperatures for 1997 were warmer than all survey years except 1983, the spread of temperatures was generally broader than other post-1991 surveys. The warm temperatures noted near the western end of the survey area were not as evident during the 2002 survey. This may have resulted from earlier than usual sampling in that area. The warm temperatures detected between about 170°W and 172°W longitudes in 2002 were probably caused by seasonal warming and may have resulted from much later than usual sampling in that area.

Figure 45 shows 2004 survey water temperatures at 12 depths from near surface to near bottom, by longitude. There were areas of warm near-surface water between approximately 170°E to 176°E and 175°W to 177°W longitudes. Generally, 2004 summer water column temperatures shallower than 200 m were somewhat warmer than in 2002. Below 200 m, temperatures were similar in both years.

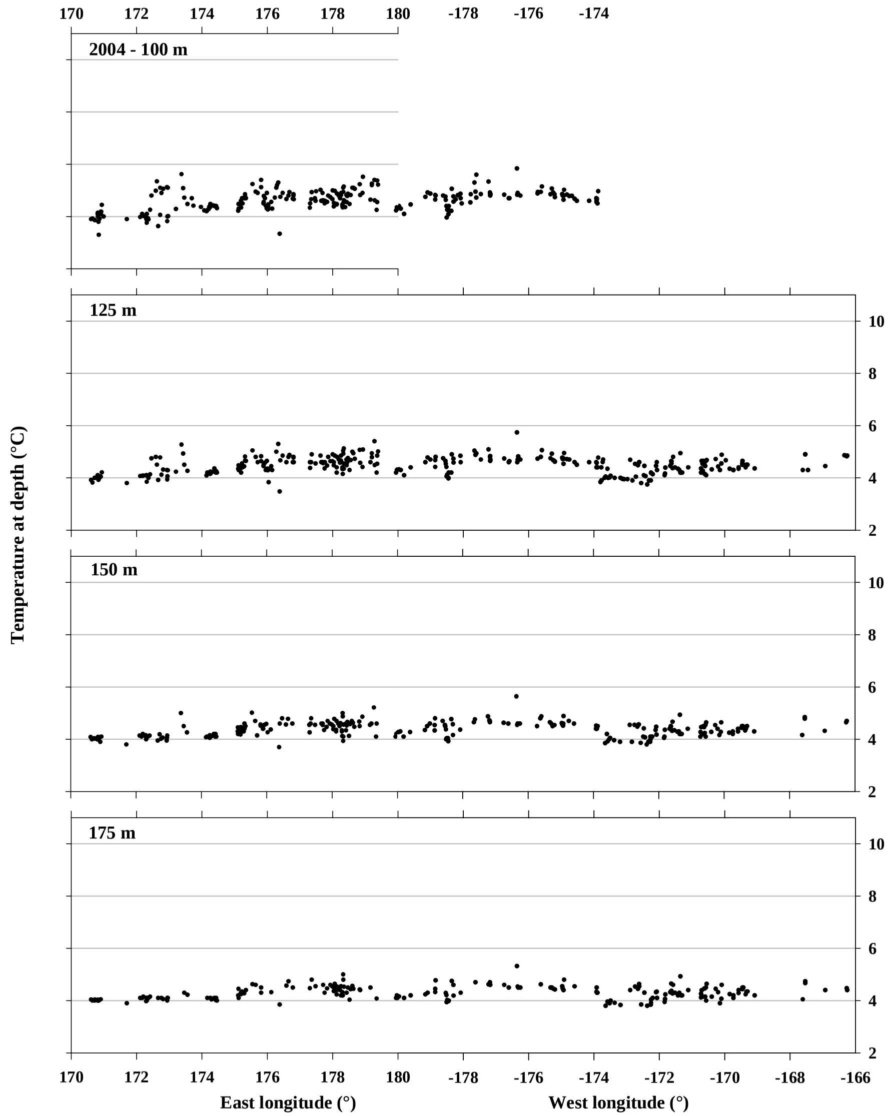
Judging by past survey results, the elevated late summer, near-surface temperatures at the western end of the survey area appear to be more the rule than the exception. In 2002 sampling occurred earlier than usual and that might have contributed to the low temperatures in 25 m or shallower noted in last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



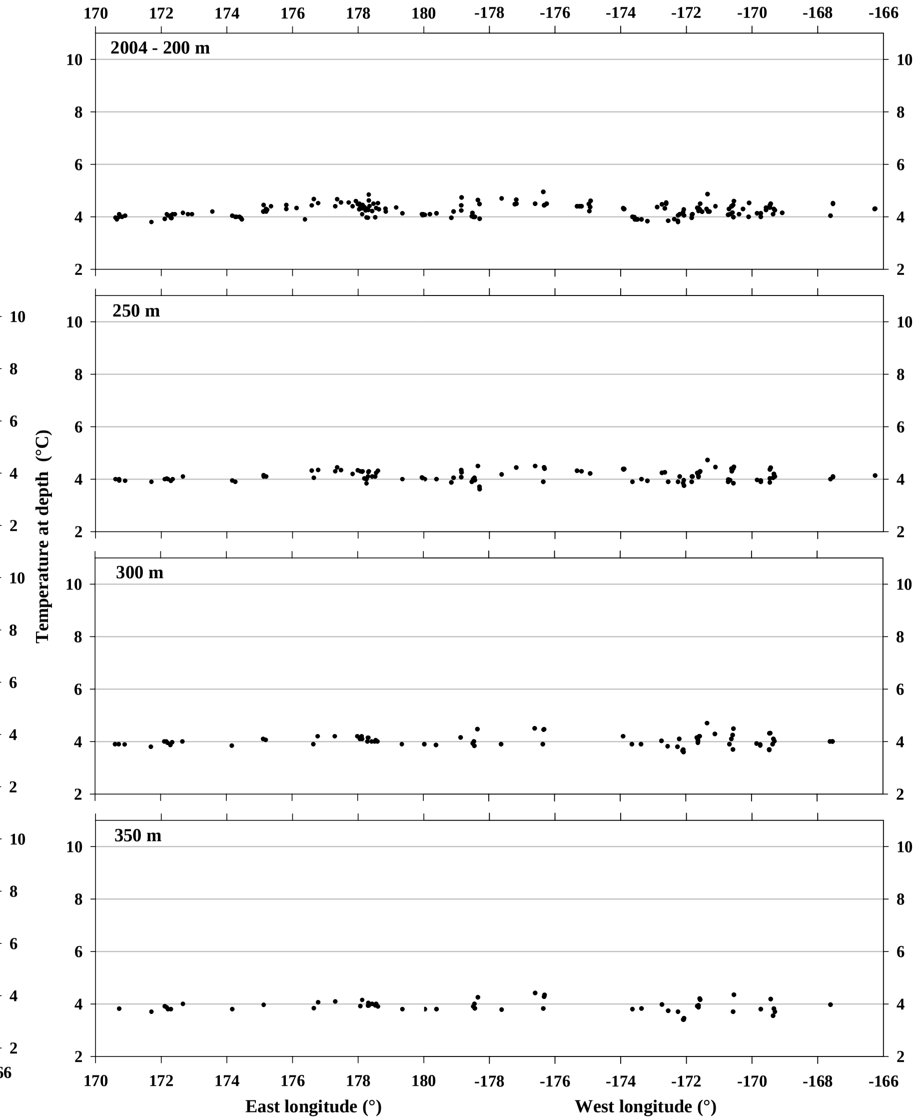


Aleutian Islands

bottom trawl survey.



2004 - 100 m
125 m
150 m
175 m
Temperature at depth (°C)
East longitude (°)
West longitude (°)



2004 - 200 m
250 m
300 m
350 m
Temperature at depth (°C)
East longitude (°)
West longitude (°)

Habitat

HAPC Biota – Gulf of Alaska

Contributed by Eric Brown

This is the first look at biomass index trends of HAPC biota (seapens/whips, coral, sponges, and anemones) from the RACE bottom trawl survey in the Gulf of Alaska. This survey is not designed to assess these organisms and in most cases may represent an inappropriate tool for tracking abundance levels. Further detailed examinations of these results are needed to assess whether there are meaningful trends.

In 2003, the catches of HAPC organisms per unit area were similar or less than those in 2001 (Figure 46). Several of the groups representing the HAPC biota exhibited large apparent changes in abundance but rather than being a result of comparable catches over a broad area, the estimates were driven by only one or two atypical catches resulting in highly variable estimates with correspondingly large confidence intervals. Examples of this are the sea pens, which are infrequent and small components of Gulf trawl survey catches. The apparent increase in abundance in the western Gulf of Alaska during the 2001 survey was primarily driven by only two catches totaling less than 7 kg each. Variability in seapen CPUE may be due, in part, to their patchy distribution; also the catchability of seapens is unknown. Seapens may require habitat with higher flow and very fine sand. Similarly, the high apparent abundance of soft coral in the western Gulf of Alaska during the 1984 survey was due to a single large catch far exceeding observed catches in subsequent surveys. Also, the large increase of Gorgonians (primarily the red tree coral) seen in the eastern Gulf of Alaska during the 1999 survey, was mainly due to several unusually large catches of 482 kg and 187 kg. The stony coral group also exhibit highly variable abundance estimates (Figure 46).

Perhaps the most likely groups for providing useful information are the sea anemones and sponges that commonly appear in survey catches, especially in the western Gulf. However, it should be emphasized that the survey trawl equipped with rubber bobbin roller gear is not well suited for sampling these types of sessile organisms. Variability in sea anemone CPUE may be due, in part, to their patchy distribution (preference for rocky areas) and low catchability.

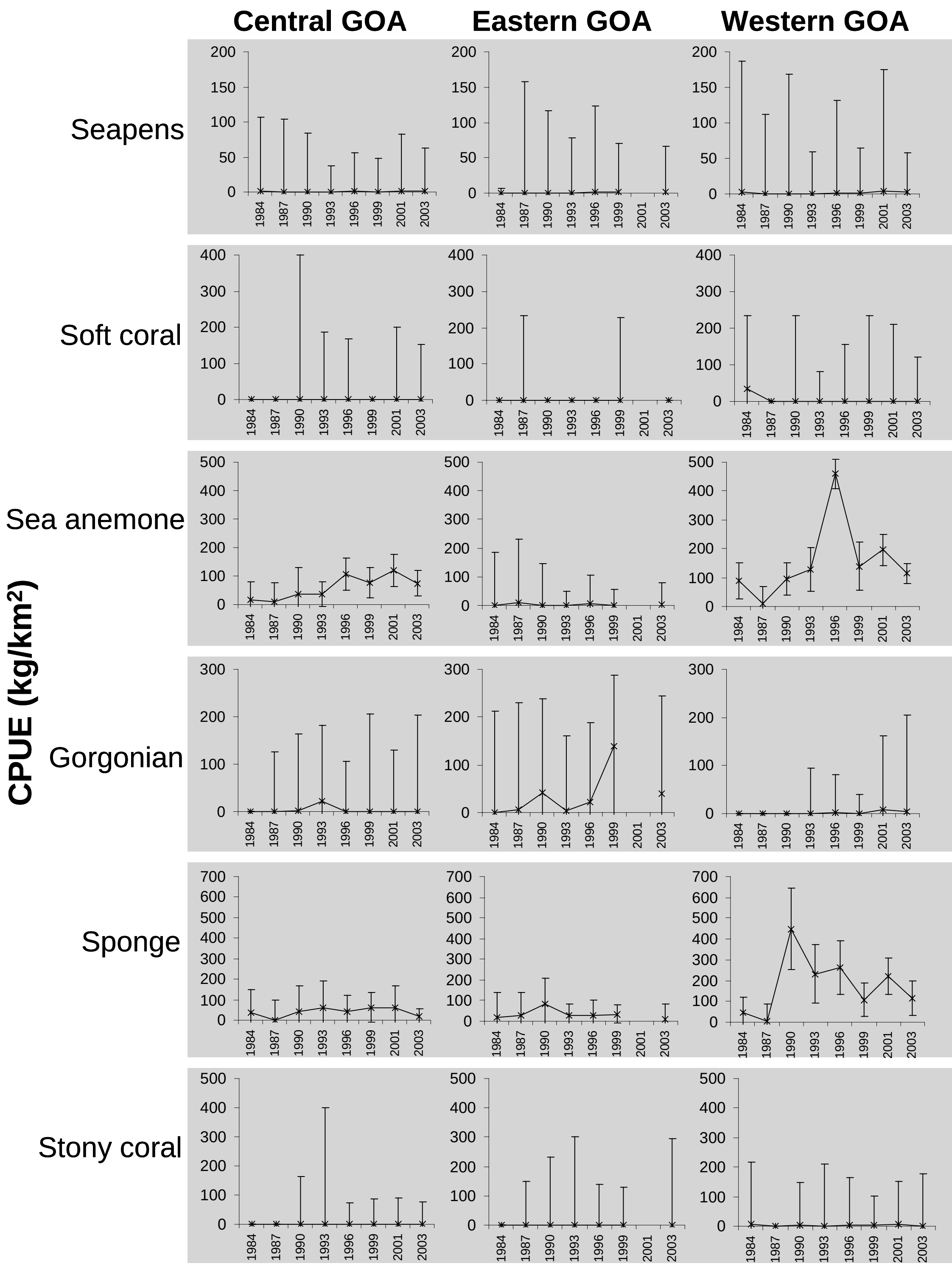


Figure 46. Catch of HAPC organisms per unit area in the central, eastern, and western GOA, in bottom trawl surveys conducted between 1984 and 2003. 95% confidence intervals are shown.

HAPC Biota – Bering Sea
Contributed by Gary Walters, Alaska Fisheries Science Center

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. RACE bottom trawl survey results from 1982 to 2004 show trends in the CPUE of HAPC groups on the Bering Sea shelf, although variability in CPUE is relative large (Figure 47). Seapens/whips trends show the possibility of three peaks in abundance: in the late 1980's, late 1990's, and in 2003 and 2004 (the highest catches in the time series). Anemone CPUE appeared to be higher in the 1980's than in the 1990's, although there are large fluctuations in anemone CPUE estimates from year to year. The sponge CPUE appeared to increase from 1991 to 2000, and then decreased to the present. Further research on the life history characteristics of these organisms is needed to interpret these trends.

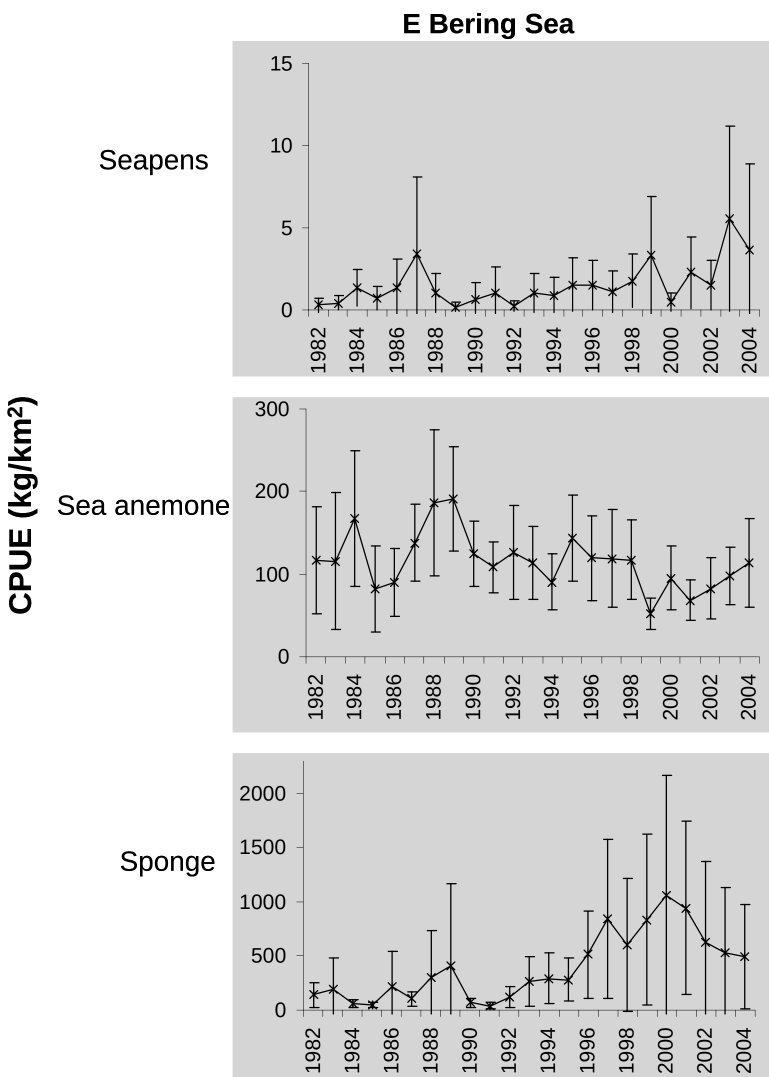


Figure 47. CPUE trends of HAPC biota from the RACE bottom trawl survey of the Bering Sea shelf, 1982-2004. 95% confidence intervals are shown.

HAPC Biota – Aleutian Islands

Contributed by Eric Brown, Alaska Fisheries Science Center

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

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

The 2004 survey results showed a slight decrease in sponge and sea pen abundance in all areas except the southern Bering Sea, which showed a modest gain. The abundance of stony corals decreased in all areas; whereas, catches of soft corals and Gorgonians were variable among areas.

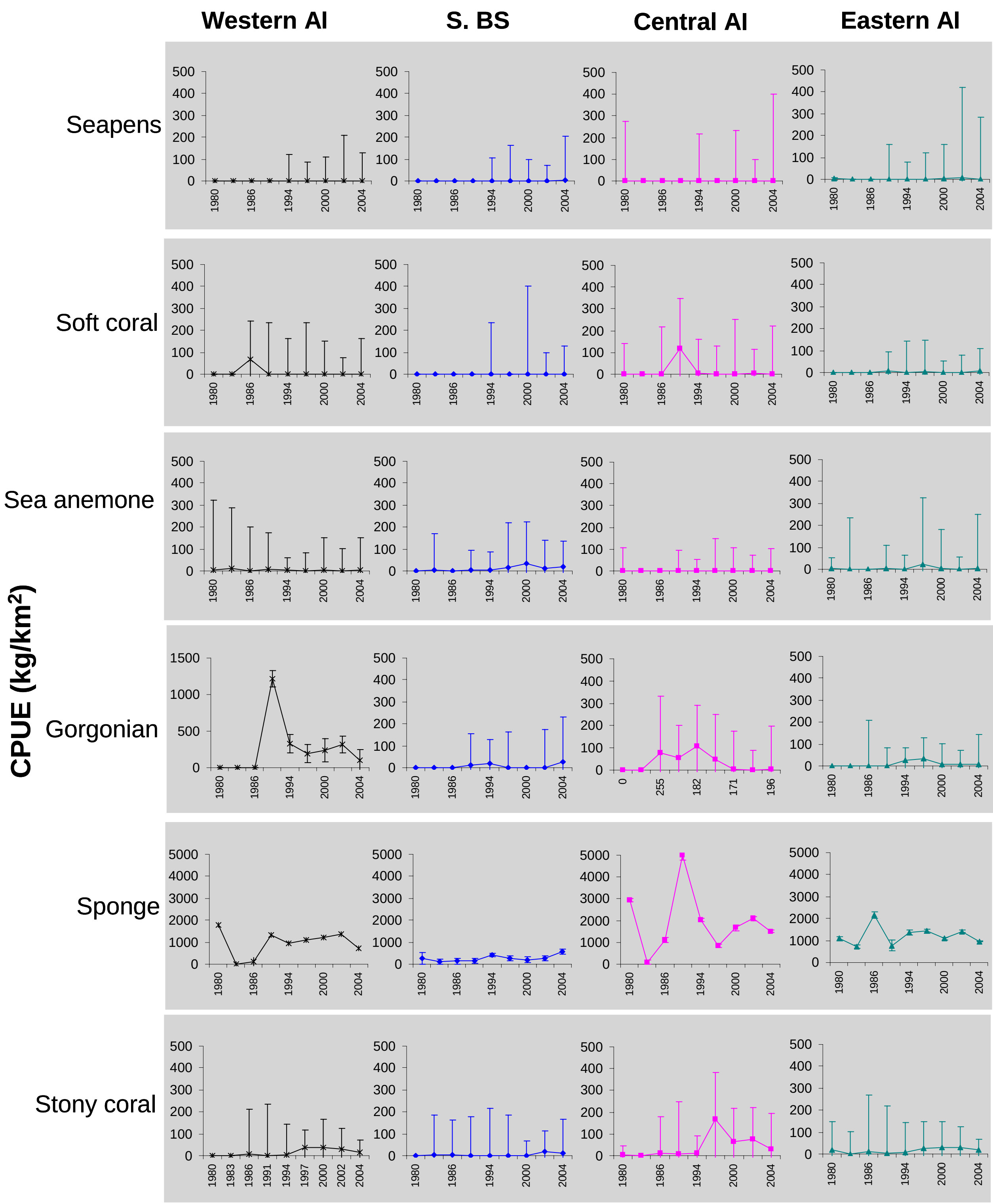


Figure 48. Catch of HAPC organisms per unit area in the western Aleutian Islands (AI), south Bering Sea (BS), central AI, and eastern AI, in bottom trawl surveys conducted between 1980 and 2004. 95% confidence intervals are shown.

Habitat Research

The Magnuson-Stevens Fishery Conservation and Management Act includes provisions requiring fishery management plans to identify and describe essential fish habitat (EFH), minimize adverse effects of fishing and encourage conservation. EFH is defined as "those waters and substrates necessary to fish for spawning, breeding, feeding, or growth to maturity." There are a variety of studies that are currently gathering basic information needed to identify and describe EFH (Table 7). Some of those studies are summarized in the next two sections: (1) Essential Fish Habitat Research by AFSC, and (2) Effects of Fishing Gear on Seafloor Habitat – Progress Report for FY2004

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

RESEARCH	SCIENTISTS	CONTACT INFO.
ABL - Habitat Investigations Program		
Hydrocarbon and habitat baseline measurement in Berners Bay, Alaska	Mandy Lindeberg, Intertidal Ecology	Tel: 907 789-6616, E-mail: mandy.lindeberg@noaa.gov
Eelgrass as EFH habitat for marine species	Scott Johnson, Task Leader, Nearshore Ecology and John Thedinga	Scott Johnson: Tel: 907 789-6063, E-mail:scott.johnson@noaa.gov; John Thedinga: Tel: 907 789-6025, E-mail: john.thedinga@noaa.gov
Mapping of eelgrass habitat in southeast Alaska	"	"
Seasonal abundance of Steller sea lion prey in nearshore habitats	"	"
Monitoring changes in eelgrass habitat in Juneau Alaska (EFH Funding FY 04)	Pat Harris, Aquatic Plants	Tel: 907 789-6022, E-mail: pat.harris@noaa.gov
Hydrocarbon and habitat baseline measurement in Berners Bay, Alaska	"	"
Juneau anadromous salmon habitat and wetland restoration	Dr. K Koski, EFH and Habitat Coordinator, Habitat Restoration	Tel: 907 789-6024, E-mail: k.koski@noaa.gov
Nearshore marine habitat mapping (EFH Funding FY 04)	"	"
Index of Eulachon spawning abundance	"	"
ABL, Juneau -Groundfish Program		
A model for evaluating fishery impacts on habitat	Dr. Jeff Fujioka, Effects of Fishing	Tel: 907 789-6026, E-mail: jeff.fujioka@noaa.gov
Availability of pre-spawning eulachon to Steller sea lions	Dr. Mike Sigler, Sea Lion Prey/Predation, HAPC review	Tel: 907 789-6037, E-mail: mike.sigler@noaa.gov
Effects of fishing on seafloor habitat	Dr. Jon Heifetz, Effects of Fishing	Tel: 907 789-6054, E-mail: jon.heifetz@noaa.gov
Deep sea coral distribution and habitat in the Aleutians	Dr. Jon Heifetz (ABL), Jennifer Reynolds (UAF), Doug Woodby (ADFG), Bob Stone (ABL)	"
Mapping of habitat features of major fishing grounds	Dr. Jon Heifetz, Dean Courtney, Kalei Shotwell	"
Exploration of coral and sponge habitat in the Aleutian Islands	Robert Stone, Effects of Fishing	Tel: 907 789-6031, E-mail: bob.stone@noaa.gov
Effects of bottom trawling on soft-sediment benthic communities in the Gulf of Alaska	"	"
Effects of experimental bottom trawling on soft-sediment sea whip habitat in the Gulf of Alaska	"	"
Growth and recruitment of an Alaskan shallow-water gorgonian coral	"	"
Age validation and growth of three species of Pennatulaceans (sea whips/pens)	"	"
Biology and taxonomy of cold-water corals	"	"

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

RESEARCH	SCIENTISTS	CONTACT INFO.
Sea whip (order Pennatulacea) resiliency to simulated trawl disturbance	Patrick Malecha, Effects of Fishing	Tel: 907 723-4457, E-Mail: pat.malecha@noaa.gov
Living substrates in Alaska: distribution, abundance, and species associations	"	"
Effects of trawling on deep hard-bottom substrate	Lincoln Freese, Jon Heifetz, Bruce Wing	Tel: 907 789-6045, E-mail: linc.freese@noaa.gov
Identification of habitat areas of particular concern	Lincoln Freese	"
Estuarine and wetland habitat surveys and fish utilization	Mitch Lorenz, Estuarine and Wetland Habitats	Tel: 907 789-6035, E-mail: mitch.lorenz@noaa.gov
Nearshore habitat mapping (EFH Funding FY04)	"	"
Resource Assessment and Conservation Engineering Division (RACE), Seattle		
Characterize potential skate nursery habitat in the southeastern Bering Sea (EFH Funding FY 04)	Gerald R. Hoff (Jerry)	Tel: 206 526-4580, E-mail:jerry.hoff@noaa.gov
Atka mackerel reproductive biology and nesting habitat (EFH Funding FY 04)	Bob Lauth, S. McDermott, UAF, and Alaska Sea Life Center)	Tel: 206 526-4121, E-mail: Bob.Lauth@noaa.gov
Sponge ecology	Dr. Chris Rooper	Tel: 206 526-4689, E-Mail: Chris.Rooper@noaa.gov
Modeling flathead sole habitat in the eastern Bering Sea	Dr. Chris Rooper, M. Zimmermann	"
Determining the value of habitat to juvenile rockfish in the Aleutian Islands (SPARE project; EFH Funding FY04)	"	"
Physical and biological effects in soft-bottom areas of EBS (TRAWLEX project)	Dr. Bob McConnaughey, with UNH, and UAF	Tel: 206 526-4150, E-mail: Bob.McConnaughey@noaa.gov
Effects on Bristol Bay RKC populations	Dr. Bob McConnaughey, B. Dew	"
Develop a systematic framework for experimental studies	Dr. Bob McConnaughey, C. Yeung	"; C. Yeung: Tel: 206 526-6530, E-mail: Cynthia.Yeung@noaa.gov
Acoustic seabed mapping and groundfish habitat characterization	"	"; "
Spatial and temporal patterns in Bering Sea invertebrate assemblages	"	"; "
Development and testing of long-range fisheries research sonar (FISHPAC project)	", UNH, NMAO, and NOS	"
Seabed classification with single beam echosounders and QTC software	Dr. Bob McConnaughey, S. Syrjala, and Quester Tangent Corporation	"
Reconnaissance mapping with side scan sonar	Dr. Bob McConnaughey with UNH	"
Ecology of mud volcanoes (nascent study)	Dr. Bob McConnaughey	"
Basic statistical research related to mobile fishing gear effects and EFH characterizations (Robust sample size estimation & Optimized data clustering)	Dr. Steve Syrjala, Effects of Fishing	Tel: 206 526-4135, E-mail: Steve.Syrjala@noaa.gov

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

RESEARCH	SCIENTISTS	CONTACT INFO.
Guidelines for multiple statistical testing	Dr. Steve Syrjala, Effects of Fishing	Tel: 206 526-4135, E-mail: Steve.Syrjala@noaa.gov
Acoustic seabed mapping and groundfish habitat characterization	"	"
Develop literature database of life history and ecology	Keith Smith, Bering Sea invertebrates	Tel: 206 526-4141, E-Mail: Keith.Smith@noaa.gov
Resolve inconsistent taxonomic IDs in trawl survey database (RACEBASE)	"	"
Recovery rates of long-lived invertebrates at hard-bottomed sites near Bogoslof Island (with UAF)(EFH Funding FY 04)	Mark Zimmermann, Effects of Fishing	Tel: 206 526-4119, E-mail: Mark.Zimmermann@nooa.gov
A model for evaluating fishery impacts on habitat	Dr. Craig Rose, Jeff Fujioka	Craig Rose: Tel: 206 526-4128, E-mail: Craig.Rose@noaa.gov; Jeff Fujioka: Tel: 907 789-6026, E-mail: jeff.fujioka@noaa.gov
Evaluation of footrope modifications (EFH Funding FY04)	Dr. Craig Rose	"
<u>Kodiak Laboratory, Kodiak, Alaska</u>		
Crab biology	Brad Stevens, Crab Investigations	Tel: 907 481-1726, E-mail: Bradley.G.Stevens@noaa.gov
<u>Hatfield Marine Science Center, Newport, Oregon</u>		
Experimental and descriptive studies of low-relief benthic habitats as essential fish habitat for juvenile flatfishes	Dr. Allan Stoner, Fish Behavioral Ecology, Habitat-Related Ecology, Experimental Behavior and Ecology	Tel: 541 867-0165, E-mail: al.stoner@noaa.gov
Experimental and descriptive studies of low-relief benthic habitats as essential fish habitat for juvenile flatfishes.	Clifford Ryer	Tel: 541 867-0267, E-mail: cliff.ryer@noaa.gov

Essential Fish Habitat Research by AFSC

Mapping of nearshore coastal habitats in southeast Alaska using the ShoreZone Inventory method - Principal Investigators: K V. Koski and Mitch Lorenz, Auke Bay Laboratory

Fishery managers need detailed information on quantity, quality, and distribution of EFH habitat in order to determine status of fish stocks, regulate fisheries, monitor habitat changes and to conserve habitats. Alaska's vastness with over 55,000 kilometers (34,375 miles) of tidal shoreline, however, make inventorying nearshore marine EFH with typical ground-based methods nearly impossible. An aerial videography technique, "ShoreZone Inventory" developed by Dr. John Harper, Coastal and Ocean Resources, Inc. was used for mapping the vast remote shorelines in southeast Alaska. A biophysical video inventory of 1755 km of the coastal intertidal and backshore of northern southeast Alaska including 840 km from St. John the Baptist Bay (SJBB) to Nakwasina, 750 km along south shore of Icy Strait/ Cross Sound, and 165 km in Berners Bay including Echo Cove was completed in June 2004 and was the first ShoreZone mapping activity in southeast Alaska. Maps of the nearshore habitat are scheduled to be completed in December 2004 for the Icy Strait/ Cross Sound South Shore segment and the Berners Bay including Echo Cove segment.

The base data used for habitat mapping in ShoreZone is low-tide, aerial video imagery. The shoreline was flown using a helicopter during the lowest tide window of the year (June 3 - June 7, 2004). Approximately 300 km of shoreline are typically imaged in one day and the appropriate low-tide windows are only 5-6 days in duration per month. In addition to aerial mapping, ground verification sampling is conducted to educate mappers to the biota and beach features. The ground-truthing supports interpretation of the aerial imagery. The southeast video imagery is currently posted on the web at www.CoastAlaska.net and will allow one to "fly" the coastline from a computer. When mapping and video interpretation is completed in December, a person will be able to fly the coastline, stop the video at a selected spot, zoom in to examine a feature, overlay biological information, or produce a custom product (e.g., map). The NMFS Alaska Region is tentatively considering hosting the website for the southeast ShoreZone imagery.

ShoreZone has been applied to the entire coasts of Washington and British Columbia. In Alaska, 4,830 km of Cook Inlet and the Kenai Peninsula, including the entire coastlines of Lake Clark and Kenai Fjords National Parks, 950 km of shoreline habitats along the coasts of Katmai and Aniakchak National Parks have been mapped. Eventually all of the Alaska coastline should be mapped with the same methodology in order to create a "seamless" data product that is not prone to bias inherent with different contractors using different mapping techniques. Managers would then be able to use data bases developed the same way for all of Alaska to make meaningful analyses and comparisons for EFH, fish stock assessment and habitat condition throughout the region.

This mapping will support the mandates of the Magnuson-Stevens Fishery Conservation and Management Act requiring Essential Fish Habitat (EFH) be mapped and will assist agencies monitor changes to sensitive habitats. The habitat maps will enable scientists to inventory and assess EFH, monitor environmental change related to natural or anthropogenic impacts, and select sites for conservation and/or more detailed research. A number of stakeholders including government agencies and non-governmental organizations will benefit from this EFH project.

Mapping and Monitoring Eelgrass Beds in the City and Borough of Juneau, Alaska - Principal Investigator: Patricia Harris, Auke Bay Laboratory

Coastal areas within the City and Borough of Juneau, Alaska continue to be under development pressure from shore-based facilities and intertidal projects. In the last three years, permits allowing fill within a few meters of eelgrass beds have been issued for a number of developments including commercial docks, fill and aquaculture. There is little information regarding the extent, biology or importance of these beds as EFH. This project will provide baseline data to the Alaska Regional Office (AKR) NOAA Fisheries and other agencies that must respond to development proposals that would impact eelgrass communities. Changes documented in bed size and biological parameters in or near permitted development will aid future planning decisions. This study will serve a NOAA strategic goal: to protect, restore, and manage the use of coastal and ocean resources by increasing our understanding of ecosystems through mapping and characterization of coastal areas.

In 2004, the first year of this project, we mapped the aerial extent of 14 eelgrass beds and determined plant density, biomass, percent cover, and canopy height in 6 of the 14 beds. Pairs of thermographs were placed in 2 beds where development has occurred or will soon occur and in 2 beds that may not see development impacts for some years. Changes in area and physical and biological parameters will be tracked over the next 5 years. Next year, light attenuation will be measured in several beds.

Preliminary data analysis indicates high variability in bed size, biomass, percent cover, stem density, and canopy height among beds. Maps of the eelgrass beds and a summary of biological data will be provided to the AKR and other agencies in November 2004. I anticipate publication of a NOAA Technical Memorandum or a journal article after 3 years that will analyze trends in bed area, physical parameters, and biological characteristics.

Investigations of Skate Nurseries in the Eastern Bering Sea - Principal Investigator: Gerald R. Hoff, NMFS Alaska Fisheries Science Center, RACE Division, jerry.hoff@noaa.gov

The goal of this study is to verify skate nurseries in the eastern Bering Sea, determine the temporal aspect of skate reproduction and skate embryo development, and to identify interaction of predatory species in the skate nurseries.

Bottom trawling was conducted at each of three sites to establish the species utilizing the area, egg spatial densities and extent of the nursery areas in July-August of 2004. The investigations identified three species specific nurseries including the Alaska skate *Bathyraja parmifera,* The Aleutian skate *B. aleutica*, and The Bering skate *B. interrupta.* Data collected at each site included skate egg developmental state, egg predation rate, egg densities and distribution, skate predation rate, and reproductive status of mature skates in the nursery.

The data collected to date verifies the location, extent, and species at three locations in the eastern Bering Sea. Each site is species specific and evidence suggests these sites are used for many years as nurseries. Each site will be sampled periodically throughout the year to track skate reproductive state and the development of the embryo population.

Reproductive Ecology of Atka Mackerel in the Aleutian Archipelago - Principal Investigator: Bob Lauth and Scott McEntire, NOAA-NMFS-AFSC

Atka mackerel support a commercial fishery in Alaska and play a key role in the marine ecosystem. More information regarding spatio-temporal distribution with respect to size, sex, and spawning condition, as well as habitat use for nesting sites, is needed to understand Atka mackerel distribution patterns during their reproductive phase. These patterns affect stock dynamics, recruitment, and distribution of Atka mackerel populations. Timing, geographic location, and hydrographic features at nesting sites can affect the dispersal of larvae and play a significant role in determining population structure. Variability in female reproductive output (i.e., maturity schedule) can also contribute to variability in recruitment; however, it is unknown if and how reproductive output varies over space and time. The specific objectives of this study are to: 1) locate and characterize nesting habitat; 2) analyze the spatiotemporal distribution of Atka mackerel populations by reproductive stage, size, and sex; 3) produce an Atka mackerel embryonic developmental series over a range of temperatures; 4) investigate the temporality of spawning, nesting, and hatching within and between nesting sites; 5) investigate the annual and spatial variation in reproductive output.

Exploratory underwater camera surveys were used to locate Atka mackerel nesting sites in the U.S. EEZ. Funds from EFH were used to improve and refurbish a portable winch and camera system so that it was more reliable and could be used during the summer of 2004 on various vessels of opportunity in the Aleutian archipelago and western Gulf of Alaska. One hundred and three camera drops were videotaped during the summer. From June to August, research was coordinated with the AFSC RACE Division's 2004 Aleutian Island groundfish trawl survey. More camera drops were completed in September in conjunction with the U.S. Fish and Wildlife research vessel Tiglax. The camera and winch system will also be used during an Atka mackerel Tag Recovery cruise in October aboard the catcher-processor Seafisher. The geographical coverage of camera drops from all cruises is from Stalemate Bank to Homer, Alaska. Numerous major nesting areas were located across the archipelago at offshore reefs and near island passes. The presence of nesting male aggregations will be analyzed in relation to bottom depth, water temperature, and the physical and biological habitat. The relation of the nesting sites to other major geographic and bathymetric features of the Aleutian archipelago will also be investigated using GIS. Results from these studies will be combined with a histological analysis of gonad samples from Atka mackerel tag and tag recovery cruises.

Effects of Fishing Gear on Seafloor Habitat – Progress Report for FY2004
Edited by Jonathan Heifetz (Alaska Fisheries Science Center, Auke Bay Laboratory)

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. A list of the 36 publications that have resulted from these projects is also included. Scientists primarily from the Auke Bay Laboratory (ABL) and the Resource Assessment and Conservation Engineering (RACE) Divisions of the AFSC have been conducting this work. A web page http://www.afsc.noaa.gov/abl/MarFish/geareffects.htm has been developed that highlights these research efforts. Included in this web page are a research plan, previous progress reports, and a searchable bibliography on the effects of mobile fishing gear on benthic habitats.

Determining the value of habitat to juvenile rockfish in the Aleutian Islands.
Principal Investigators - Chris Rooper and Mark Zimmermann (AFSC – RACE), and Jennifer Boldt (University of Washington)

Linking the specific benefits of habitats to fish is important to determining Essential Fish Habitat for species. The objective of this study is to assess the value of Aleutian Islands habitat to juvenile (< 250 mm fork length) Pacific ocean perch (POP) by examining abundance, condition and growth in five study areas. The initial phase of habitat mapping was completed during a research cruise beginning and ending in Dutch Harbor, Alaska from May 28 to June 9, 2004. Video transects and sediment samples were completed in a cruise from August 13-24, 2004. Each of five study areas surrounding the Islands of Four Mountains was mapped using a towed side scan sonar (Klein 3000) and a multibeam system (Simrad SM2000), to collect bathymetry and backscatter data. Much of the data processing was completed aboard the F/V *Ocean Explorer* and side scan sonar mosaics were produced (Figure 49). In total, 25 km^2 were mapped using side scan sonar, and multibeam data was collected over almost twice that area. Video and sediment samples were collected to groundtruth the acoustic data. Preliminary results indicate habitats at each area varied widely, from bare sand fields to rocky ledges, ridges and pinnacles. Sponge and coral were the dominant epibenthic invertebrates observed in the video and trawl collections. Juvenile POP were collected from 4 of the 5 study areas for laboratory analyses. Sponge and coral were observed at most sites where juvenile POP were collected. During the fall and winter of 2004-05 sediment samples, zooplankton, and fish collections will be analyzed in the laboratory, and data analyses will begin later. The approach presented here will provide information to determine the value of habitats to their inhabitants, as well as insight into the processes controlling fish-habitat relationships. This project was supported by a grant from the North Pacific Research Board.

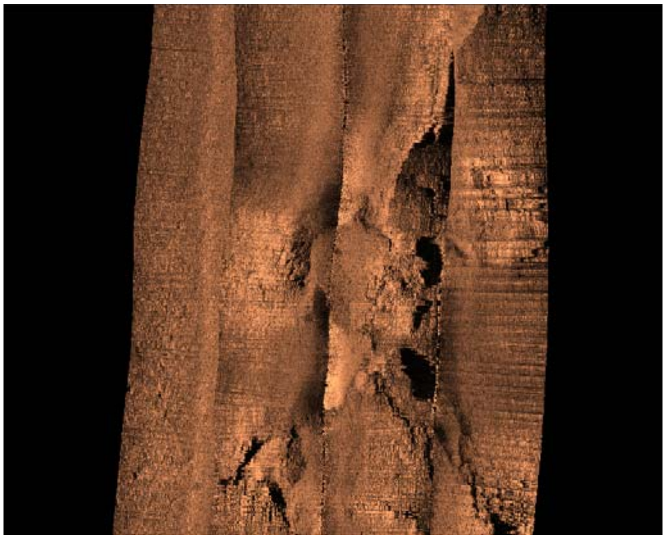


Figure 49. Side scan sonar mosaic from the Islands of Four Mountains west study location, showing interesting geological features on the seafloor.

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

During July 24 – August 8, 2004 the ROV *Jason II* (Woods Hole Oceanographic Institute) and support vessel RV *Roger Revelle* were used to study deep-sea coral and sponge habitat in the central Aleutian Islands. The dives made with the *Jason II* were at ten sites from 131 m to 2948 m in depth. Video footage of the seafloor was collected along strip transects from 2.4 to 13.2 km in length. Corals and sponges were widely distributed at the study sites with an apparent change in density, diversity, and species composition at a depth of approximately 1400 m. Samples were collected at stations along transects and included 260 corals, 45 sponges, 165 miscellaneous invertebrates, and 82 rocks. Preliminary results indicate that representatives from all seven coral families known to occur in the North Pacific were collected and that several of the collected sponges represent species new to science.

NOAA's Undersea Research Program funded the cruise and this was the final component of a comprehensive study initiated in 2003 and funded by the AFSC and the North Pacific Research Board. Coupled with detailed multibeam mapping and previous in-situ observations in shallow water (< 365 m) these findings will be used to construct a model to predict where coral habitat is located in the Aleutian Islands. The model will provide fisheries managers with a powerful tool to conserve coral habitat. Results from this cruise will provide information on the distribution of corals and sponges in the Aleutian Islands that will aid in fisheries management decisions. Our findings will greatly add to the understanding of the role of corals and sponges in seafloor ecology and their susceptibility to disturbance. An overview of the coral research can be seen at http://www.alaskascienceoutreach.com/

Bogoslof Island mapping and colonization. Principal Investigators - Mark Zimmermann (AFSC - RACE), Jennifer Reynolds (University of Alaska Fairbanks), and Chris Rooper (AFSC - RACE)

We are studying the colonization process of benthic invertebrates at hard-bottom sites about 10-200 years old on Bogoslof Volcano to provide estimates of habitat recovery rates from benthic fishing activities. Bogoslof provides a natural laboratory for our study because lava and tephra (fragments of volcanic rock and lava) from historical eruptions (since 1796) have resurfaced different areas of the shallow seafloor around the island. The results will provide information needed for fisheries management by defining an upper bound on the time needed for recovery. Currently there are no reliable estimates of habitat recovery time from field work, and recovery rates on hard-bottom areas have been estimated as 1-9% per year whereas gorgonian coral recovery rates were estimated as 0.5-2% per year (or 50-200 years) for use in the Fujioka habitat impacts model.

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 50). After the final multibeam maps are delivered, the second phase will be completed this winter, and we will develop a census plan for studying the invertebrates. In summer 2005 we plan to conduct ROV transects within selected seafloor patches. We anticipate that there may be three possible levels of resolution for the video census: 1) presence/absence of species or taxa groups, 2) density or percent horizontal coverage, and 3) age estimates of individuals.

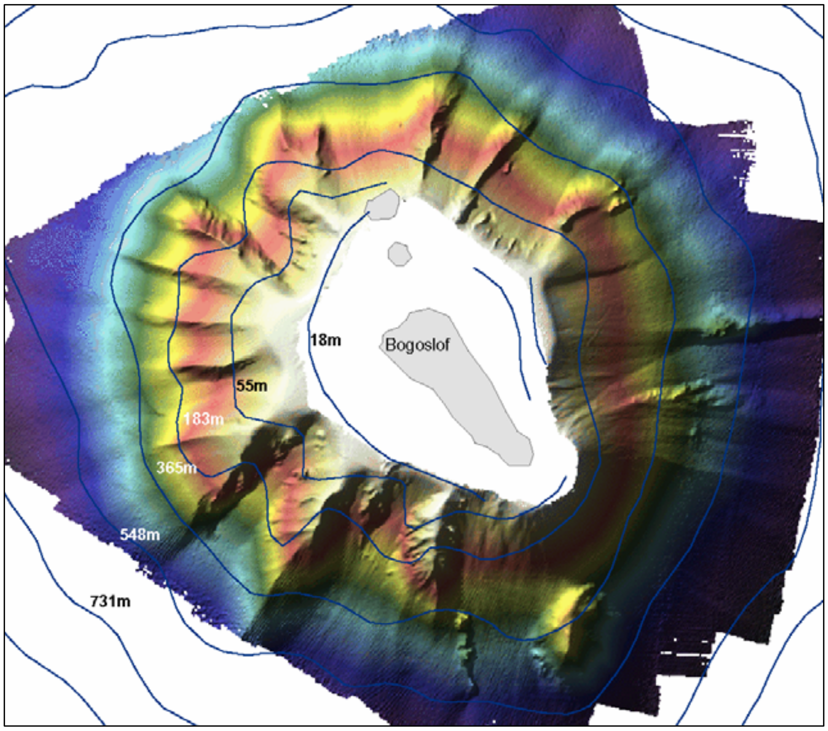


Figure 50. Preliminary multibeam map of the seafloor surrounding Bogoslof Island. Relief is artificially shaded from the northwest.

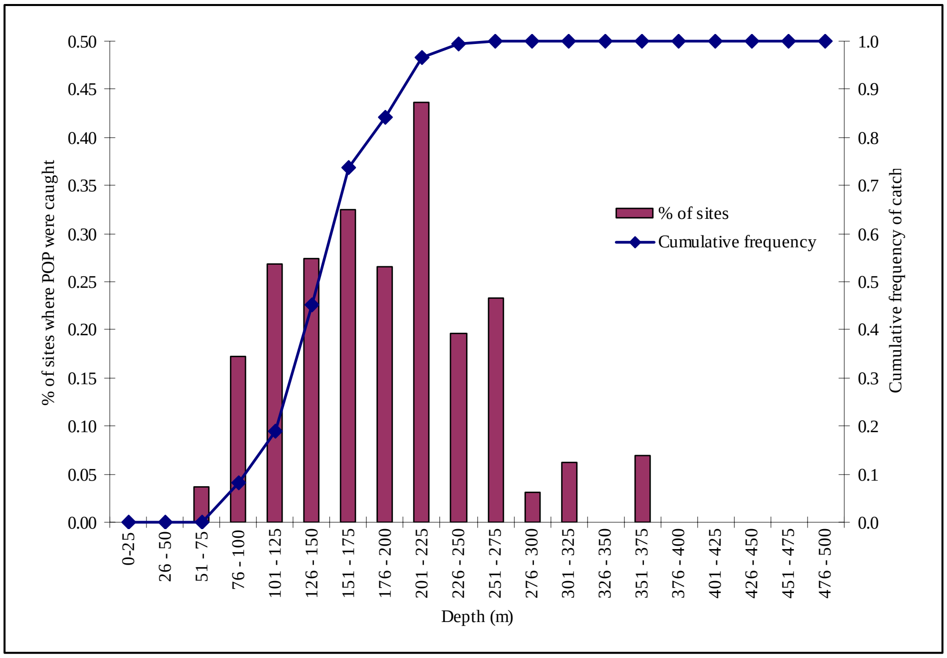
A model for evaluating fishery impacts on habitat. Principal investigator - Jeffrey Fujioka (AFSC - ABL)

A mathematical model to evaluate the effects of fishing on benthic habitat was developed within the context of the Programatic and Essential Fish Habitat (EFH) supplemental environmental impact statements (EIS). The initial formulation of the model was comprised of equations that incorporate the basic factors determining impacts of fishing on habitat. Given values, either estimated or assumed, of 1) fishing intensity, 2) sensitivity of habitat to fishing effort, and 3) habitat recovery rate, the model predicts a value of equilibrium (i.e., long term) habitat level, as a proportion of the unfished level.

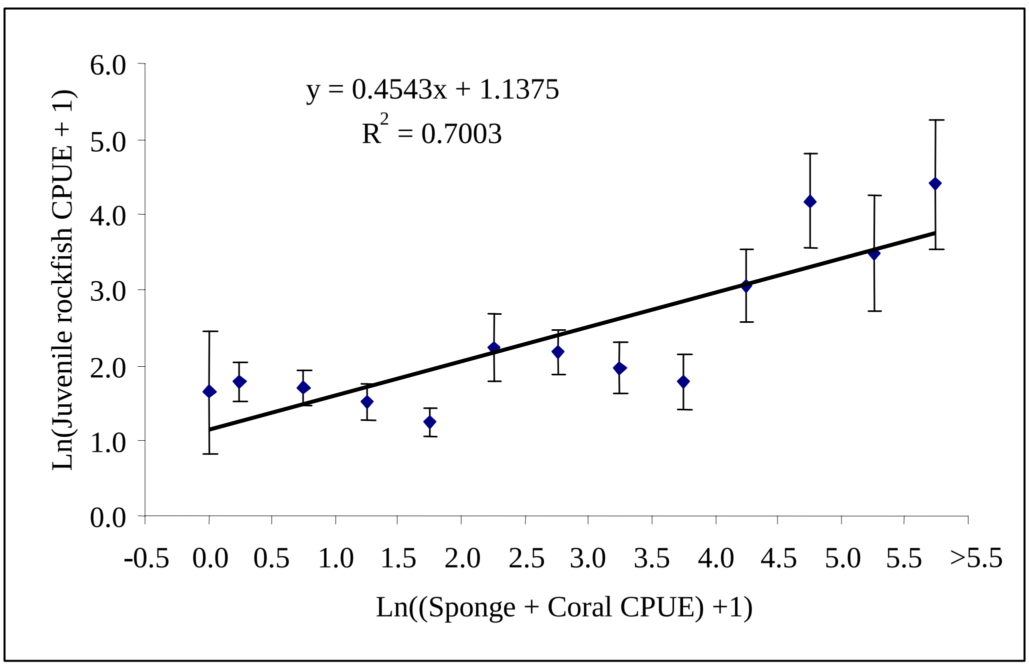
In 2004 new equations were formulated to expand on application of the model. In addition, model properties and new examples were developed which provide guidance in evaluating or designing mitigation strategies. The equations in the initial development of the model dealt with constant fishing effort situations and the EIS habitat impact analyses compared hypothetical equilibrium levels. During review of the EFH EIS concerns were raised about the current status of habitat impact. One new equation provides a simple way to determine the time it takes to approach equilibrium habitat reduction. Another equation was derived to extend model application to non-constant fishing effort so that if actual fishing effort history exists, habitat reduction over time can be modeled.

Distribution of juvenile Pacific ocean perch (*Sebastes alutus*) in the Aleutian Islands. Principal Investigators - Chris Rooper (AFSC - RACE) and Jennifer Boldt (University of Washington)

The objective of this research was to identify juvenile (< 250 mm fork length) Pacific ocean perch (POP) habitat, using data from trawl surveys conducted by NMFS. Analyses were carried out to evaluate the POP CPUE relationship to depth, temperature, and sponge and coral CPUE. A principal component analysis indicated that sponge and coral CPUE were tightly linked, and depth and temperature were negatively correlated. The survey data indicate that juvenile POP were present at depths from 76 to 225 m (Figure 51). Juvenile POP CPUE increased with depth from 76 to 140 m, and decreased with increasing temperature from 3 to 5.5 ºC. Juvenile POP CPUE also increased with increasing sponge and coral catch rates (Figure 52). A statistical model predicting juvenile CPUE at stations where POP were caught explained 34% of the CPUE variability using bottom temperature, depth, and combined sponge and coral CPUE. Juvenile POP were most abundant at sites in the western Aleutians (beyond 170º W longitude), on large underwater banks (Stalemate and Petrel banks), and in passes between islands where currents are strong and production may be higher than surrounding areas. These results suggest sponge and coral have an important role in the early life history of juvenile POP.



% of sites where POP were caught
Cumulative frequency of catch
% of sites
Cumulative frequency
Depth (m)
0-25
26 - 50
51 - 75
76 - 100
101 - 125
126 - 150
151 - 175
176 - 200
201 - 225
226 - 250
251 - 275
276 - 300
301 - 325
326 - 350
351 - 375
376 - 400
401 - 425
426 - 450
451 - 475
476 - 500



y = 0.4543x + 1.1375
R^2 = 0.7003
Ln(Juvenile rockfish CPUE + 1)
Ln((Sponge + Coral CPUE) +1)
>5.5

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

In June 2001 a study was initiated to investigate the immediate effects of intensive bottom trawling on soft-bottom habitat and in particular an area colonized by sea whips. Sea whip biological characteristics and their resistance to two levels of trawling were studied. Sea whips are highly visible and changes in their abundance can be readily quantified. Within the study site, at least two species of sea whips (*Halipterus willemoesi* and *Protoptilum* sp.) are present with densities up to 10 individuals per m^2. Sea whip beds provide vertical relief to this otherwise homogeneous, low relief habitat. This habitat may be particularly vulnerable since sea whips can be removed, dislodged, or broken by bottom fishing gear. Furthermore, since sea whips are believed to be long-lived, recolonization rates may be very slow.

The study plan consisted of three phases. In *Phase 1*, baseline data was collected. The *Delta* submersible was used to collect *in situ* videographic documentation of the seafloor along 20 predetermined transects within the study area. Additionally, a bottom sampler was deployed from the submersible tender vessel to collect sediment samples (n=42) from the seafloor. During *Phase 2*, a commercial trawler outfitted with a Bering Sea combination 107/138 net, mud gear, and two NETS High Lift trawl doors made a single trawl pass in one corridor of the study area and repetitively trawled (six trawl passes) a second corridor. A third corridor was the control and was not trawled. *Phase 3* repeated the videographic and sediment sampling (n= 42) following the trawling phase. A scientist on board the *Delta* observed the seafloor and verbally identified biota and evidence of trawling including damaged or dislodged biota and marks on the seafloor from the various components of the bottom trawl (e.g., trawl door furrows, and ground gear striations) in synchrony with the external cameras. Analyses of sediment, chemical, and infauna abundance and diversity was completed in 2002. Video analysis of epifauna data was completed in Spring 2003 and data analyses are underway.

Growth and recruitment of an Alaskan shallow-water gorgonian coral. Principal Investigator - Robert Stone (AFSC - ABL)

Little is known about the growth rates and lifespan of cold-water gorgonian coral. Some evidence exists that growth rates for these habitat-forming corals are low and that they are long-lived. Consequently, recovery rates from disturbance are likely slow. A study was initiated in 1999 to examine the growth and recruitment of *Calcigorgia spiculifera*, the most common and abundant species of shallow-water gorgonian in Alaskan waters. During June and July 2004 two sites established in July 1999 were revisited and 36 of 38 tagged colonies were relocated and video images recorded. These images will be digitized and growth determined from baseline images collected during the five previous years. A third study site was established in Kelp Bay, Baranof Island in 2000 where 30 colonies were tagged and images recorded. This site was unique in that it contained more than 1000 colonies, many of which were young (i.e., non-arborescent). At this site 18 of 30 colonies were relocated in July 2004 and video images were recorded. Additionally, branch samples were collected from untagged colonies at all three locations in 2002 and 2003 and will be examined microscopically to determine the gonadal morphology, gametogenesis, and reproductive schedule for this species. This research on reproductive biology should provide insights into the capability of cold-water gorgonians to recolonize areas set aside as mitigative measures, such as Marine Protected Areas.

Age validation and growth of three species of Pennatulaceans. Principal Investigator - Robert Stone (AFSC - ABL)

Pennatulaceans (sea whips and sea pens) are locally abundant in Alaskan waters, susceptible to disturbance by bottom fishing activities, and are an important structural component to benthic ecosystems. Furthermore, research on one species (*Halipterus willemoesi*), indicates that they are long-lived and have low growth rates. This research was based on ring couplet (growth rings) counts but the periodicity of the couplets was not verified. To determine if the couplets are indeed annuli, 14 *Halipterus willemoesi* colonies were immersed in calcein solution and tethered to the seafloor where they were collected at 25 m depth. Preliminary results indicated that the calcein produced clear detectible marks on the axial rods. The 14 tethered specimens were retrieved between March and September 2004. Examination of these specimens is currently underway and may provide verification of the periodicity of ring couplets.

Axial rods from approximately 20 specimens each of the sea whips *Halipterus willemoesi* and *Protoptilum* sp. and the sea pen, *Ptilosarcus gurneyi*, are being examined for ring couplet counts. Examination of a wide size range for each species will provide estimates of growth rate, asymptotic size, and life span. One species (*Halipterus willemoesi*) will be collected from two populations subjected to different temperature regimes (Southeast Alaska and Bering Sea) and will allow us to examine the effects of temperature on growth rates. These data will allow us to estimate the growth rates of pennatulaceans throughout their geographical range and depth distribution.

Effects of bottom trawling on soft-sediment epibenthic communities in the Gulf of Alaska. Principal Investigator - Robert Stone (AFSC - ABL)

In April 1987 the North Pacific Fishery Management Council closed two areas around Kodiak Island, Alaska to bottom trawling and scallop dredging (Type 1 Areas). These areas were designated as important rearing habitat and migratory corridors for juvenile and molting crabs. The closures are intended to assist rebuilding severely depressed Tanner and red king crab stocks. In addition to crab resources, the closed areas and areas immediately adjacent to them, have rich stocks of groundfish including flathead sole, butter sole, Pacific halibut, arrowtooth flounder, Pacific cod, walleye pollock, and several species of rockfish.

These closures provide a rare opportunity to study the effects of an active bottom trawl fishery on soft-bottom, low-relief marine habitat because bottom trawling occurs immediately adjacent to the closed areas. In 1998 and 1999 studies were initiated to determine the effects of bottom trawling on these soft-bottom habitats. The goal of these studies was to determine if bottom trawling in some of the more heavily trawled areas of the Gulf of Alaska, has chronically altered soft-bottom marine communities. Direct comparisons were possible between areas that were consistently trawled each year and areas where bottom trawling had been prohibited for 11 to 12 years. The proximity of the closed and open areas allowed for comparison of fine-scale infauna and epifauna diversity and abundance and microhabitat and community structure. Continuous video footage of the sea floor was collected with an occupied submersible at two sites that were bisected by the boundary demarcating open and closed areas.

The positions of 155,939 megafauna were determined along 89 km of seafloor. At both sites we detected general and site-specific differences in epifaunal abundance and species diversity between open and closed areas that indicate the communities in the open areas had been subjected to increased disturbance. Species richness was lower in open areas. Species dominance was greater in one open area, while the other site had significantly fewer epifauna in open areas. Both sites had decreased abundance of low-mobility taxa and prey taxa in the open areas. Site-specific responses were likely due to site differences in fishing intensity, sediment composition, and near bottom current patterns. Prey taxa were highly associated with biogenic and biotic structures; biogenic structures were significantly less abundant in open areas. In addition a relationship between epifaunal biomass and sea whip abundance was apparent. This relationship indicates that sea whip habitat may have increased productivity. Recent studies in the Bering Sea have shown a similar functional relationship for sea whip habitat. Evidence exists that bottom trawling has produced changes to the seafloor and associated fauna, affecting the availability of prey for economically important groundfish. These changes should serve as a "red flag" to managers since prey taxa are a critical component of essential fish habitat. Results from the epifauna component of this study were presented at Effects of Fishing Activities on Benthic Habitats symposium held in Tampa during November 2002 and will be published in the American Fisheries Society Symposium 41 planned for publication in October 2004.

Ecological value of physical habitat structure for juvenile flatfishes. Principal Investigator **–** Allan W. Stoner (AFSC - RACE)

Our previous field and laboratory studies have shown that some juvenile flatfishes have strong preferences for habitats with physical structure created by large epibenthic invertebrates, biogenic structures in the sediment, and sand waves. New experiments in large laboratory pools revealed that predation vulnerability of age-0 rock sole and Pacific halibut decreases substantially in the presence of habitat complexity presented by sponges. Predator-prey encounter rates decreased with habitat structure as predator swim speed and search behavior was impeded. Physical structure in the environment also impeded pursuit of prey. Young halibut were more likely to flee from predators than rock sole, but once flight was initiated halibut were more likely to escape than rock sole because of greater speed and agility. Subsequent experiments have shown that mortality decreases with amount of structural complexity, but the function is not linear. These experiments support an accumulating body of evidence that emergent structure in otherwise low-relief benthic habitats may play a critical role in the survival and recruitment of juvenile flatfishes.

During 2003 and 2004, field experiments were conducted near Kodiak to increase the structural complexity of large bare sand plots within flatfish nurseries. Bivalve shells were added (5 shells/m2) to replicated plots. The modified plots and reference plots were then monitored with a towed camera sled at several intervals over the following month to characterize changes in the fish fauna occupying those plots. Unexpectedly, numbers of age-0 flatfishes decreased inside the structurally enhanced plots, but older flatfishes increased in abundance. Subsequent laboratory experiments showed that both large and small flatfishes are attracted to structurally complex habitats, but disturbance by the larger flatfishes resulted in the smallest fishes moving away. This illustrates the complexity of mechanisms behind fish/habitat associations.

Camera sled surveys for juvenile flatfishes were continued in three key nursery grounds near Kodiak during 2004, with the purpose of quantifying flatfish/habitat associations. Surveys were expanded to include a seasonal component during the early summer to fall recruitment season. Surveys have now been conducted for three years, yielding ~150 hours of video tape. Analysis of the video is currently underway. Statistical and spatially-explicit analyses of the distribution patterns will begin during FY-05. A new manuscript shows that densities of age-0 flatfishes recorded with our small camera sled are equivalent to the values provided in diver surveys and with small beam trawls. The camera gear, integrated with navigational data, provides a permanent record of the habitat, can be used for large spatial coverage, and has been a very effective way to explore fish/habitat associations.

Mapping marine benthic habitat in the Gulf of Alaska: geological habitat, fish assemblages, and fishing intensity. Principal Investigators - Jon Heifetz (AFSC – ABL), Kalei Shotwell (AFSC – ABL), Dean Courtney (AFSC – ABL), and Gary Greene (Moss Landing Marine Labs)

Since 2001 we have mapped about 4,000 km^2 of seafloor in the Gulf of Alaska using a high-resolution multibeam echosounder that includes coregistered backscatter data. The mapping has mainly focused on areas in the vicinity of major groundfish fisheries such as Portlock Bank, Albatross Bank, Pamplona Spur, and Yakutat slope. This past year we focused our analyses on the 790 km^2 mapped area on Portlock Bank northeast of Kodiak. We evaluated the utility of integrating various sources of biological data with high resolution bathymetry and backscatter for describing benthic habitat, fish/habitat associations, and habitat specific fishing intensity. The biological information evaluated included data acquired from programs external to our study such as fishery observer data and trawl survey data and new data from the multibeam mapping and submersible dive transects. Habitat classification derived from mapping data indicated the presence of twenty-two different benthic habitats. Although biological data were limited on the mapped site for identifying fish/habitat associations and habitat specific fishing intensity, we were able to determine general and habitat specific fish distributions over the surveyed area through occurrence measurements and density calculations. We also created a density surface of the commercial fishing trawls in the mapped area that enabled basic patterns in fishing intensity by habitat type. We recommend a directed survey that collects biological samples in each of the established benthic habitats for more quantitative measurements of fish-habitat preference. Other properties within the area, such as oceanography and predator/prey fields, may also influence fish distributions and should be considered during benthic habitat classification.

Red king crab and bottom trawl interactions in Bristol Bay. Principal Investigators - C. Braxton Dew and Robert A. McConnaughey (AFSC - RACE)

The 1976 U.S. Magnuson-Stevens Fishery Conservation and Management Act effectively eliminated the no-trawl zone known as the Bristol Bay Pot Sanctuary, located in the southeastern Bering Sea, Alaska. Implemented by the Japanese in 1959, the boundaries of the Pot Sanctuary closely matched the well-defined distribution of the red king crab (*Paralithodes camtschaticus*) population's mature-female brood stock, thus affording a measure of protection to the reproductive potential of the stock. In 1980, the point at which the commercial harvest of Bristol Bay legal-male red king crab reached an all-time high after a decade-long increase, domestic bottom trawling in the brood-stock sanctuary began in earnest with the advent of a U.S.-Soviet, joint-venture, yellowfin sole fishery. In the first year of trawling in the Pot Sanctuary, the Bering Sea/Aleutian Islands (BSAI) red king crab bycatch increased by 371% over the 1977-79 average; in 1981 the BSAI bycatch increased another 235% over that in 1980, most of which were mature females. As the number of unmonitored domestic trawls in the brood-stock area increased rapidly after 1979 and anecdotal reports of "red bags" (trawl cod-ends plugged with red king crab) began to circulate, the proportion of males in the mature population (0.25 in 1981 and 0.16 in 1982) jumped to 0.54 in 1985 and 0.65 in 1986. It is unlikely that normal demographics caused this sudden reversal in sex ratio. Our hypothesis is that sequential, sex-specific sources of fishing mortality were at work. Initially there were ten years (1970-1980) of increasing, male-only exploitation in the directed pot fishery, followed by a drastic reduction in the male harvest after 1980 (to zero in 1983). Then, beginning around 1980, there was an increase in bottom trawling among the highly aggregated, sexually mature female brood stock concentrated near the western end of the Alaska Peninsula, an area documented by previous investigators to be the most productive spawning, incubation, and hatching ground for Bristol Bay red king crab. There has been considerable discussion about possible natural causes (e. g., meteorological regime shifts, increased groundfish predation, epizootic diseases) of the abrupt collapse of the Bristol Bay red king crab population in the early 1980s. Our research focused on the association between record harvests of male crab in the directed fishery, the onset of large-scale commercial trawling within the population's primary reproductive refuge, and the population's collapse.

Short-term trawling effects and recovery monitoring in the eastern Bering Sea (2001-present). Principal Investigator - Robert A. McConnaughey (AFSC - RACE Division)

Whereas our earlier work focused on chronic effects of trawling this ongoing multi-year study is a process-oriented investigation of short-term effects and recovery using a BACI experimental design. The study area is located within the Crab and Halibut Protection Zone 1 closed area, approximately 25-50 mi south and west of the chronic effects site. During a 35-day cruise in 2001, 6 pairs of predesignated 10-mi long research corridors were sampled before and after a trawling disturbance with commercial gear (NETS 91/140 Aleutian cod combination). Biological sampling consisted of 15 min research trawls for epifauna (n=72 total) and 0.1 m^2 van Veen grab samples for infauna (n=144 total at 2 per epifauna site). At each infauna-sampling site, a second grab sample (n=144 total) was collected for characterizing carbon and nitrogen levels in surficial sediments, as well as grain size properties. The experimental and control corridors were also surveyed before and after trawling using a Klein 5410 side scan sonar system, to evaluate possible changes in sediment characteristics and bedforms. Taken together, the 2001 data quantify short-term changes in the experimental corridors due to trawling.

To investigate the recovery process, these same corridors were resampled in 2002 during a 21-day cruise aboard the same 155' trawler *F/V Ocean Explorer*. Sampling effort was equally divided between experimental and control corridors and was consistent with the level of effort in 2001. There was no commercial trawling event in 2002. A total of 36 epifauna trawls, 72 infauna grabs, 72 sediment grabs, and one side scan survey per corridor were performed. Combined, these data quantify recovery in the experimental corridors after one year using corrections for temporal variability measured in the control corridors.

The experimental design for this study will accommodate one additional series of epifauna sampling and multiple years of grab sampling after 2002, however the final recovery monitoring event has not yet been scheduled. At present, processing of all 2001 and 2002 samples is complete and analysis is pending. Preliminary observations indicate a very diverse epifaunal community (approximately 90 distinct taxa) on very-fine olive-gray sand at 60 m depth. The seafloor appears to be brushed smooth in the 2001 side scan imagery, probably due to sizable storm waves and strong tidal currents that regularly disturb the area. Occasional video deployments on the trawls indicated somewhat greater complexity. Derelict crab pots are scattered throughout the study area and there is evidence of extensive feeding by walrus.

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

To some degree, our understanding of fishing gear impacts is constrained by the experimental methods being used. In general, the process of understanding mobile gear effects has three distinct phases. It begins with the identification of changes caused by gear contact, followed by controlled studies to determine the ecological effects and, ultimately, decision making based on some form of cost-benefit analysis. Nearly all of the research to date has targeted the specific changes in benthic invertebrate populations that occur when mobile fishing gear, particularly bottom trawls, contact the seabed. This worldwide focus on benthic invertebrates reflects their limited mobility and vulnerability to bottom-tending gear, and observations that structurally complex seabeds are an important element of healthy productive benthic systems. Effects are typically measured as changes in abundance or community structure. However, despite decades of intensive research, the overall impact of mobile fishing gear on marine ecosystems and, in particular, on fish production is largely unknown. This reflects a need for substantially more research on the ecology of the affected invertebrates and their linkages to managed fish stocks, as well as more systematic studies of disturbance effects. Although certain gross generalities are possible, site-specific results are likely given variation in the composition of the benthos as well as the intensity, severity and frequency of both natural and anthropogenic disturbances. Because of the manner in which study areas are typically selected, any application of findings to other geographic areas is extremely tenuous. As such, there is a strong need to examine the issue more systematically so that research can move ahead from "case studies" of effects to the more interpretive (i.e. second) phase of investigation. To this end, we are working to identify areas with distinct invertebrate assemblages within which replicated *experiments* (not samples) could be placed and the aggregate findings applied to the entire area. The approaches being investigated are of two primary types and are detailed in sections that follow: (1) mapping surficial sediments as a physical proxy for invertebrate assemblages, given benthic organisms have demonstrated strong affinities for particular substrates and (2) analyzing spatial patterns of the benthic invertebrates themselves. Whereas the former approach has potential advantages in terms of cost and relatively rapid spatial coverage, the latter has clear advantages related to the direct nature of the measurements since, after all, invertebrates are the *de facto* measure of gear effects.

Evaluating single beam echosounders for synoptic seabed classification. Principal Investigators Robert A. McConnaughey and Stephen Syrjala (AFSC – RACE Division)

Acoustic technology is particularly suited to synoptic substrate mapping since quantitative data are collected rapidly and in a cost-effective manner. The QTC View seabed classification system (Quester Tangent Corporation, Sidney, B.C.) is capable of background data acquisition during routine survey operations. Echo returns from the seafloor were simultaneously collected at two frequencies (38 and 120 kHz) along a 9,000 nm trackline in the eastern Bering Sea (EBS) during a 1999 hydroacoustic fishery survey on the *R/V Miller Freeman*.

Acoustic diversity directly represents substrate diversity. Surface roughness, acoustic impedance contrast, and volume homogeneity are characteristic of different seabed types, and these factors influence echo returns from a vertical-incidence echo sounder. The standard QTC method uses a set of algorithms to extract features from individual echoes. These features include cumulative amplitude and ratios of samples of cumulative amplitude, amplitude quantiles, amplitude histogram, power spectrum, and wavelet packet transform. Principal components analysis (PCA) is used to reduce the full set of features to the three linear combinations that explain a large fraction of echo (seabed) variance. A three-factor cluster analysis then groups the echoes into distinct seabed types based on their acoustic diversity. Variation in continuous seabed properties is thus represented in discrete classes of seabed. The optimum classification scheme for any particular data set strikes a balance between high information content (i.e., many acoustic classes) and high confidence in the assigned class (e.g., if only one class). Clustering methods typically require significant user input to decide which class to split next and when to stop splitting. To overcome this subjectivity and develop a fully-automated objective process, a new application of the Bayesian form of the Akaike Information Criterion (BIC) was developed to guide the clustering process. Because of the computational intensity of the Bayesian method, analytical methods based on simulated annealing have been introduced to improve the program's ability to locate the global minimum (rather than a local minimum) of the BIC function. Alternatively, the three principal components may themselves be used to represent acoustic seabed diversity.

Results of this collaborative research with QTC include guidelines for acoustic mapping of seabeds and an optimal classification scheme for the EBS shelf. A total of 14 distinct classes of bottom types (clusters) were identified from the 38 kHz data. These results have now been merged with 22 years of RACE trawl survey data from the EBS shelf (1982-2003). Statistical analyses are being conducted to examine the degree to which acoustic variability corresponds to environmental features that influence the distribution and abundance of groundfish and benthic invertebrates.

Reconnaissance mapping with side scan sonar. Principal Investigator Robert A. McConnaughey (AFSC – RACE Division)

Upon completion of the 2002 bottom trawl study in the eastern Bering Sea, a reconnaissance of Bristol Bay seafloor habitats was undertaken using a high-resolution 500 kHz side scan sonar (Klein 5410). The reconnaissance effort was centered on an 800 mi^2 area of central Bristol Bay that has never been surveyed by NOAA hydrographers. The primary research objective is to identify large homeogenous regions that would be the basis for more systematic study of mobile gear effects. Secondary objectives include a study of walrus feeding ecology, a comparison of supervised and unsupervised classification methods for EFH characterization, and potential updates of nautical charts for the area.

A 150 m swath of bathymetric data and imagery were collected along survey lines totaling nearly 600 linear miles. The survey intentionally intersected six of the Bering Sea trawl study corridors currently being studied (above) in order to provide a spatial context for these results. In support of coordinated EFH characterization studies in the area, the reconnaissance survey also crossed 18 RACE Division trawl survey stations and followed 78 mi of seabed previously classified using a *QTC View* single beam acoustic system. Imagery was systematically groundtruthed using an underwater video camera and van Veen grab samples. Overall, a great diversity of complex sand-bedforms and other geological features were encountered in the survey area.

Thus far, a subset of the data has been classified using geological (supervised) and statistical (unsupervised) methods. A new software product, *QTC Sideview*, uses automated processing techniques to read the data on a line by line basis, segment the imagery, extract features based on pixel intensity and image texture, and classify the segments using multivariate statistics. Thirteen distinct acoustic classes were identified. A geologist identified seven major bottom types: (1) degraded bedforms, (2) hummocky seabed, (3) mixed sediments, (4) sand lenses, (5) smooth seabed, (6) sand ribbons, and (7) sand waves, with subdivisions loosely based on scale and shape of features, acoustic reflectivity, and presence or absence of walrus feeding tracks. There was general agreement, albeit with important differences, between the methods. The statistical classification did not seem to identify the differing scales of bedforms identified by the geologist, nor did it distinguish between sand waves and sand ribbons. On the other hand, the statistical classification used information at the scale of the acoustical wavelength (~3 mm) that may not have been considered the geologist. Further experimentation with the image patch size chosen for the statistical classification may improve the correlation between the methods. The Klein 5410 side scan sonar system is co-owned with the NOAA Office of Coast Survey.

Spatial and temporal patterns in eastern Bering Sea invertebrate assemblages.
Principal Investigators Cynthia Yeung and Robert A. McConnaughey (AFSC – RACE Division)

Invertebrate taxa exhibit highly specific geographical patterns reflecting their environmental requirements and ecological niches. These animals add important vertical complexity to the otherwise flat seabeds of the Bering Sea shelf and are also prey for commercially valuable species. In order to (1) characterize benthic habitats by invertebrate communities, and (2) detect temporal and spatial changes in community structure, invertebrate bycatch recorded during the annual RACE Division groundfish trawl surveys in the eastern Bering Sea (1982-2002) was examined. This study lays the groundwork for identifying the underlying biotic and environmental dependencies that define EFH for the benthic component of the eastern Bering Sea ecosystem. Spatio-temporal variability in the benthic invertebrate community structure is also a measure of natural and anthropogenic disturbance on the benthic environment, and clear, established community patterns could provide a basis for systematic study of fishing gear impact.

Of some 400 invertebrate taxa recorded over all the surveys, twenty-eight taxa were selected as the ‘core’ group for community analysis. They represent the dominant taxa in every survey either by frequency of occurrence (presence) or by biomass (kg/ha). Stations in each survey were grouped by the similarity of their assemblage of core taxa using hierarchical clustering. A persistent, interannual spatial pattern emerged of an “inshore” and an “offshore” group partitioned approximately along either side of the dynamic oceanographic “inner front” that runs mostly along the 50 m isobath (Figure 53). Offshore-type stations are mostly of > 50 m in depth; inshore-type stations are characteristically of < 50 m in depth. Stations extending southwest along the coast of the Alaska Peninsula from Bristol Bay up to about the 100-m isobath near Unimak Pass and some around the Pribilof Islands also typically fall into the inshore category. The key inshore indicator taxon is the sea star, *Asterias amurensis*; the key offshore indicator taxa are Gastropoda, Paguridae, and the snow crab *Chionoecetes opilio*.

The inshore-offshore spatial structure of the epibenthic communities is robust across the 21-year time series. Variations in this typical structure are only evident in 1982-84 and 1998-99 (Figure 53). Both periods saw a shoreward reduction in the domain of the inshore community (shoreward expansion of the domain of the offshore community). These anomalies coincided with significant climate events, namely the extreme El Niños in 1982-83 and 1997-98, and the Pacific Decadal Oscillation circa 1997-98. Multivariate ordination also indicates a trend of movement in the center of biomass of at least some of the core taxa towards the offshore (west). The dampening of these shifts in biomass distribution in the recent decade could signify the establishment of a stable and perhaps new spatial distribution of the taxa.

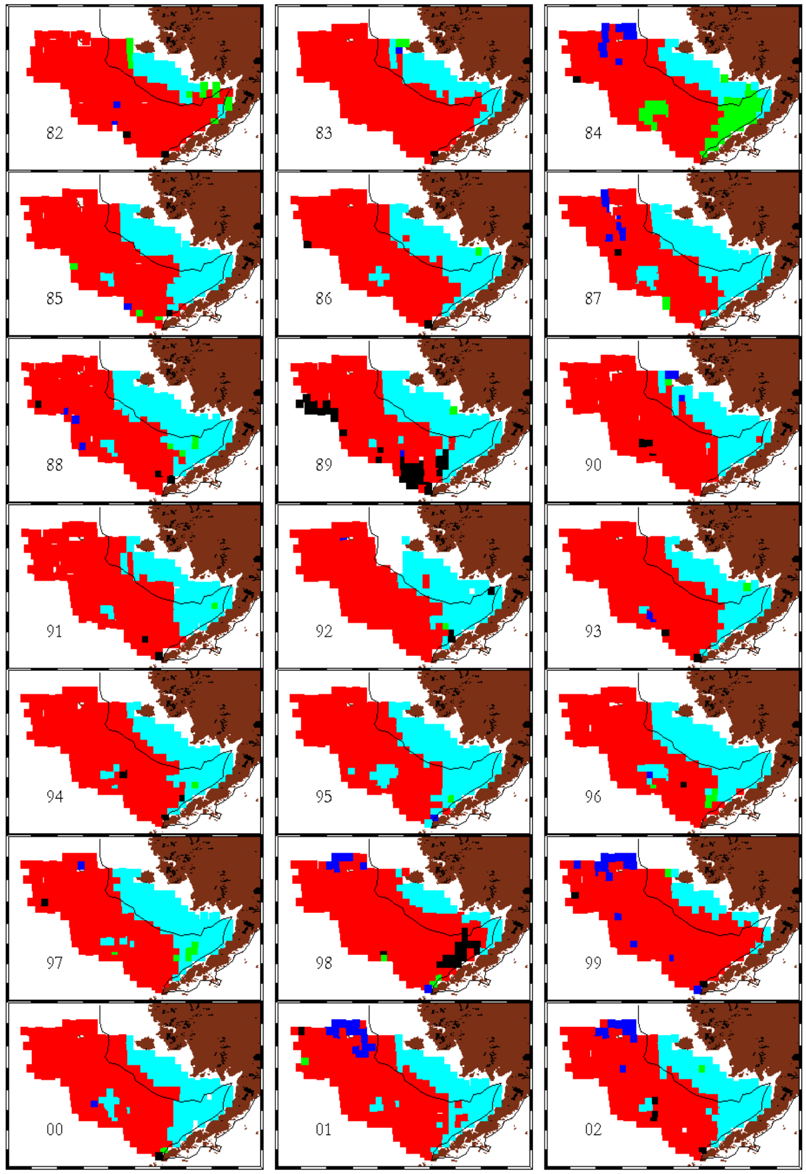


Figure 53. Survey stations clustered by the similarity of their core taxa assemblage. A maximum of 5 clusters are displayed. Stations are color-coded by cluster membership for visual interpretation. Colors are assigned to clusters to facilitate the spatial comparison of station groupings across surveys, not necessarily to imply the same colored stations across surveys have the same underlying community structure. Solid black line delineates the 50 m isobath. The two largest clusters are respectively 'inshore' (cyan) and 'offshore' (red) of the 50 m isobath. Each panel has the 2-digit survey year.

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Nutrients and Productivity

Contributed By Terry E. Whitledge, Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, PO Box 757220, Fairbanks, AK 99775-7220

Nutrient and Chlorophyll Processes on the Gulf of Alaska Shelf

Amy R. Childers, Terry E. Whitledge, and Dean A. Stockwell

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

Nutrients and Productivity Processes in the southeastern Bering Sea

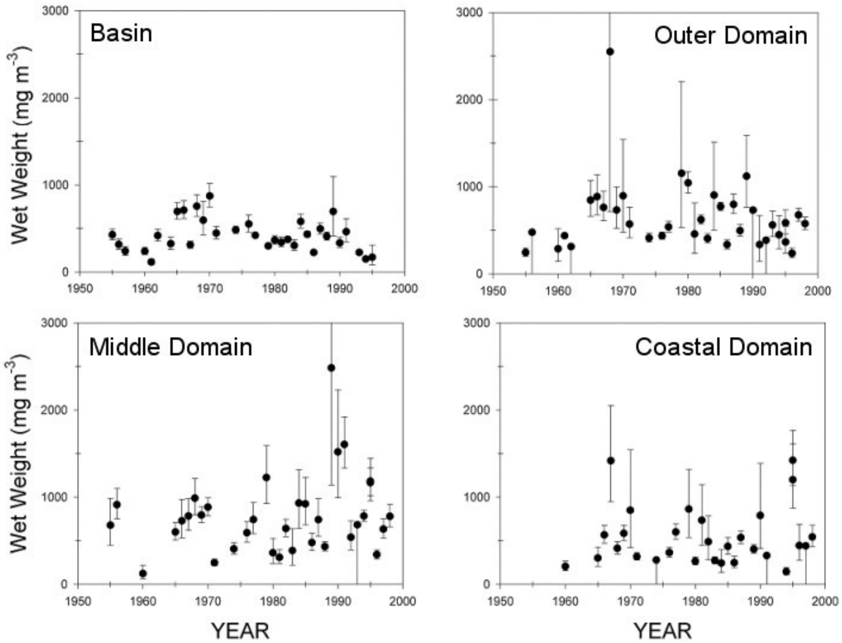
TaeKeun Rho, Terry E. Whitledge, and John J. Goering

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

Zooplankton

Bering Sea Zooplankton (not updated for 2004)

Contributed by Jeff Napp, Alaska Fisheries Science Center



Summer zooplankton biomass data was collected in the eastern Bering Sea by the T/S Oshoru Maru (Hokkaido University) from 1954 to 1999. These data were recently re-analyzed to examine trends in zooplankton by domain on the Bering Sea shelf. There was no apparent long-term trend in zooplankton biomass on the Bering Sea shelf (Figure 54; Napp et al. 2002). Nor were there any differences detected in zooplankton biomass among time periods in the 3 domains of the Bering Sea shelf (Hunt et al. 2002). Preliminary evidence suggests that the spring biomass of shelf copepods is higher in warm years than in cold years (Smith and Vidal 1986, Stockwell et al. 2001, Napp et al. 2002, Coyle and Pinchuk 2002). *Calanus marshallae*, an important prey item of juvenile fish from the Middle Shelf Domain behaves differently. Its springtime biomass and timing of appearance of C1 copepodites is related to cold temperatures and the southern extent of sea ice (Baier and Napp 2003).

Forage Fish

Gulf of Alaska Spring Ichthyoplankton Interannual Trends Study

Contributed by Miriam Doyle, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington and Susan Picquelle, Alaska Fisheries Science Center.

A time-series of Gulf of Alaska spring ichthyoplankton data, 1981-2001, is being examined at the Alaska Fisheries Science Center (NOAA) for interannual trends in occurrence, abundance and larval size of numerically dominant ichthyoplankton species in the vicinity of Shelikof Strait. All data were collected by oblique tows using 60 cm paired Bongo nets (mesh size of 0.333 or 0.505 mm). Local wind indices, physical oceanographic data and model output, along with basin-scale climate/ocean indices are being utilized to investigate trends in the ichthyoplankton in relation to interannual trends in ocean temperature, circulation, and production in this region. The goal of the study is to elucidate the potential links between fluctuating ocean conditions and the early life history dynamics of fish species in the northwest Gulf of Alaska. The same data are being used in an ongoing parallel study to investigate interannual variation in spatial patterns and assemblage structure in the ichthyoplankton of this region.

Results show unique periodicity and amplitude of interannual variation in abundance among species but some similarities are apparent (Figures 55 and 56). There is an implied decadal trend of elevated levels of larval abundance during the late 1980s through the mid or late 1990s, relative to the early to mid 1980s, for a variety of species including northern lampfish, Pacific cod, arrowtooth flounder and Pacific halibut. Data for the most abundant species, Walleye pollock and Pacific sandlance, did not yield this decadal trend in larval abundance. Evidence is poor overall for interannual shifts in timing of egg and larval production among species as indicated by statistically insignificant correlations between average larval size and abundance over the time-series. Interannual variation in the observed abundance of species of larvae in the area of investigation may therefore be related to interannual variation in adult spawning distribution in the vicinity, egg production and survival to hatching, larval survival and growth, and transport of eggs (if pelagic) and larvae into and out of the specific geographic sector. It is hypothesized that these early life history dynamics of fish species in the coastal and shelf zone of the northwest Gulf of Alaska are linked in a species-specific way to three key environmental variables: ocean temperatures, current patterns and larval food availability. In order to explore these ecosystem links a variety of multivariate analytical techniques, including cluster analysis, ordination (multi dimensional scaling, specifically), and dynamic factor analysis, are being applied to the data to detect patterns in the ichthyoplankton species time series and relationships between this time series and potential explanatory variables.

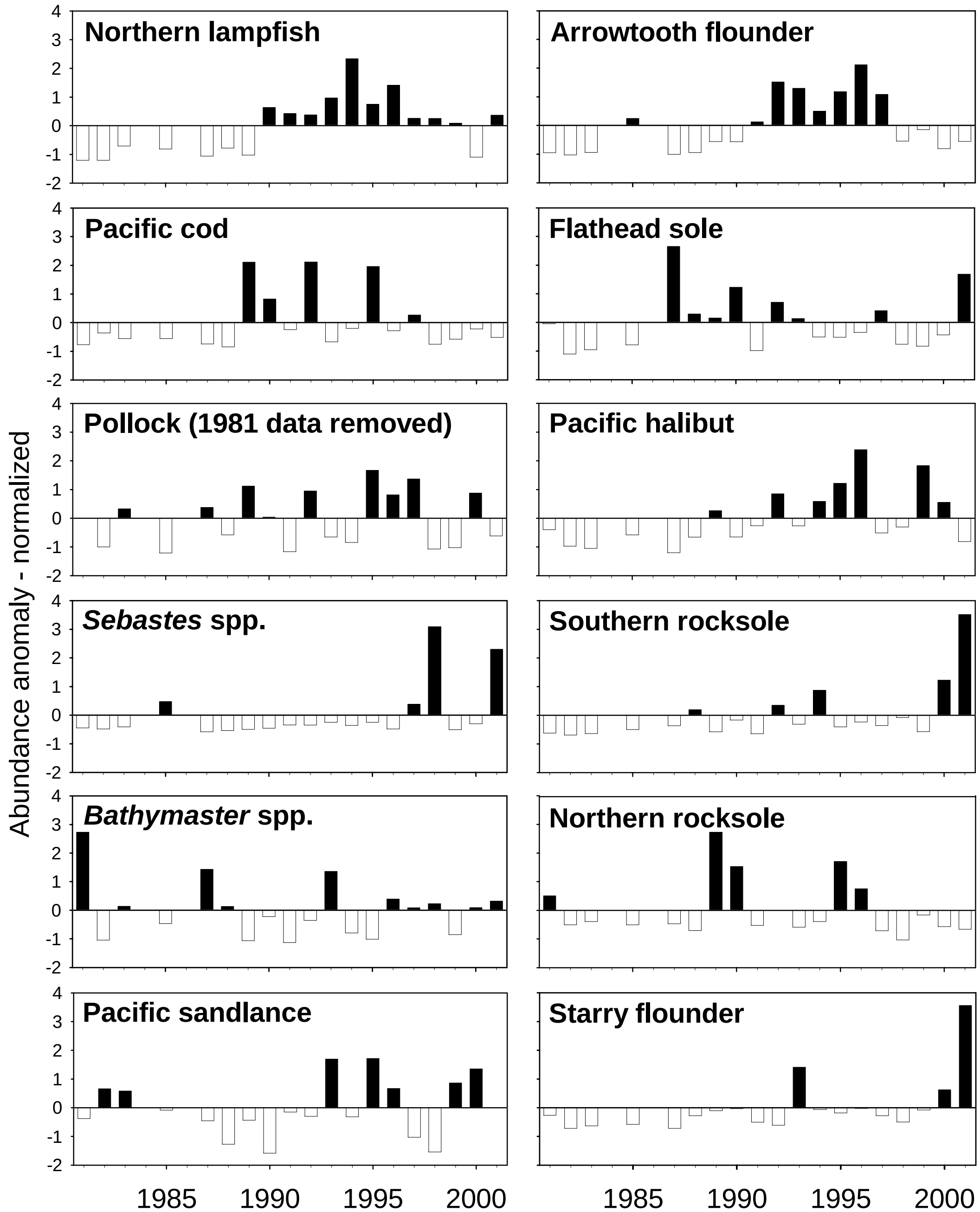


Figure 55. Two-week average abundance anomalies, normalized by standard deviation, for the dominant species of fish larvae occurring in plankton samples collected from May 16 to June 5, 1981 to 2001. No data available for 1984 or 1986 in this time series. Because of a super abundance of pollock larvae in samples collected during 1981, this value was not used in the calculation of anomaly values for this species.

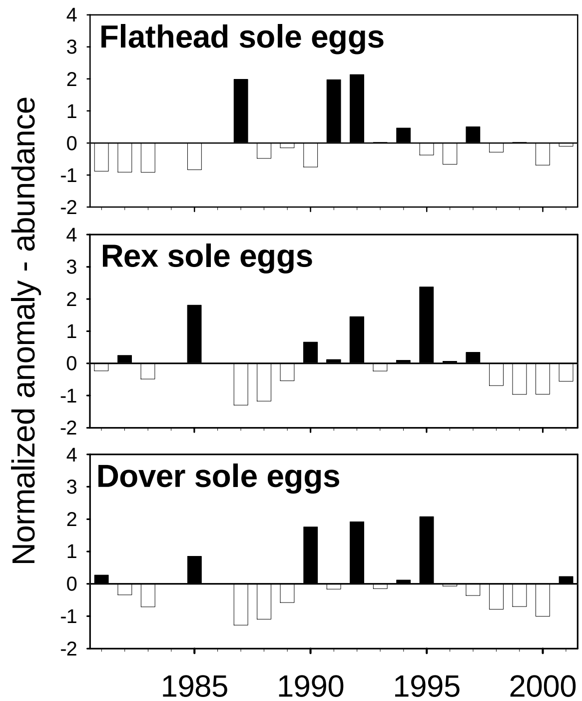


Figure 56. Two-week average abundance anomalies, normalized by standard deviation, for the dominant species of fish eggs occurring in plankton samples collected from May 16 to June 5, 1981 to 2001. No data available for 1984 or 1986 in this time series.

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

Angela Middleton[1], Ed Farley[1], and Nicola Hillgruber[2] [1]Auke Bay Laboratory, (907) 789-6007; [2]School of Fisheries and Ocean Sciences, Univ. of Alaska Fairbanks

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

Age-0 pollock were distributed throughout all geographic areas, with the highest concentration in the middle domain of Bristol Bay (Figure 57). There was a significant difference in energy density between geographic areas ($P < 0.00001$). Pair-wise tests indicated that pollock from the Chukchi Sea and Bristol Bay had significantly greater energy densities than pollock from the Bering Sea shelf (4226 J/g, 3985 J/g, and 3340 J/g, respectively), and there was no difference in energy density between the Chukchi Sea and Bristol Bay (Figure 58). Stomach content analysis indicated that age-0 pollock from Bristol Bay had a more cosmopolitan diet dominated by calanoid copepods (49%) and euphausids (23%), where as pollock from the Bering Sea shelf had a less varied diet dominated by calanoid copepods (65%; Figure 59).

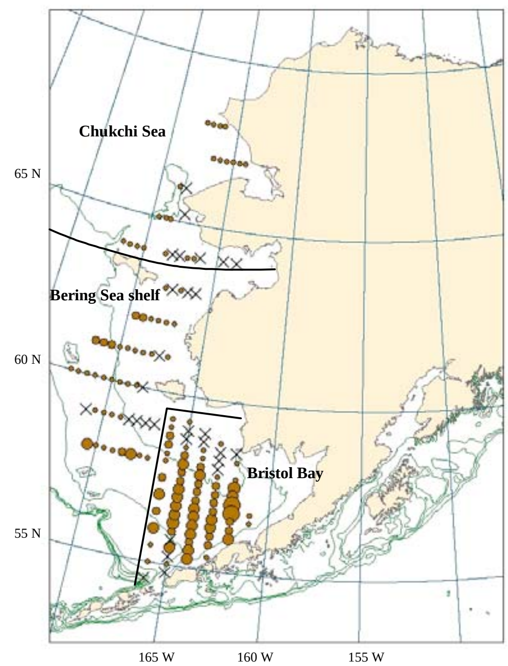


Figure 57. Age-0 pollock distribution in the Bering Sea and Chukchi Sea. X indicates no pollock were caught and the largest brown circle indicates 300,000 fish caught.

The lower energy density of fish from the Bering Sea shelf could be due to the presence of a coccolithophore bloom in that region during the summer of 2003 (Saitoh and Iida unpublished data), which might have reduced the fish's reactive distance, thus resulting in diminished ingestion rates. To understand the factors driving the observed differences in energy density, and whether these differences have an effect on early marine survival of pollock, variability in zooplankton biomass and oceanographic conditions of these geographical areas needs to be investigated.

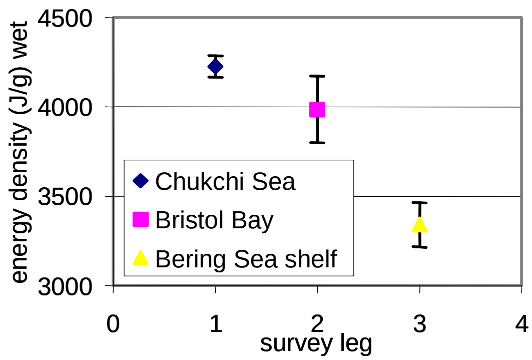


Figure 58. Average energy density (J/g wet weight) of age-0 pollock at each survey location, with 95% confidence intervals.

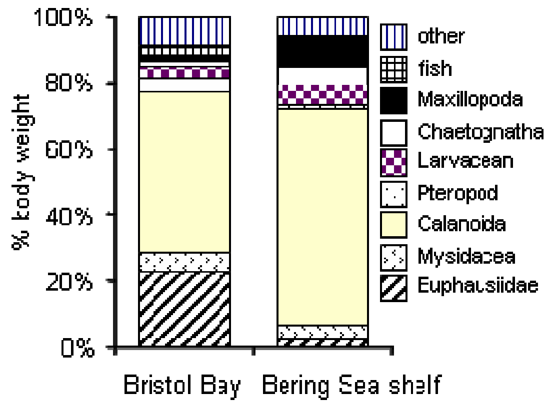


Figure 59. Diet composition by % body weight for age-0 pollock from Bristol Bay and the Bering Sea shelf.

Forage – Gulf of Alaska
Contributed by Eric Brown, Alaska Fisheries Science Center

Several groups have been defined as forage species by the North Pacific Fishery Management Council for management purposes. These groups include gunnels, lanternfish, sandfish, sandlance, smelts, stichaeids, and euphausiids. Several of these groups are captured incidentally in the RACE bottom trawl survey of the shelf, which may provide an index of abundance (Figure 60). This survey is not designed to assess these types of organisms and further detailed examinations of these results are needed to assess whether there are meaningful trends.

Several of these forage species exhibited highly variable patterns of distribution and abundance. Pacific sandlance appear only sporadically in survey catches and in very small quantities. These typically small fish are generally not readily available to the bottom trawl, probably due to a combination of their vertical distribution within the water column and their ability to pass through the meshes of the survey trawl. A peak in catches was seen in the central Gulf in 1990 and was due to a single catch consisting of 150 individuals; 95% confidence intervals reveal the large variability in catches. Pricklebacks also typically occur in small quantities but in 2001, one unusually large catch of 123 kg (632 fish) in the central Gulf contrasted sharply with catch patterns from previous surveys. Similarly, in 2001, the increase in abundance of capelin in the central and eastern Gulf was influenced by a very few and unusually large catches. In 2003, Pacific sandfish in the eastern GOA had the highest CPUE (45 kg/km^2) of any year or area; however, this was influenced by a few large catches. In 2003, eulachon in the central GOA had the highest CPUE of any year or area with a few very large catches and many smaller catches. The Alaska Department of Fish and Game conducts an annual GOA small mesh survey and also observed record high catches of eulachon in 2003 (see page 132 of this report).

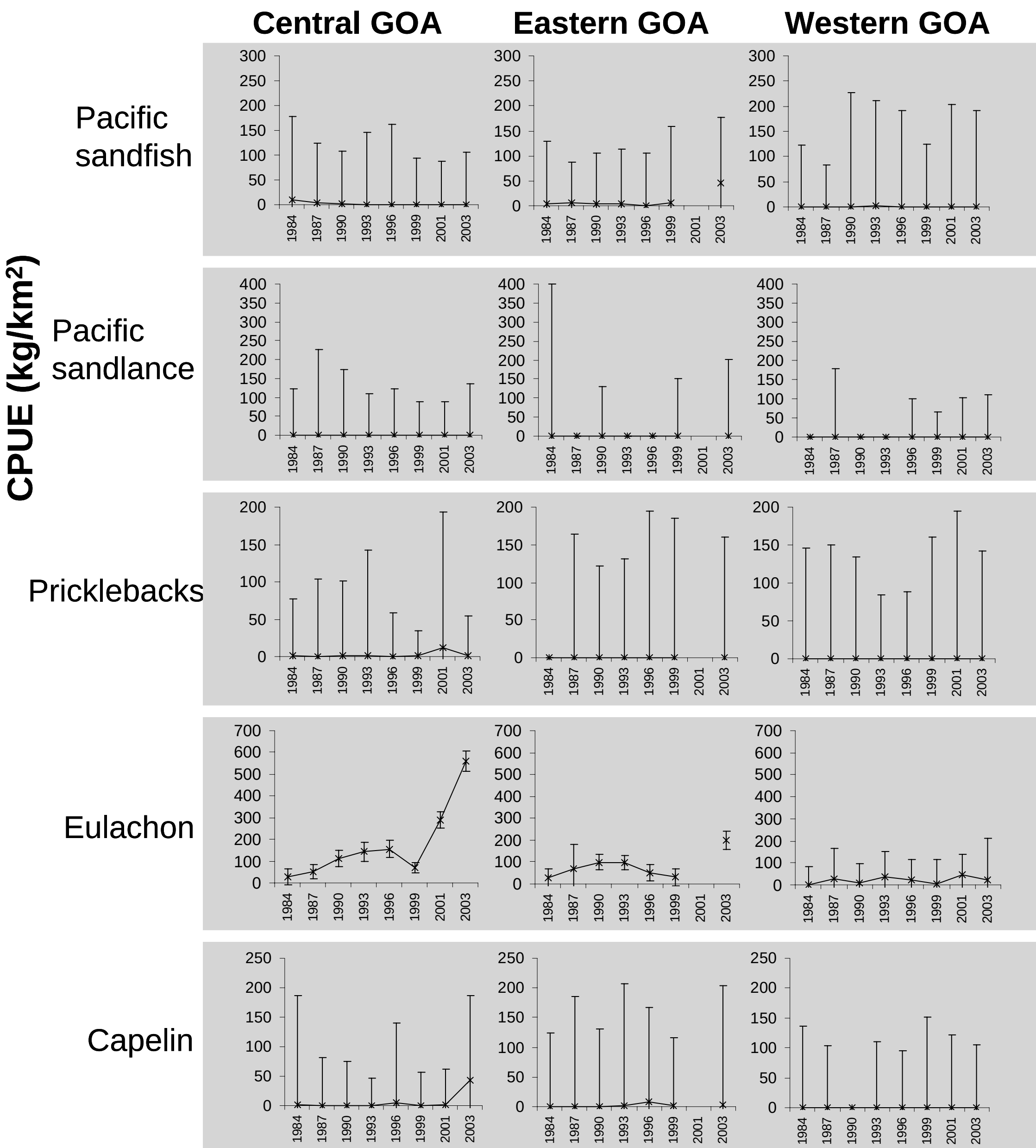


Figure 60. Catch per unit effort of forage fish per unit area in the central, eastern, and western Gulf of Alaska, in bottom trawl surveys conducted between 1984 and 2003. 95% confidence intervals are shown.

Forage – Eastern Bering Sea
Contributed by Gary Walters, Alaska Fisheries Science Center

Several groups have been defined as forage species by the North Pacific Fishery Management Council for management purposes. These groups include: gunnels, lanternfish, sandfish, sandlance, smelts, stichaeids, and euphausiids. Some of these groups are captured incidentally in the RACE bottom trawl survey of the shelf, which may provide an index of abundance (Figure 61). Sandfish appeared in the trawl surveys in the early 1990's but did not appear to be abundant in other years until 2003, which had the highest catches in the time series (Figure 61). Stichaeids, which likely include the longsnout prickleback (*Lumpenella longirostris*), daubed shanny (*Lumpenus maculatus*) and snake prickleback (*Lumpenus sagitta*), are small benthic-dwelling fish. Their relative abundance in trawl survey catches was relatively low from 1982 to 1998, and has been very low since then. Similarly, sandlance biomass appeared to be increasing in survey catches in the 1990's, but has been very low since 1999. Eulachon CPUE appeared to be relatively stable in the 1990's to the present. Capelin catches in the survey have been relatively stable with the exception of one year (1993) when CPUE was very high (Figure 61).

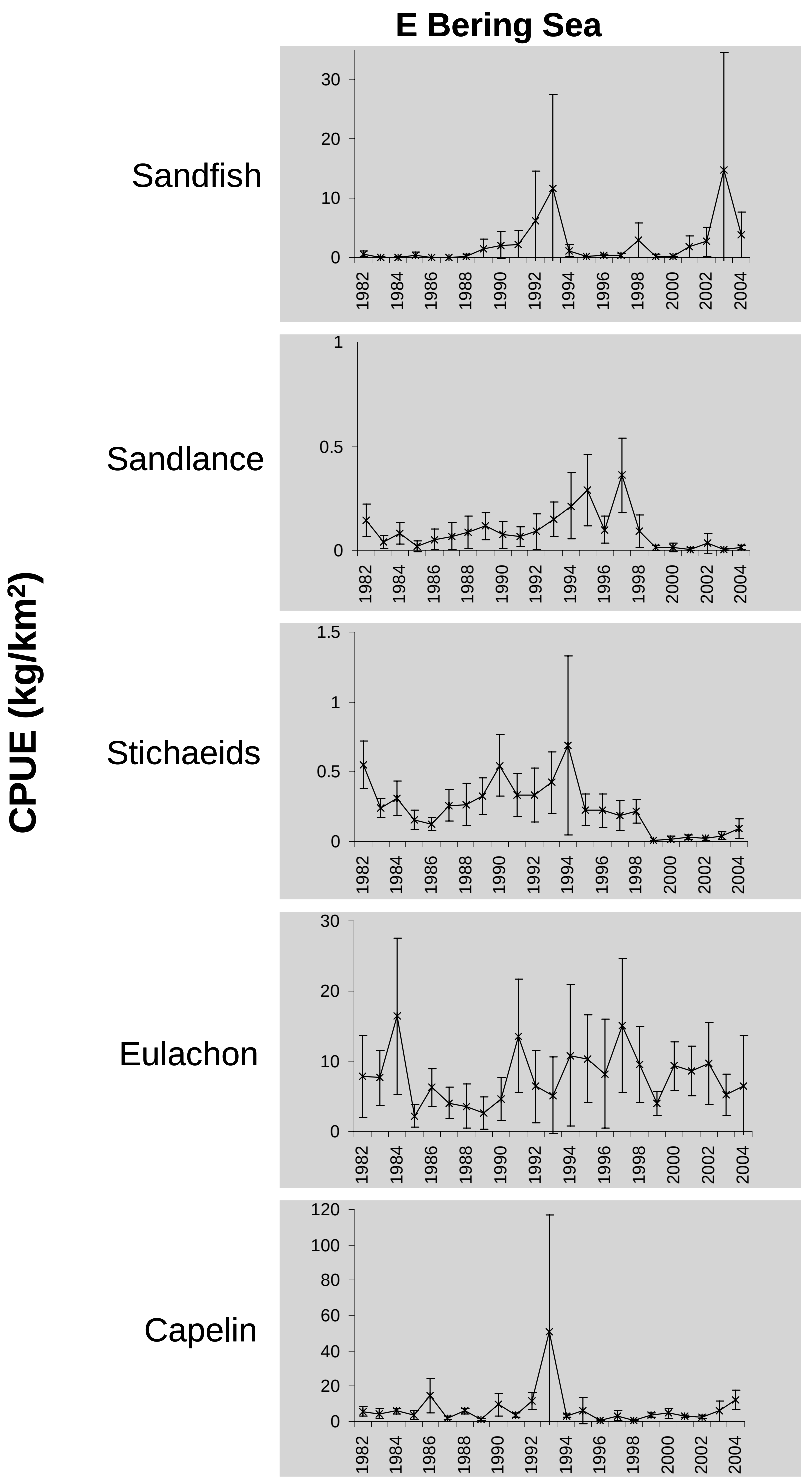


Figure 61. CPUE of several forage fish groups from the eastern Bering Sea summer bottom trawl survey, 1982-2004. 95% confidence intervals are shown.

Forage – Aleutian Islands
Contributed by Eric Brown, Alaska Fisheries Science Center

Several groups have been defined as forage species by the North Pacific Fishery Management Council for management purposes. These groups include gunnels, lanternfish, sandfish, sandlance, smelts, stichaeids, and euphausiids. Some of these groups are captured incidentally in the RACE bottom trawl survey of the shelf, which may provide an index of abundance (Figure 62). This survey is not designed to assess these organisms and further detailed examinations of these results are needed to assess whether there are meaningful trends.

The Aleutian Islands forage species appear only sparingly in survey catches with occasional higher than normal catches. The spike of Pacific sandfish seen in the western Aleutian Islands in 1986 is a result of only 4 individuals appearing in one catch. Similarly, the highest catch rates for pricklebacks, eulachon and capelin are driven by only two to three unusually high catches. The large increase in pricklebacks seen in the western Aleutians in 1991 was attributable to only three catches, the largest being less than 8 kg. The high abundance of eulachon in the western Aleutians in 1994 was due to only two unusually large catches of 431 kg and 63 kg while the high cpue of capelin in the southern Bering Sea in 2000 was the result of one very unusually large catch of 221 kg.

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

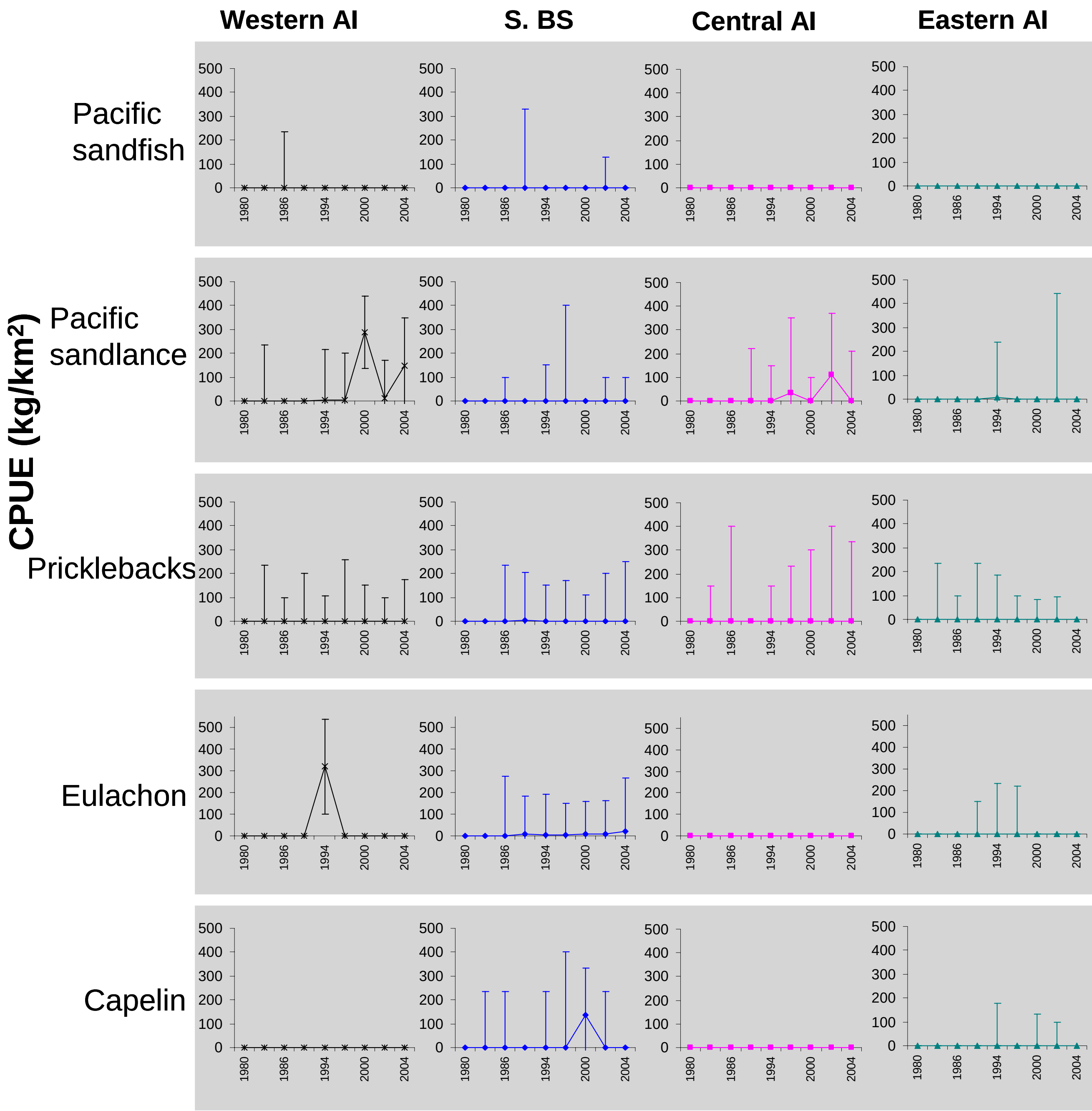


Figure 62. Catch per unit effort of forage fish per unit area in the western Aleutian Islands (AI), southern Bering Sea (BS), central AI, and eastern AI, in bottom trawl surveys conducted between 1980 and 2004. 95% confidence intervals are shown.

Herring

Prince William Sound Pacific Herring

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The Alaska Department of Fish and Game (ADF&G) has completed Pacific herring stock assessments in Prince William Sound (PWS) since ~1973. Population trends were initially monitored with aerial surveys to estimate biomass and the linear extent of beach used for spawning (Brady 1987), and have continued almost without interruption through 2004. Age, sex, and size data has been collected from most fisheries and spawning aggregations since 1973 (e.g., Baker et al. 1991). Dive surveys to estimate spawning biomass began with feasibility studies in 1983 and 1984 and continued in 1988-1992 (Brown and Baker 1998) and 1994-1997 (Willette et al. 1999). In 1993, ADF&G in cooperation with the Prince William Sound Science Center began fall acoustics surveys (Thomas and Thorne 2003). Spring acoustics surveys began in 1995 and have continued in March of each year, 1995-2004. Age structured models have been used since 1993 to estimate historical population parameters and project future biomass, recruitment, and abundance (Funk 1994).

In the 1980s a strong recruitment occurred approximately every four years (Figure 63). The recruitment as age-3 fish from the 1984 and 1988 year classes were particularly large (~ 1 billion fish in 1988). The prefishery run biomass estimate peaked in 1988 and 1989 at >100,000 metric tons (mt; Figure 64). The 1993 biomass projection was >100,000 mt; however, the 1993 observed biomass was < 30,000 mt (Marty et al. 2003). The stock collapsed and the biomass has remained (1993 – 2004) at levels less than half of the 1980-1992 average of 84,000 mt.

The Prince William Sound Pacific herring fishery is managed to allow harvest of 0-20% of the biomass above a spawning biomass threshold of 22,000 tons (20,020 mt). Since the stock collapse in 1993, purse seine sac roe harvest has only occurred in 1997 and 1998 (2 of 13 years). The fishery is also closed for the fall 2004 and spring 2005 fisheries because the projected biomass is under the threshold spawning biomass.

The variability of recruitment in Prince William Sound herring is probably at least related to large-scale environmental factors (Williams and Quinn 2000), smaller-scale environmental factors (Norcross et al. 2001) and disease (Marty et al. 2003, 2004). Disease assessments conducted from 1993 through 2002 indicate that viral hemorrhagic septicemia virus (VHSV) and associated ulcers were related to population declines in 1993/1994 and 1998; and *Ichthyophonus hoferi* was related to a population decline in 2001 (Marty et al. 2004). The age-structured assessment model currently used by ADF&G was selected among several models that include disease information (Marty et al. 2004).

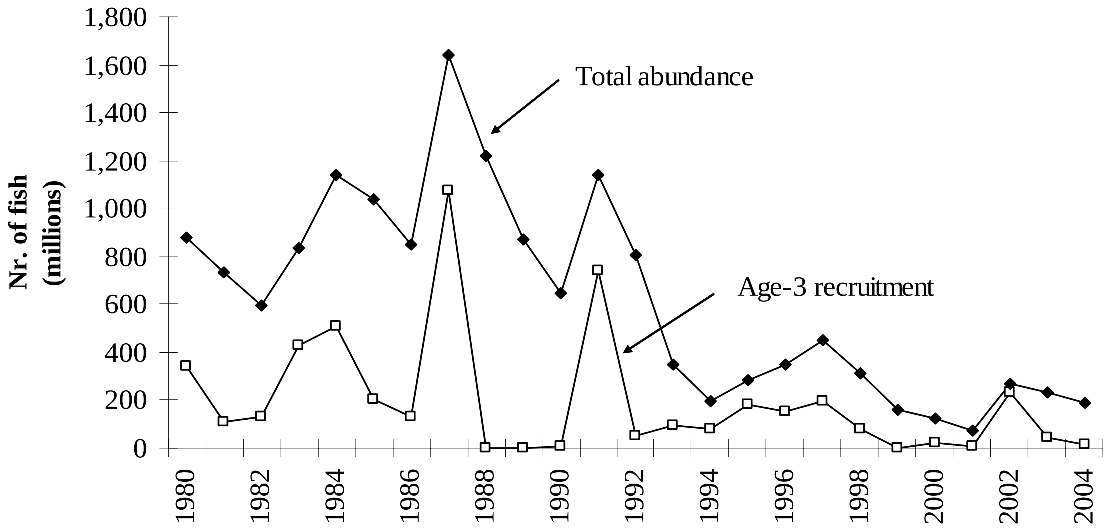

Figure 63. Age-3 recruitment and total prefishery abundance of Pacific herring in Prince William Sound, 1980-2004. The abundance values are outputs of the age-structured model used to produce the 2005 projections.

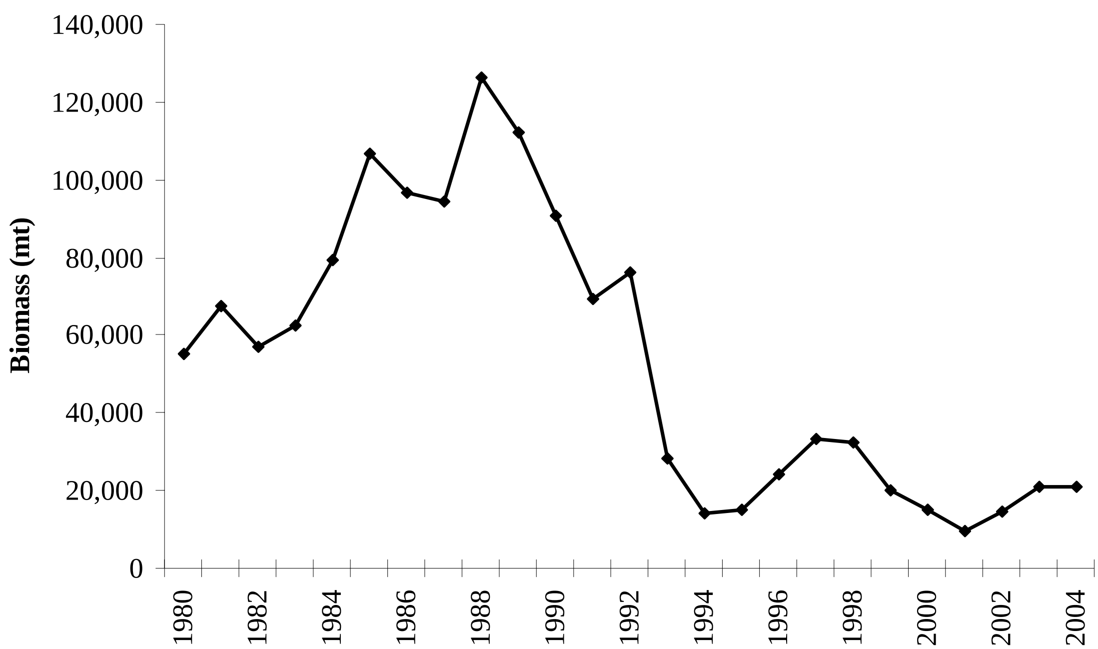

Figure 64. Prefishery run biomass (metric tons) of adult Pacific herring in Prince William Sound, 1980-2004. The biomass values are calculated from the age-structured model used to produce the 2005 projections.

Southeast Alaska Herring

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

Herring stock assessments have been conducted each fall by the Alaska Department of Fish and Game at nine spawning areas in Southeast Alaska for most years since 1980. Recurrent, annual spawning and biomass levels have warranted yearly stock assessment surveys, and potential commercial harvests, at these locations during most of the last 22 years. More limited spawning occurs at other locales throughout S.E. Alaska. However, other than aerial surveys to document shoreline miles of spawning activity, little stock assessment activity occurs at these locations. Spawning at the nine primary sites for which regular assessments are conducted have probably accounted for 95-98% of the spawning biomass in S.E. Alaska in any given year.

Herring spawning biomass in S.E. Alaska often changes markedly from year to year, rarely exhibiting consistent, monotonic trends (Figure 65). Since 1980 seven of the nine primary locations have exhibited long term trends of at least slightly increasing biomass, one area (Craig) has not shown any long term trend, and biomass in one area (Kah Shakes/Cat Island) has had a pronounced downward trend. There have been major fluctuations around these long-term trends with periods of both increasing and decreasing trends over the shorter term. Since 1997, southeast Alaska spawning herring biomass has been above the long-term median of 75,299 tons (1980-2003; Figure 65). The 2001 and 2003 estimates of spawning biomass were the highest of the 24-year time series (Figure 65). Since 1980 herring biomass at Sitka has contributed 37 to 64% (median: 56%) of the total annual biomass among the nine spawning locations. Excluding the Sitka biomass from a combined estimate, S.E. Alaska herring biomass has generally been above the 24-year median since 1997 (except in 2000).

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

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

Channel has declined in recent years, this decline may be at least partially attributable to a shift in spawning grounds to Annette Island, bordering Revillagigedo Channel.

A threshold management policy in S.E. Alaska allows for harvests ranging from 10 to 20% of forecast spawning biomass when the forecast biomass is above a minimum threshold biomass. The rate of harvest depends upon how much the forecast exceeds the threshold. Consequently, catch, at most areas, has varied roughly in proportion to forecast biomass (Figure 65).

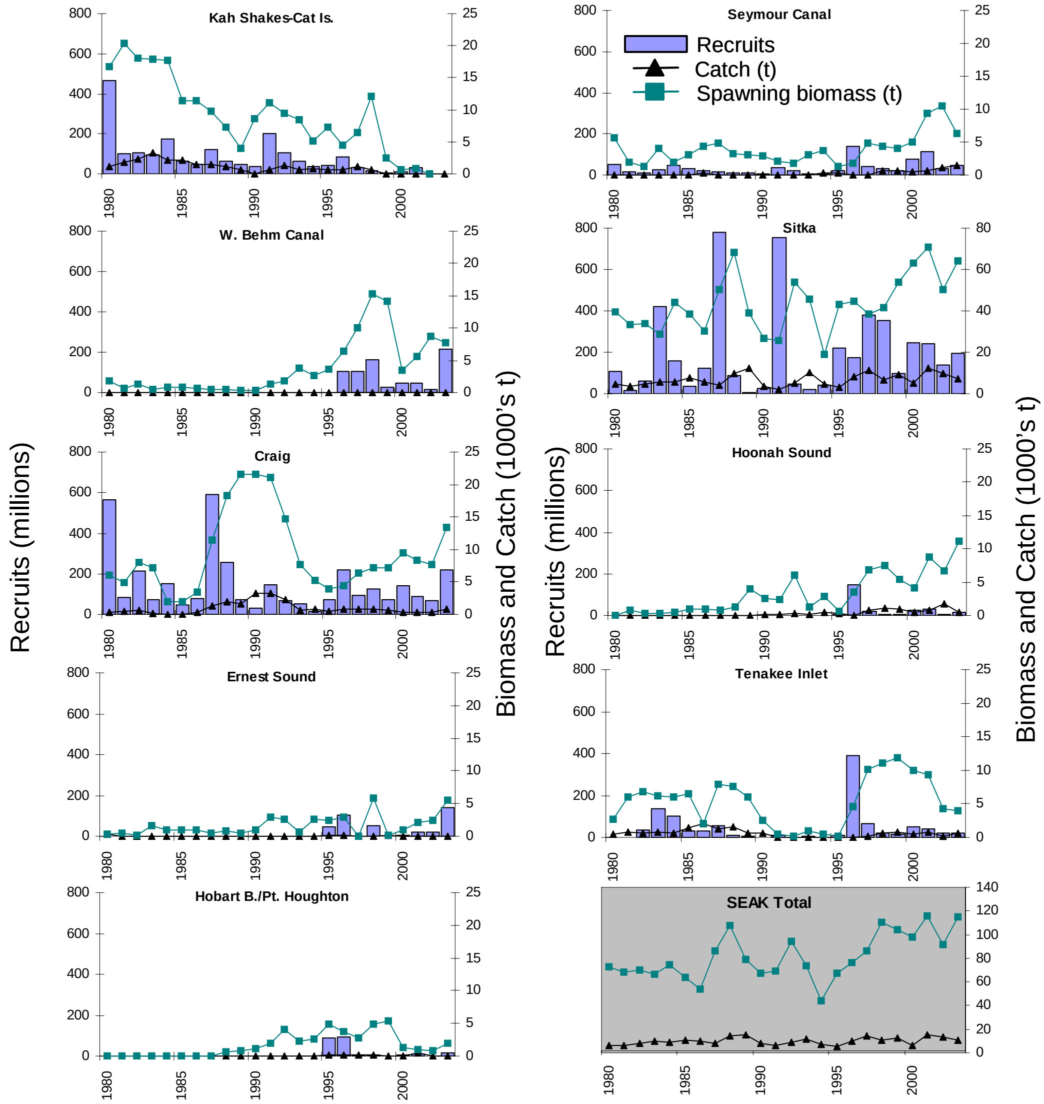

Figure 65. Estimated herring spawning biomass (tons), catch (tons), and age-3 recruits (millions of fish) in nine areas of S.E. Alaska, 1980-2003. Total biomass and catch for southeast Alaska (SEAK) is shown (bottom right panel). Recruits were not estimated in all years in all areas; therefore, missing values may not be zero estimates.

Togiak Herring Population Trends

Contribution by Fred West, Alaska Department of Fish and Game

An age-structured analysis model developed by Fritz Funk was used to assess Pacific herring population trends in the Togiak District of Bristol Bay (Funk et al. 1992). Abundance peaked in the early 1980's with approximately 2.5 billion fish when herring from the 1977 and 1978 year classes recruited into the fishery as age-4 fish in 1981 and 1982 (Figure 66). Beginning in 1983, total abundance steadily declined until modest recruitment events occurred in 1991 and 1992 from the 1987 and 1988 year classes. We are currently seeing moderately strong recruitment from the 1996 and 1997 year classes that recruited into the fishery in 2000 and 2001. Temporal trends in Togiak herring abundance show that total abundance in much of the 1980s was above the 1978 - 2003 average but fell below in 1989 and has remained below average since, with the exception of slightly above average values in 1991 and 1992 (Figure 66).

The high abundance estimates in the early 1980's may be a result of projecting backwards from the ASA model which was used beginning in 1993. The aerial survey data for the same time period conflicts with those estimates yielding much lower biomass estimates. This has not yet been resolved, but the aerial survey data is currently being used to "ground truth" the ASA estimates. With the 1996 and 1997 recruitment entering the fishery in strength now, and the outlook that recent mild years should also provide substantial recruitment to the stock, the status of the Togiak herring stock has been changed from "nominal decline" to "stable".

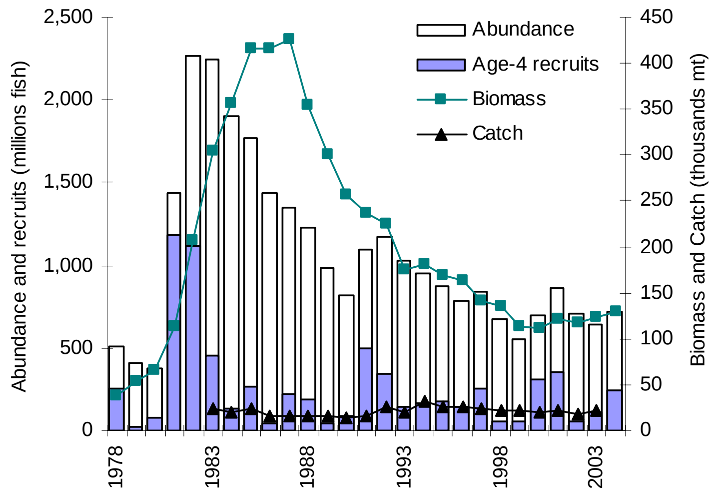

Figure 66. Total abundance, age-4 recruits, mature biomass, and total harvest of Pacific herring in the Togiak District of Bristol Bay, 1978 – 2004.

Pacific herring recruitment trends are highly variable, with large year classes occurring occasionally at regular intervals of approximately every 9-10 years (Figure 66). These large recruitment events drive the Togiak herring population. Environmental conditions may be the critical factor that influences strength of herring recruitment. Williams and Quinn (2000) have demonstrated that Pacific herring populations in the North Pacific are closely linked to environmental conditions with temperature having the strongest correlation. A general consensus in fisheries points towards the larval stage of herring life history as being the most important factor for determining year class strength (Cushing 1975, Iles and Sinclair 1982). Ocean conditions relative to spawn run timing would greatly influence the strength of each year class. Closer examination of trends in sea surface temperature, air temperature, and Bering Sea ice cover specific to the Bristol Bay area may find a specific correlate for Togiak herring recruitment.

Salmon

Historical trends in Alaskan salmon

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With contributions from Lowell Fair (ADFG).

Overall Catch Trends

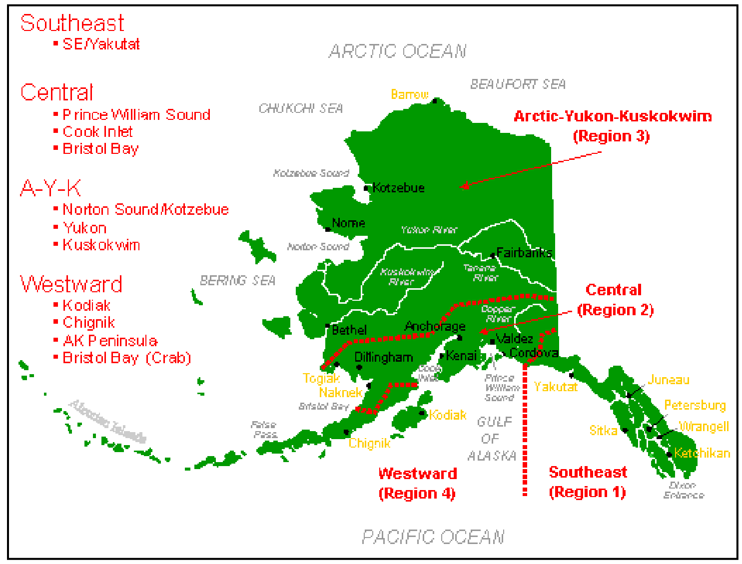


Figure 67. The four fishery management regions of the Alaska Department of Fish and Game, Division of Commercial Fisheries.

Pacific salmon rear in the Gulf of Alaska (GOA) and Central Bering Sea (BS) and are managed in four regions based on freshwater drainage areas, Southeast, Central (Cook Inlet, Prince William Sound, Bristol Bay), Westward (Alaska Peninsula, Chignik, Kodiak), and Arctic-Yukon-Kuskokwim (Figure 67). Salmon distribution throughout the GOA and BS varies by species and stock, some of which migrate between the two areas (K.W. Myers, University of Washington, personal communication). All salmon, except chinook, generally spend the majority of their ocean life in offshore pelagic waters, bounded by brief periods of migration through coastal areas as juveniles and returning adults. Chinook salmon migrate through coastal areas as juveniles and returning adults; however, immature chinook salmon undergo extensive migrations and can be found inshore and offshore throughout the North Pacific and Bering Sea (Morrow 1980). In summer, chinook salmon concentrate around the Aleutian Islands and in the western GOA (Morrow 1980).

Generally, Alaskan salmon stocks have been at high levels of abundance in the last 20 years (Figures 68, 70, and 72-74). Asian stocks have shown similar trends as Alaskan salmon. Salmon stocks in the Pacific Northwest and British Columbia were at lower levels in the 1980's and 1990's; however, since 1999 survival of some salmon stocks has improved. In Alaska, during the last decade, there have been some weak runs observed, particularly in certain areas of western Alaska, due to weak recruitment events. Notable examples include Yukon River fall chum, Yukon River summer chum, Yukon River chinook, and Kvichak River sockeye salmon. Observed weak yearclass strengths, however, have not been observed for most other Alaskan salmon stocks. For example, recruitment for most Bristol Bay sockeye salmon stocks other than Kvichak has been moderate to strong during this period, and most Bristol Bay stocks increased in 2003. The levels of recruitment observed for weak stocks during the recent period are not unprecedented. Similar levels of returns per spawner were observed for Bristol Bay sockeye during the 1960's to early 1970's. Trends in salmon production have been attributed to PDO scale variability (Hare and Francis 1995), ocean temperature (Downton and Miller 1998), and regional-scale sea surface temperatures (Mueter et al. 2002). A simple and comprehensive summary of stock status is not possible because long term assessments of stock specific catch and escapements by age are not available for some important salmon stocks (eg. Kuskokwim River, Noatak River, and important components of the Yukon River). The Alaska Department of Fish and Game is developing comprehensive stock assessment documents that will be available in the future.

Catch Trends by Species

Catch of salmon species by management area data was provided by Doug Eggers (Alaska Department of Fish and Game). A full report (Plotnick and Eggers 2004) of run forecasts and a review of the 2003 season is available on the web under "Forecasts" at:
http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/salmhome.php
Bristol Bay sockeye salmon catch and escapement data was provided by Lowell Fair (Alaska Department of Fish and Game).

SOCKEYE

Abundance of sockeye salmon in all areas increased from the mid 1970s to the 1980s (Figure 68). Since then the increased abundance has been stable and at high levels. Recruitment for most Bristol Bay sockeye salmon stocks other than Kvichak has been moderate to strong in the last decade (Figure 69). The levels of recruitment observed for weak stocks during the recent period are not unprecedented. Similar levels of returns per spawner were observed for Bristol Bay sockeye during the 1960 to early 1970's. Beginning with the 1973 brood year (>1979 return year) of Bristol Bay sockeye salmon, the number of returning adults produced from each spawner showed a dramatic increase across most stocks (Fair 2003). Poor returns in 1996-98, however, suggested a return to a level of productivity similar to the pre-1978 period (Fair 2003). Fish from the 1996-98 return years reared in the ocean when temperatures were above average, whereas, cooler than average ocean temperatures characterized the pre-1978 period. Recent ocean temperatures and returns to Bristol Bay in 1999 and 2003 suggest that returns in 2004 may be more characteristic of the 1978-95 period (Fair 2004).

PINK

Pink salmon catches increased in the late 1970's to the mid-1990's and have generally remained high in all regions in the last decade (Figure 70). Marine survival of Prince William Sound hatchery pink salmon appeared to increase after 1977, but does not appear to have shifted after the 1988/89 or the 1998/99 regime shifts (Figure 71). Hatchery pink salmon marine survival in 2003 was the second highest recorded during the 1977-2003 time period (Figure 71).

CHUM

Chum salmon are generally caught incidental to other species and catches may not be good indicators of abundance. In recent years chum salmon catch in many areas has been depressed by low prices (Figure 72). Directed chum salmon fisheries occur in AYK and on hatchery runs in Prince William Sound and Southeast Alaska. Chum salmon runs to AYK rivers have been declining in recent years (Figure 72). Chum salmon in the Yukon River and in some areas of Norton Sound have been classified as stocks of concern (Eggers 2003).

COHO

Coho catches have been moderate to high in all regions. Coho fisheries in Central and Western Alaska are not fully developed due to the late run and lack of processor interest. The coho catch in AYK from 1998 to 2003 has been lower than the previous decade, but still above catches in the 1960's and 1970's (Figure 73).

CHINOOK

Directed commercial chinook salmon fisheries occur in the Yukon River, Nushagak District, Copper River, and the Southeast Alaska Troll fishery. In all other areas chinook are taken incidentally and mainly in the early portions of the sockeye salmon fisheries. Catches in the Southeast Alaska troll fishery have been declining in recent years due to U.S./Canada treaty restrictions and declining abundance of chinook salmon in British Columbia and the Pacific Northwest. Chinook salmon catches have been moderate to high in most regions over the last 20 years (Figure 74). Chinook salmon production for many stocks in the Yukon River has been declining in recent years. These stocks have been classified as stocks of concern (Eggers 2003).

Average Weight of Returns

A period of high Alaskan salmon production from the mid-1970's to the late 1990's has been attributed to changes in ocean and atmospheric conditions that increased survival, as well as enhanced hatchery releases (Beamish and Bouillon 1993, Coronado and Hilborn 1998, Mantua et al. 1997). The increased production was accompanied by a decrease in average salmon weight at maturity, 1975-1993, which has been attributed to density dependence (Bigler et al. 1996, Ishida et al. 1993), sea surface temperature (Pyper and Peterman 1999, Hinch et al. 1995, Ishida et al. 1995), and sea surface salinity (Morita et al. 2001). Exceptions to this decreasing trend include AYK sockeye, pink, and chum salmon (Figure 75). The decreasing trend observed in other species and areas generally appears to have leveled off within the last decade (Figure 75).

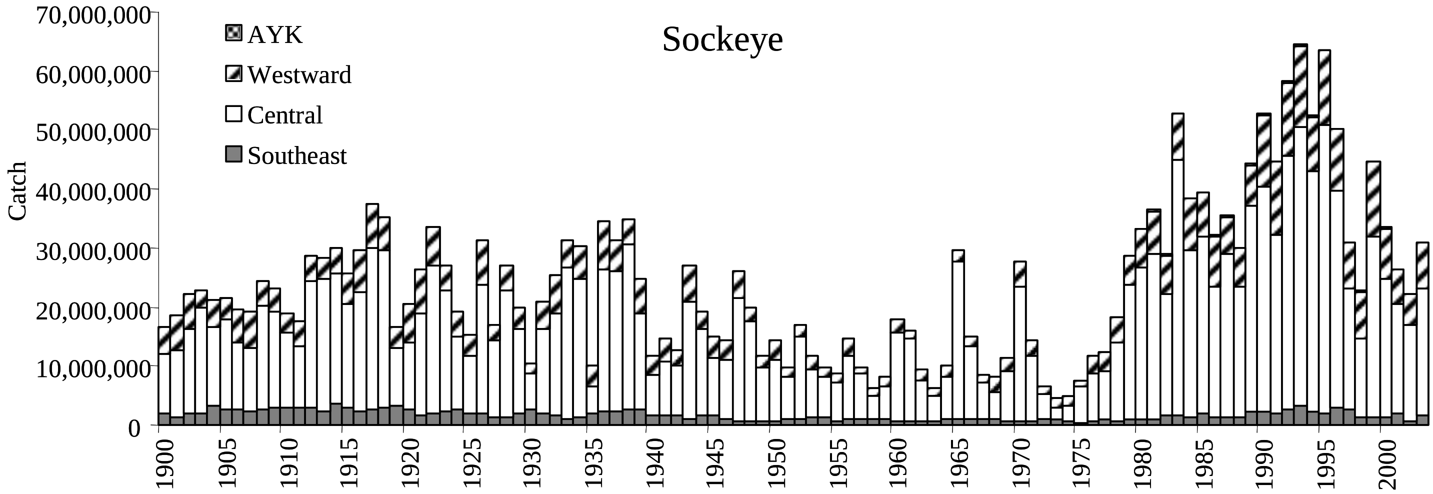


Figure 68. Historical catch of sockeye salmon by area in Alaska, 1900-2003.

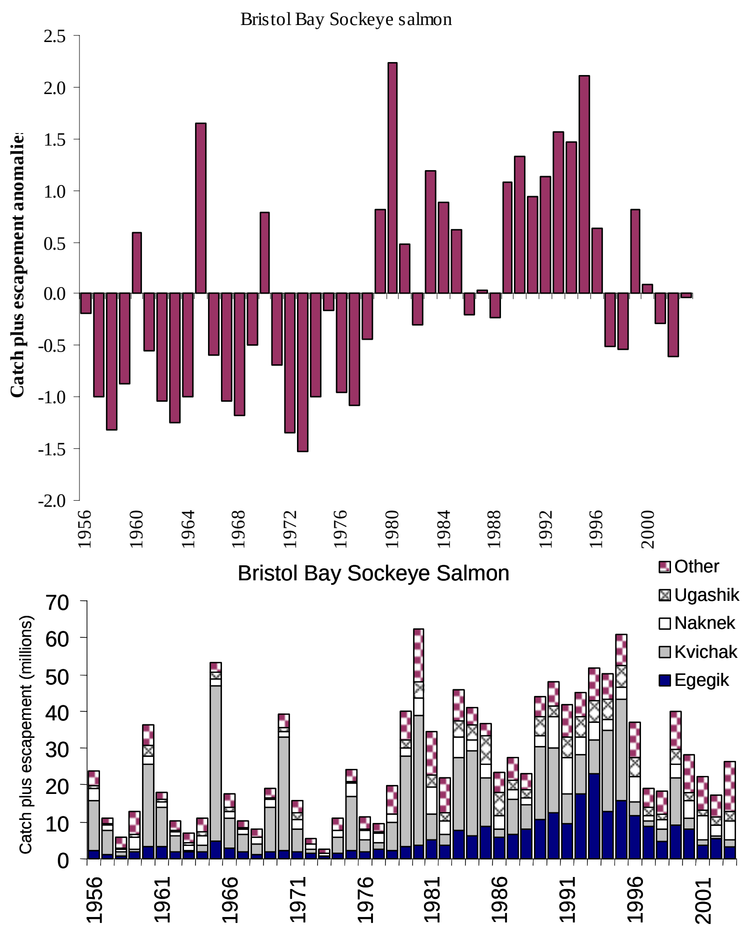


Figure 69. Historical catch plus escapement anomalies of Bristol Bay sockeye salmon, 1900-2003 (top panel). Bristol Bay sockeye salmon catch plus escapement by stock, 1900-2003 (bottom panel). Data provided by Lowell Fair (Alaska Department of Fish and Game).

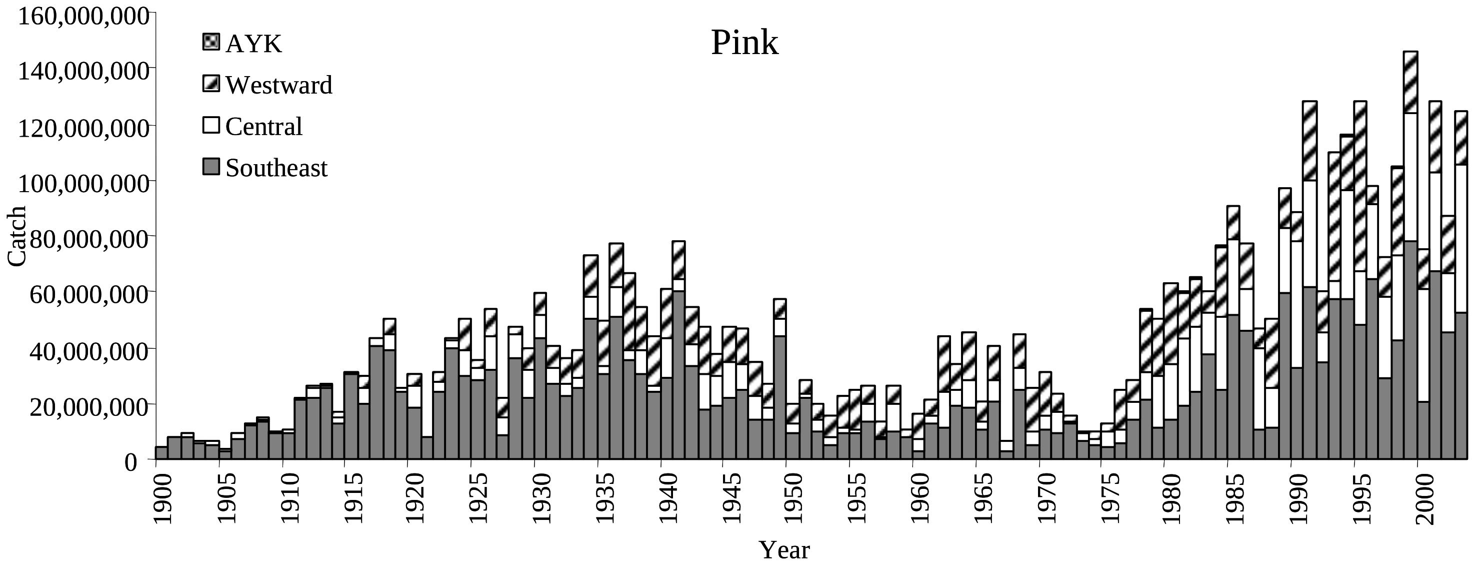


Figure 70. Historical catch of pink salmon by area in Alaska, 1900-2003.

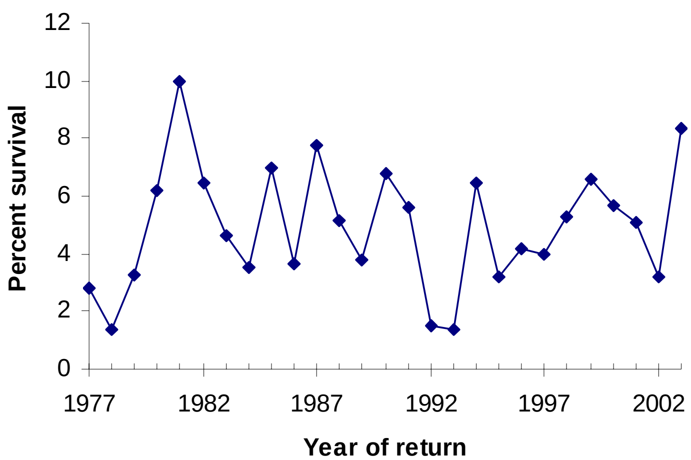


Figure 71. Marine survival of Prince William Sound hatchery pink salmon by year of return, 1977-2003. Data from 1977-2002 taken from Gray et al. (2002); 2003 data from Gray (Alaska Department of Fish and Game, personal communication).

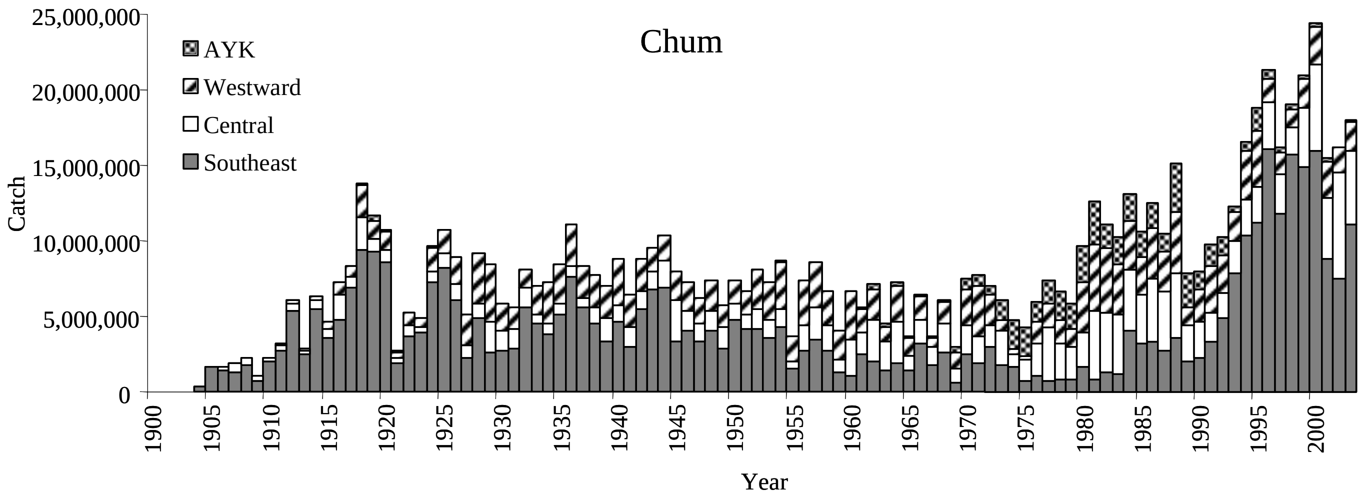


Figure 72. Historical catch of pink salmon by area in Alaska, 1900-2003.

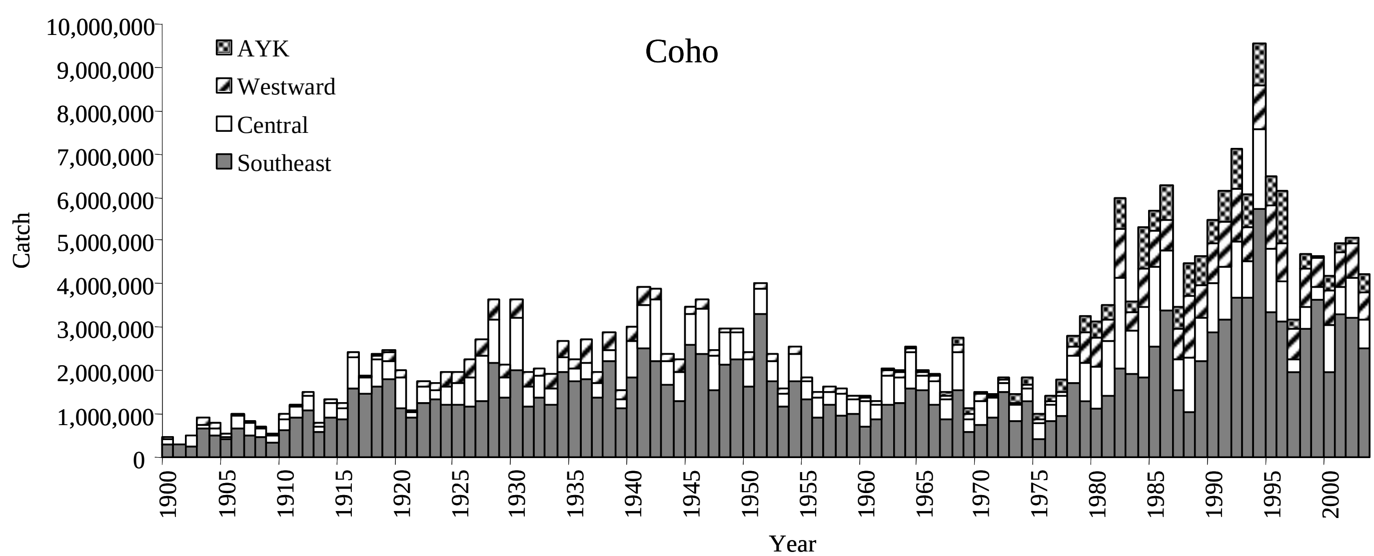


Figure 73. Historical catch of coho salmon by area in Alaska, 1900-2003.

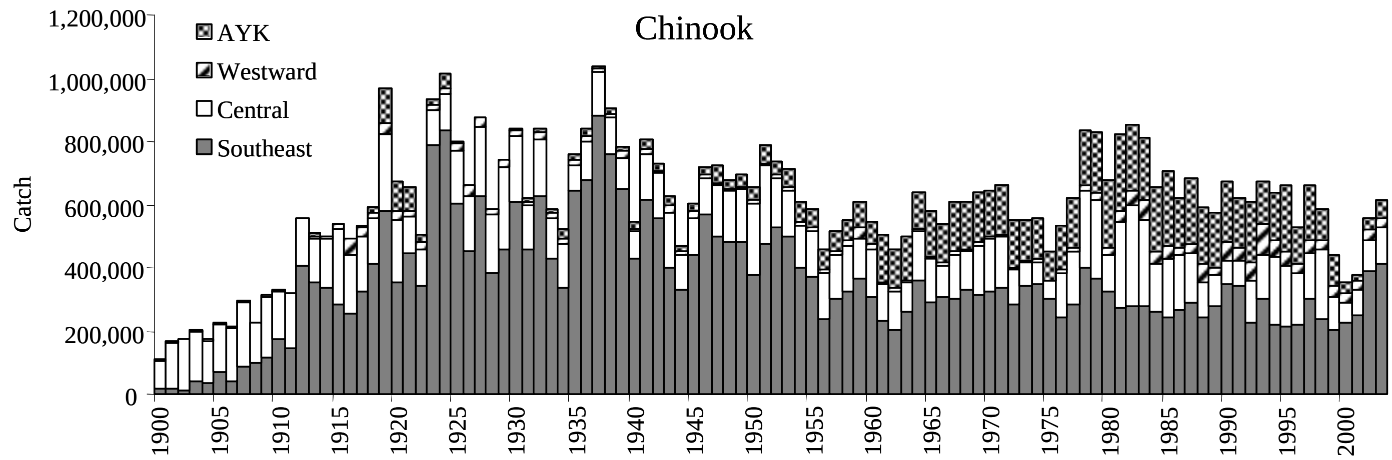


Figure 74. Historical catch of chinook salmon by area in Alaska, 1900-2003.

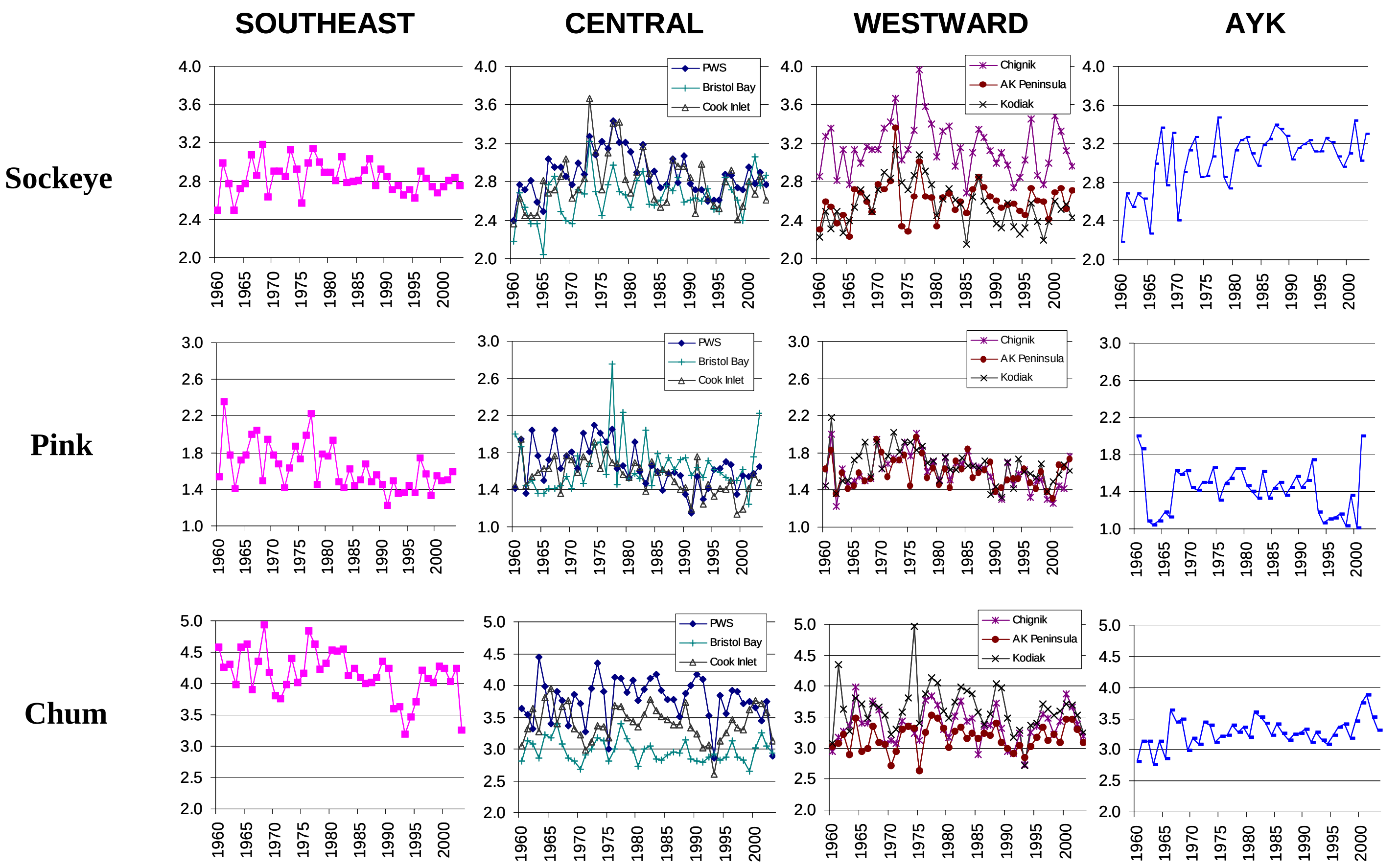


Figure 75. Average weight (kg) of sockeye, pink, and chum salmon in commercial fishery catch by management area, 1960-2003. Data for years 1960-1976 from INPFC (1979). Data for later years from the ADF&G fish ticket system.

Groundfish

Trends in Groundfish Biomass and Recruits per Spawning Biomass
By Jennifer Boldt, Elizabeth Conners, and the AFSC Stock Assessment Staff

Groundfish that are assessed with age- or size-structured models in the Bering Sea/Aleutian Islands (BSAI) and the Gulf of Alaska (GOA) show different trends (Figure 76). The assessment information is available in the NPFMC stock assessment and fishery evaluation reports (2003 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).

BIOMASS
Total biomass of BSAI groundfish was apparently low in the late 1970's but increased in the early 1980's to around 20 million metric tons. Some fluctuations in the total biomass have occurred, with biomasses below the 1978 to present average occurring in 1978-82 and 1990-91 (Figure 76). 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 76) are different from those in the BSAI. Although biomass increased in the early 1980's, as also seen in the BSAI, GOA biomass declined after peaking in 1982 at over 6 million metric tons. Total biomass has been fairly stable since 1985, however the species composition has changed. Pollock were the dominant groundfish species prior to 1986 but arrowtooth flounder has increased in biomass and is now dominant. The 2003 IPHC stock assessment of halibut, ages 6 and older, for the GOA (areas 2C, 3A, and 3B) indicates halibut biomass increased from 1978 to 1996 and declined slightly during 1997-2003. Biomass levels in 2003 were still well above the 1978-present average.

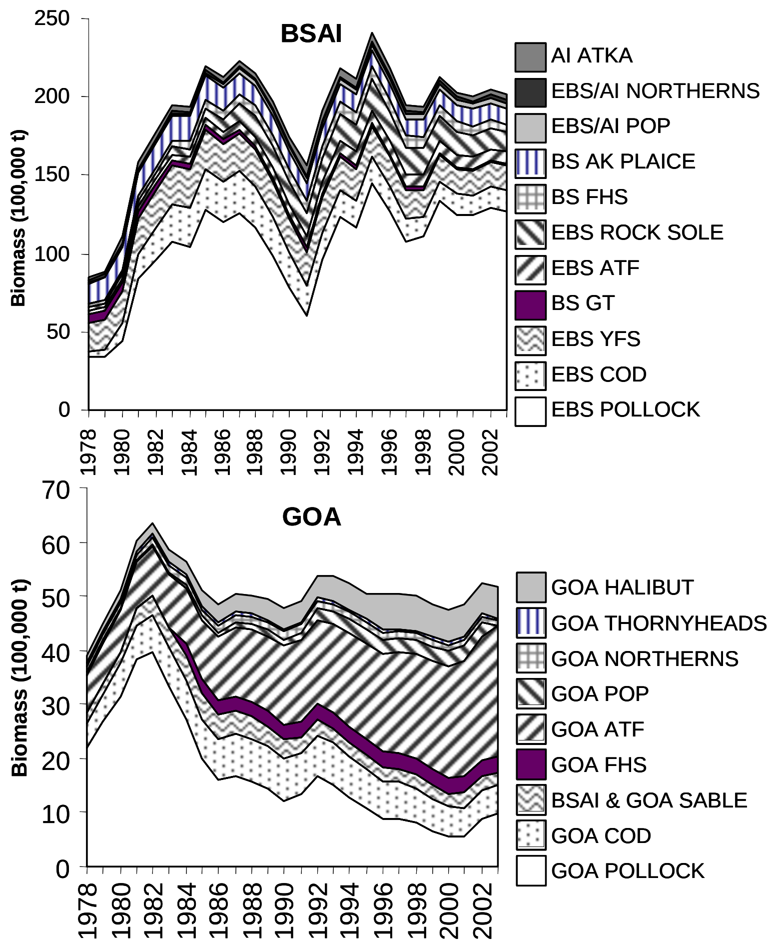


Figure 76. Groundfish and halibut biomass trends (metric tons) in the BSAI and GOA from 1978-2003, as determined from age-structured models of the Alaska Fisheries Science Center reported by NPFMC (2003 a, b) and by IPHC.

RECRUIT PER SPAWNING BIOMASS

Methods

Median recruit per spawning biomass anomalies were calculated for each species to provide an index of survival (Figures 77 and 78). 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. An analysis of recruitment is not included in this section. Recruit abundance of each species was lagged by the appropriate number of years to match the spawning biomass that produced them. For graphical display, the median of each time series was subtracted from the log-transformed recruit per spawning biomass ratios and expressed as a proportion of the median (Figures 77 and 78). Two analyses were conducted to test for differences in the index of survival over time:

1.) Kruskal and Wallis test on residuals that were averaged over years within each of four accepted North Pacific climate regimes: i.) pre-1976 (1960-1976), ii.) 1977-1988, iii.) 1989-1997, and iv.) 1998-2002;

2.) a non-parametric change-point analysis procedure (Lanzante 1996) was used to determine whether a discontinuity or a linear trend model best fit the entire time series data for each species.

Results

Kruskal and Wallis tests on residuals

Generally, climate regime-scale variability in recruit per spawner time series was detected in flatfish and rockfish, but not roundfish (pollock, cod, Atka mackerel, and sablefish) species (Figures 77 and 78 and Table 8). The 1988/89 shift was apparent in all winter spawning flatfish species of the Bering Sea but not the GOA (Table 8). Shifts in other flatfish of the Bering Sea were not detected, except Yellowfin sole which showed the 1976/77 shift. A shift in 1988/89 was detected in the survival of two rockfish species (EBS POP and GOA Northern rockfish) and a shift in 1976/77 was detected in three rockfish species (EBS POP, GOA POP, and GOA Thornyhead rockfish). No shift was seen in the EBS Northern rockfish time series (Table 8). The effect of fishing during the 1960's may have influenced the EBS POP recruit per spawner biomass ratios; therefore, the analysis was performed on recruits to reduce this effect. The results of this analysis were the same as that for recruit per spawners, indicating there was a shift in EBS POP survival in 1976/77 and 1988/89 (no shifts were seen in GOA POP recruits).

Change-point analysis results

The results of a non-parametric change-point analysis procedure indicate that a linear trend was the best fit model for most roundfish species, whereas, a discontinuity model provided the best fit for most flatfish and rockfish species in the BSAI and GOA (Table 9). Primary step changes in recruit per spawner time series were found for 12 of the 19 groundfish species, 6 of which were significant ($p<0.05$). There were three general time periods in which step changes were detected: 1968, 1974-79, and 1987-92. Winter spawning flatfish step changes typically occurred from 1987-92; most rockfish step changes occurred in the mid-1970's and 1980's.

Conclusions

The survival of roundfish does not appear to be related to decadal-scale climate variability as defined by the hypothesized 1976/77, 1988/89, or 1998 years of regime shifts. Examination of the average recruit per spawning biomass anomalies, however, indicates roundfish experience similar trends in survival within ecosystems. For example, pollock and cod have similar recruit per spawner trends within both the BSAI and GOA (Figure 79). Aleutian Island pollock and Atka mackerel (not included in this analysis) also show similar patterns in recruitment (Figure 79; Barbeaux et al. 2003). This may be an indication that roundfish respond in similar ways to large-scale climate changes that are not defined by the years of hypothesized regime shifts or are not detected with the type of analyses conducted in this study.

Flatfish survival does show decadal-scale variability in survival. In particular, the BSAI winter spawning flatfish (rock sole, flathead sole and arrowtooth flounder) show a negative shift in survival in the late 1980's. Examination of the recruitment of winter-spawning flatfish in the Bering Sea in relation to decadal atmospheric forcing indicates favorable recruitment may be linked to wind direction during spring (Wilderbuer et al. 2002; Figure 80). Years of consecutive strong recruitment for these species in the 1980s corresponds to years when wind-driven advection of larvae to favorable inshore nursery grounds in Bristol Bay prevailed (Figure 80). The pattern of springtime wind changed to an off-shore direction during the 1990s which coincided with below-average recruitment. Rockfish survival also appears to be related to decadal-scale variability; however, the mechanism is unknown. Also, recruit per spawning biomass ratios are autocorrelated in long-lived species, such as rockfish; however, analyses on recruits showed similar results as those conducted on the recruit per spawning biomass ratios for EBS POP.

Table 8. Summary of Kruskal-Wallis and multiple comparison tests performed on recruit per spawner ratios of groundfish in the Bering Sea and Gulf of Alaska. A "Y" indicates there was a significant difference between two adjacent time periods defined by one of the hypothesized regime shifts (1976/77, 1988/89, or 1997/98); an "N" indicates there was no significant difference between adjacent time periods; a "-" indicates there was not enough data available to test for a significant difference. df = degrees of freedom.

			Kruskal-Wallis results			Multiple comparison results		
Fish Type	Area	Species	Chi square	df	p-value	1977/66	1988/89	1997/98
Roundfish								
	Bering Sea/Aleutian Islands	Pollock	8.8300	3	**0.0316**[a]	N	N	N
		Cod	1.8527	2	0.3960	-	N	N
		Atka mackerel	4.0556	2	0.1316	-	N	N
	Gulf of Alaska	Sablefish	4.1486	2	0.1256	N	N	-
		Pollock	13.6968	3	**0.0033**[b]	**Y**	N	N
		Cod	6.5785	2	**0.0373**	-	N	N
Flatfish								
Winter spawning	Bering Sea/Aleutian Islands	Arrowtooth flounder	14.7273	1	**0.0001**	-	**Y**	-
		Rock sole	14.1869	1	**0.0002**	-	**Y**	-
		Flathead sole	17.4306	2	**0.0002**	-	**Y**	N
Other	Bering Sea/Aleutian Islands	Yellowfin sole	26.2741	3	**0.0000**[b]	**Y**	N	-
		Greenland turbot	8.7036	2	**0.0129**[b]	N	N	-
		Alaska plaice	0.6111	1	0.4344	-	N	-
Winter spawning	Gulf of Alaska	Flathead sole	1.0000	1	0.3173	-	N	-
		Arrowtooth flounder	4.4061	2	0.1105	N	N	-
Rockfish								
	Bering Sea/Aleutian Islands	Pacific Ocean perch	18.2099	2	**0.0001**	**Y**	**Y**	-
		Northern rockfish	1.6000	1	0.2059	-	N	-
	Gulf of Alaska	Pacific Ocean perch	20.0752	2	**0.0000**	**Y**	N	-
		Northern rockfish	4.8286	1	**0.0280**	-	**Y**	-
		Thornyhead rockfish	16.1450	2	**0.0003**[a]	**Y**	N	-

[a] No significant difference was detected among adjacent time periods; however, the pre-1977 regime was significantly different from the post-1997 regime.

[b] No significant difference was detected among adjacent time periods; however, the pre-1977 regime was significantly different from the 1988-97 regime.

Table 9. Years of step changes or linear trends detected in recruit per spawner time series of groundfish in the Bering Sea/Aleutian Islands and the Gulf of Alaska with non-parametric change-point analyses (Lanzante 1996). All models, both linear and discontinuity, are shown with the associated Rtn (for linear models) and Rdn (for discontinuity models) and p-values. In cases where a linear trend model fit the data, R^2 and p-values are shown. In some cases, more than one model or step-change was found. Bold font indicates significant results ($p<0.05$).

Fish Type	Area	Species	Model number	Models	Years	Rdn or Rtn**	R^2	Approximate p-value
Roundfish								
	Bering Sea/Aleutian Islands	Pollock	1	Linear trend	1964-2002	0.655	0.282	**0.001**
		Cod	1	Discontinuity	1982	0.681		0.260
		Atka mackerel	1	Linear	1977-2000	0.037	0.072	0.204
		Atka mackerel	2	Discontinuity	1984	0.106		0.118
	Gulf of Alaska	Sablefish	1	Linear trend	1960-1999	0.365	0.033	0.260
		Pollock	1	Linear trend	1969-2001	0.035	0.247	**0.003**
		Cod	1	Linear trend	1977-2001	0.317	0.427	**0.000**
Flatfish								
Winter spawning	Bering Sea/Aleutian Islands	Arrowtooth flounder	1	Discontinuity	1988	0.618		0.114
		Rock sole	1	Discontinuity	1987	*		**0.000**
		Flathead sole	1	Linear trend	1977-2000	2.314	0.609	**0.000**
Other	Bering Sea/Aleutian Islands	Yellowfin sole	1	Linear trend	1964-1998	1.521	0.413	**0.000**
		Greenland turbot	1	Discontinuity	1979	1.484		0.064
		Greenland turbot	2	Discontinuity	1983	0.459		**0.000**
		Greenland turbot	3	Discontinuity	1990	0.720		**0.000**
		Greenland turbot	4	Discontinuity	1986	0.366		**0.000**
		Alaska plaice	1	Discontinuity	1980	0.894		0.135
Winter spawning	Gulf of Alaska	Flathead sole	1	Discontinuity	1992	*		**0.000**
		Arrowtooth flounder	1	Discontinuity	1968	0.773		**0.003**
		Arrowtooth flounder	2	Linear trend	1968-1997	0.402	0.485	**0.000**
		Arrowtooth flounder	3	Discontinuity	1979	0.372		**0.000**
		Arrowtooth flounder	4	Discontinuity	1989	0.637		**0.000**
Rockfish								
	Bering Sea/Aleutian Islands	Pacific Ocean Perch	1	Discontinuity	1974	0.291		**0.000**
		Pacific Ocean Perch	2	Discontinuity	1986	0.686		**0.000**
		Pacific Ocean Perch	3	Discontinuity	1980	0.410		**0.000**
		Pacific Ocean Perch	4	Discontinuity	1969	0.604		**0.000**
		Northern rockfish	1	Discontinuity	1989	*		**0.000**
	Gulf of Alaska	Pacific Ocean Perch	1	Discontinuity	1976	0.306		0.129
		Northern rockfish	1	Discontinuity	1984	*		0.201
		Thornyhead rockfish	1	Linear trend	1967-1993	0.283	0.409	**0.000**

* time series has less than 20 data points; therefore, a complete analysis could not be performed.

** Rtn is the ratio of the linear trend model to the noise; Rdn is the ratio of the discontinuity model to the noise. The best-fit model was chosen based on the Rtn and Rdn values. If Rtn was greater than Rdn, the linear trend was the best-fit model. If Rdn was greater than Rtn, the best-fit model was the discontinuity.

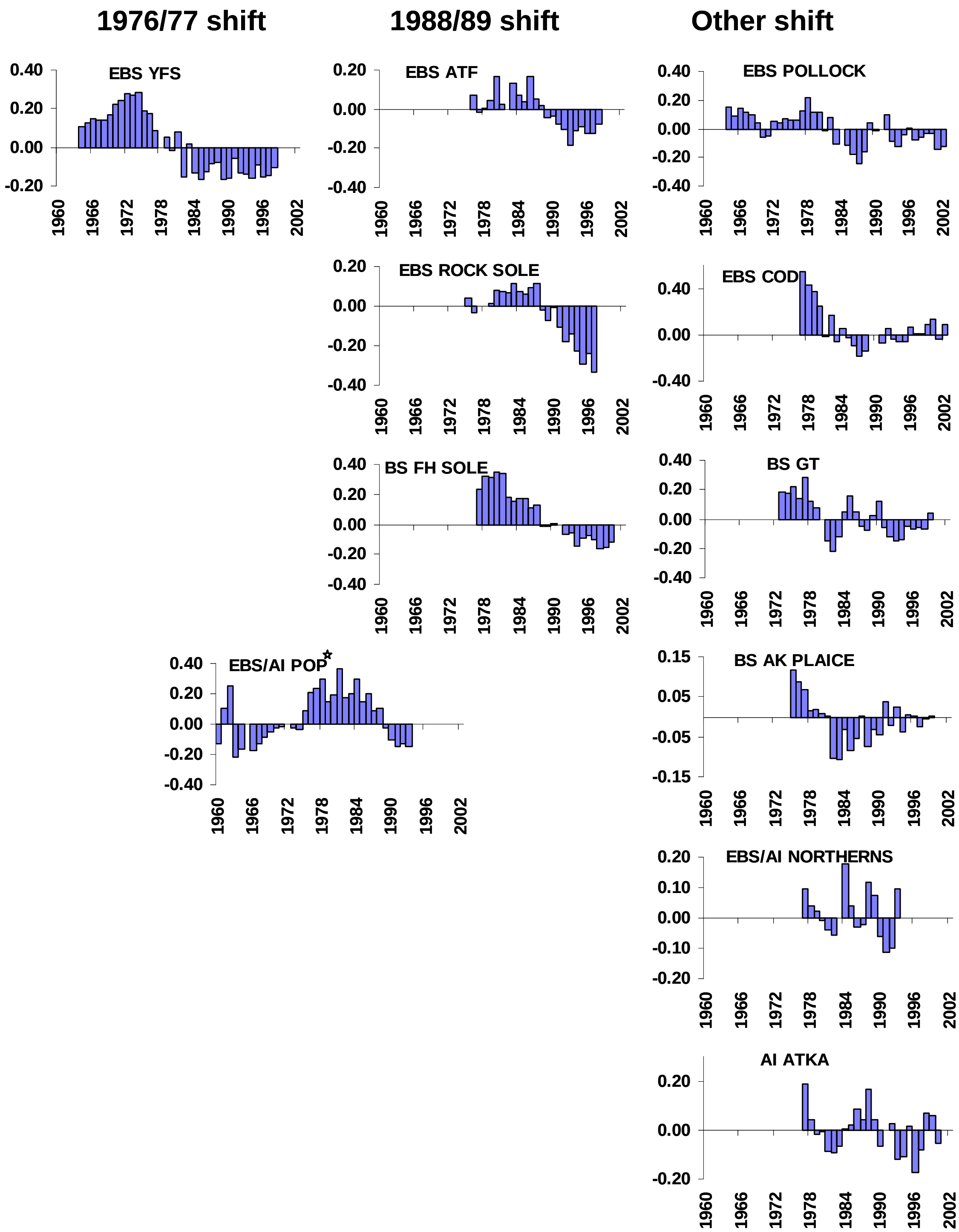


Figure 77. Median recruit per spawning biomass anomalies for BSAI groundfish species assessed with age- or size-structured models, 1960-2002. EBS = Eastern Bering Sea, BS = Bering Sea, AI = Aleutian Islands, YFS = yellowfin sole, ATF = arrowtooth flounder, FH sole = flathead sole, POP = Pacific Ocean perch, GT = Greenland turbot, Atka = Atka mackerel.

*EBS/AI POP showed a shift in 1976/77 and 1988/89.

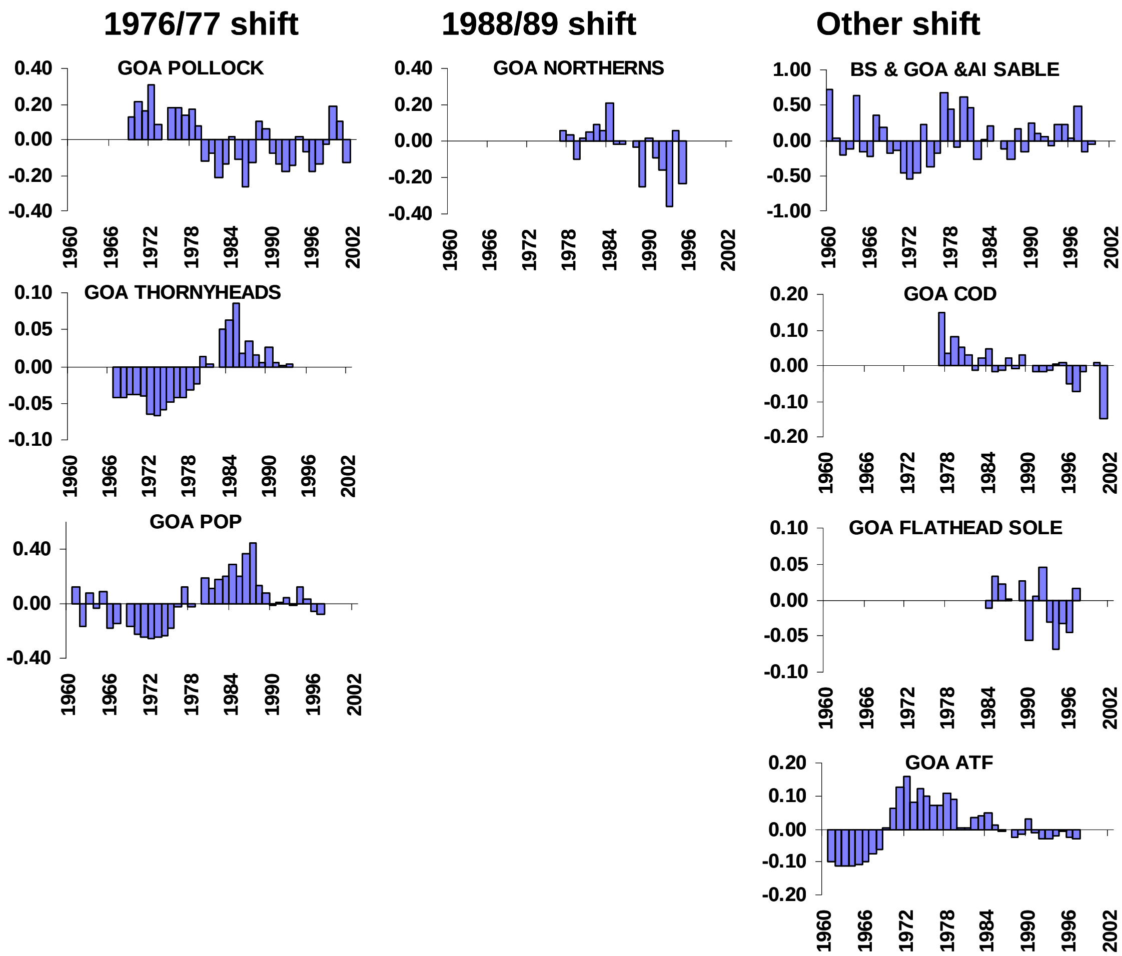


Figure 78. Median recruit per spawning biomass anomalies for GOA groundfish species assessed with age- or size-structured models, 1960-2002. Note: full data set for GOA POP was not available at time of analyses but will be updated in the future (i.e. data that extends back to 1960 exists). GOA = Gulf of Alaska, ATF = arrowtooth flounder, POP = Pacific Ocean perch, Sable = sablefish.

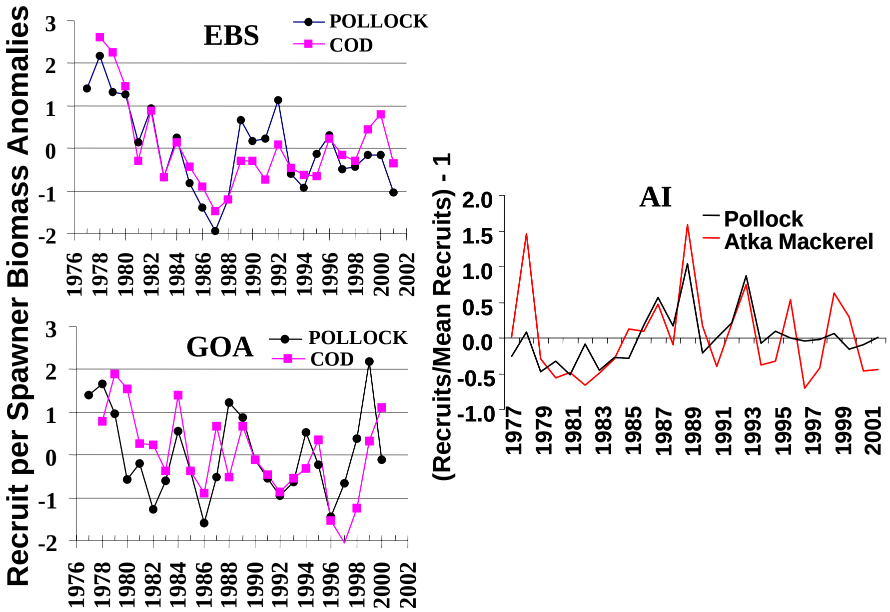


Figure 79. Recruit per spawner anomalies of BSAI and GOA pollock and cod and Aleutian Islands pollock and Atka mackerel (lagged back one year) recruits expressed as a proportion of mean recruits. Atka mackerel spawn in the summer and pollock spawn in the winter; therefore, the Atka mackerel were lagged by one year, to match the yearclasses that experienced similar conditions (modified from Barbeaux et al. 2003)

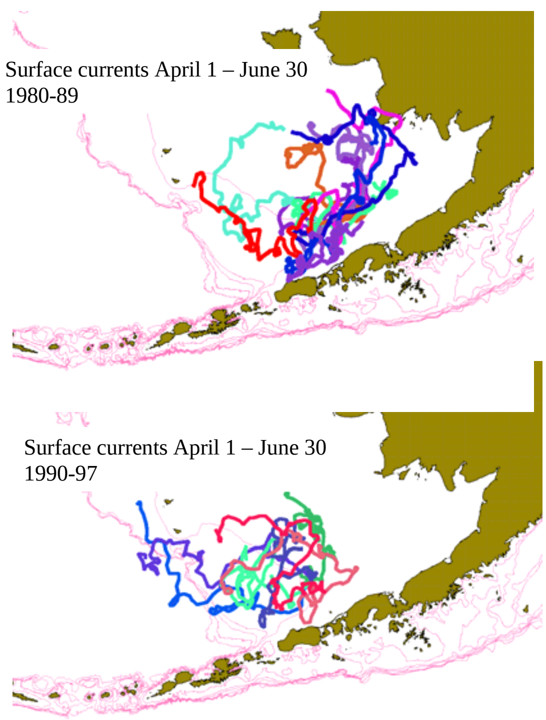


Figure 80. OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56° N, 164° W from April 1 – June 30 for the 1980's (upper panel) and 1990-96 (lower panel). Figure adapted from Wilderbuer et al. (2002).

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

A previous Ecosystem Considerations chapter (2002) on groundfish summarized a study examining the recruitment of winter-spawning flatfish in relation to decadal atmospheric forcing, linking favorable recruitment to the direction of wind forcing during spring. OSCURS model time series runs indicated in-shore advection to favorable nursery grounds in Bristol Bay during the 1980s. The pattern change to off-shore in the 1990- 97 time series coincided with below-average recruitment. The time series is updated (1998-2004; Figure 81) for the last 7 years.

Five out of six OSCURS runs for 1998-2003 were consistent with those which produced above-average recruitment in the original analysis, 2000 being the exception. The north-northeast drift pattern suggests that larvae may have advected to favorable, near-shore areas of Bristol Bay by the time of their metamorphosis to a benthic form of juvenile flatfish.

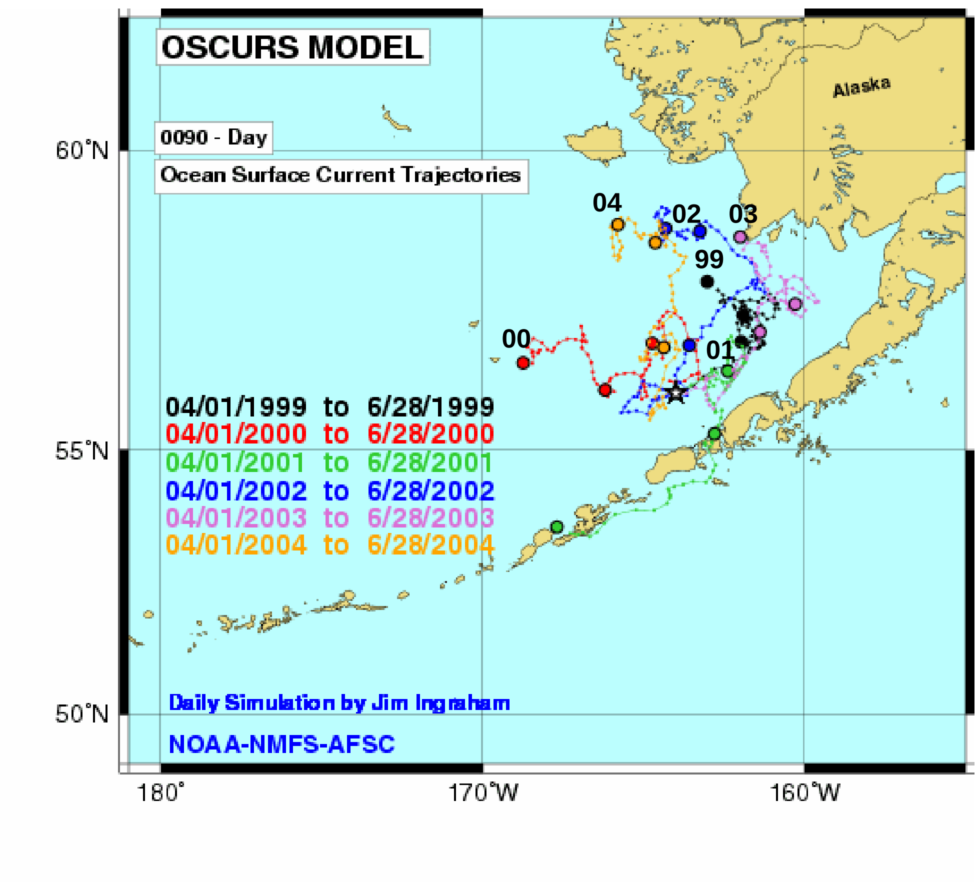


Figure 81. OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56° N, 164° W from April 1-June 30 for 1999-2004.

Relationships between flatfish spatial distributions and the cold pool from 1982-2003.
Principal Investigator: Paul Spencer (Alaska Fisheries Science Center – REFM)

Previous studies have noted that the relationship between habitat use of EBS flatfish (as measured by CPUE from summer trawl surveys) and temperature has generally remained constant over time (Swartzman et al. 1992), motivating the hypothesis that flatfish may shift distributions in order to maintain temperature preferences. Recent bottom temperatures in the EBS show considerable contrast and thus provide opportunity to examine the relationship of flatfish distributions to temperature variability. For example, 1999 was one of the coldest years on record and a warming trend has occurred since 2000 such that 2003 was one of the warmest years observed. The average latitude and longitude, by year, of the surveys stations within the "cold pool" (defined as water < 2° C) from the 1997 to 2003 EBS shelf surveys is shown in Figure 82, as well as the annual centroids for individual species (average latitude and longitude of survey stations containing a particular species, weighted by CPUE). From 1998 to 1999, the centroid of the cold pool moved to the southeast and was at its lowest latitude observed during the time period 1982-2003. The warming trend since 2000 is revealed in the northwest movement of the cold pool centroid such that the 2003 centroid is at it highest latitude observed from 1982-2003.

The centroids of many flatfish populations, including yellowfin sole, rock sole, flathead sole, and arrowtooth flounder, also appear to have moved to the southeast in 1999, presumably in response extreme environmental conditions. Scaled time series (1982-2003) of the location of the cold pool and flatfish centroids along an axis running from the southeast to northwest EBS shelf are shown in Figure 83a. Although most species do not show a significant statistical relationship to the location of the cold pool over the entire time series from 1982-2003, the pattern of a southeast movement across several species in 1999 is observed in these time series. This finding suggests that flatfish habitat selection is related not only to sea floor characteristics, but is also influenced by temporally varying environmental conditions.

A significant relationship was found between the centroids of the cold pool and flathead sole from 1982 to 2003, indicating that flathead sole centroids are generally not found in the northwest during very cold years. The diet of flathead sole consists of a greater proportion of fish than other small flatfish, and one hypothesis is that flathead sole distributions may be linked to prey fish populations which in turn may be related to temperature. Alternatively, another hypothesis is that flathead sole temperatures in more northwestern areas of the EBS shelf may be outside the preferred temperature range during cold years. Additional research will investigate these hypotheses.

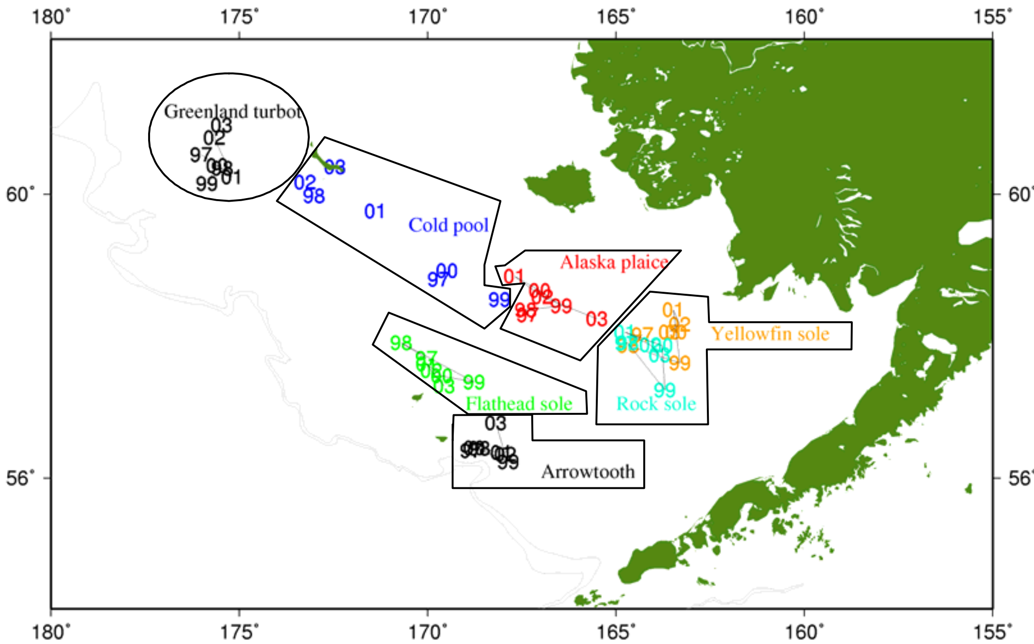


Figure 82. Centroids of various flatfish species and the cold pool in the EBS from 1997-2003, as derived from summer bottom trawl surveys. Lines are drawn around the centroids and cold pool for visual display only.

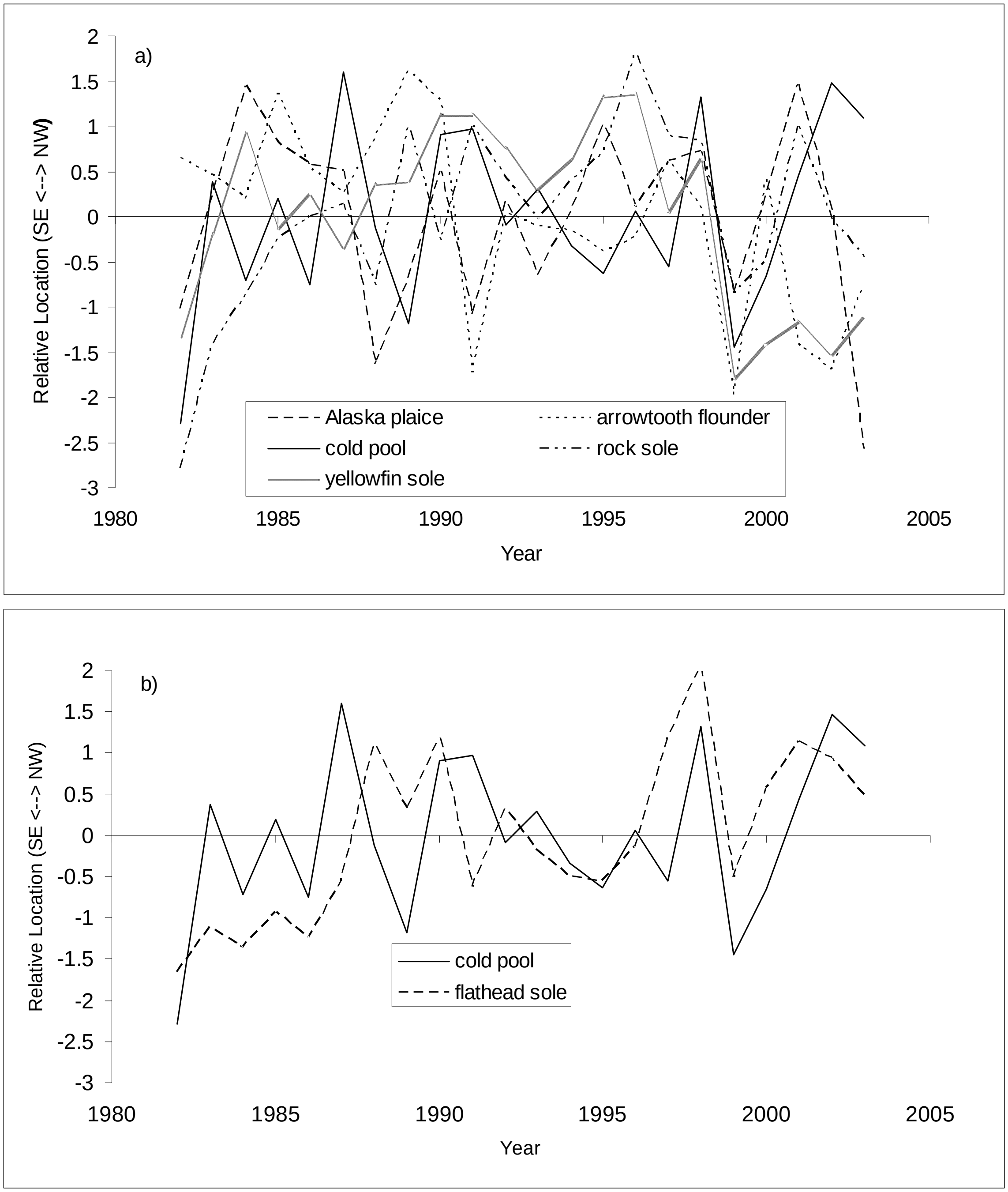


Figure 83. a) Normalized time series of centroid location along a southeast-northwest axis from 1982 to 2003, indicating the shift to the southeast for several species in 1999. The time series of flathead sole and the cold pool (b) are significantly related at the 0.05 level.

Benthic Communities and Non-target Fish Species

ADF&G Gulf of Alaska Trawl Survey

Contributed by Dan Urban, Alaska Department of Fish and Game, 211 Mission Road, Kodiak, Alaska 99615, Ph. 907-486-1849; email: dan_urban@fishgame.state.ak.us

The Alaska Department of Fish and Game continued its trawl survey for crab and groundfish in 2004. The 400 Eastern trawl net is targeted on areas of soft substrate around Kodiak Island, the Alaska Peninsula, and the Eastern Aleutian Islands. While the survey covers a large portion of the central and western Gulf of Alaska, results from Kiliuda and Ugak Bays and the immediately contiguous Barnabas Gully (Figure 84) are broadly representative of the survey results across the region. These areas have been surveyed continuously since 1984, and Ugak Bay was also the subject of an intensive trawl survey in 1976 (Blackburn 1977). Ugak Bay continues to be a very different place than it was in 1976. Red king crabs were once a main component of the catch, but now are nearly non-existent. Tanner crab, flathead sole, and walleye pollock catch rates have all increased roughly 10-fold.

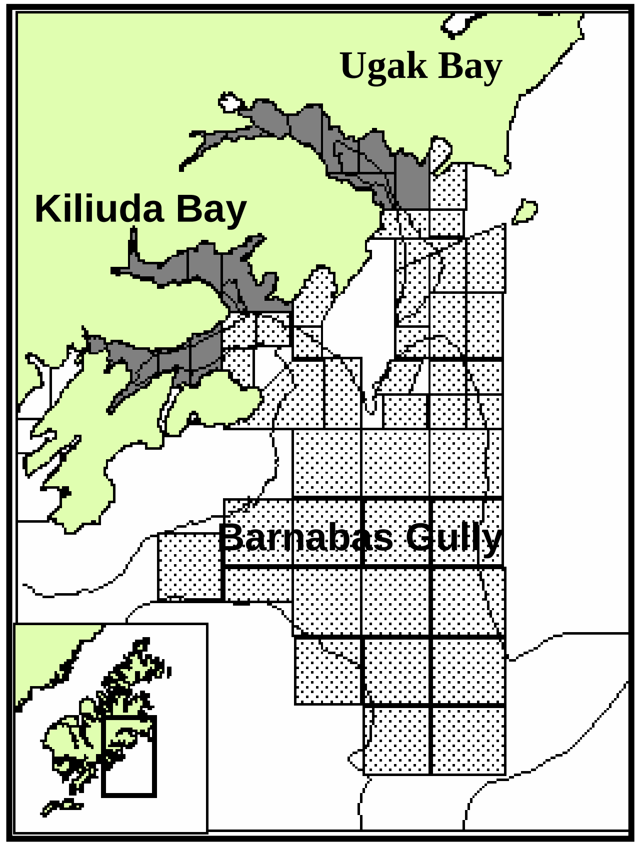
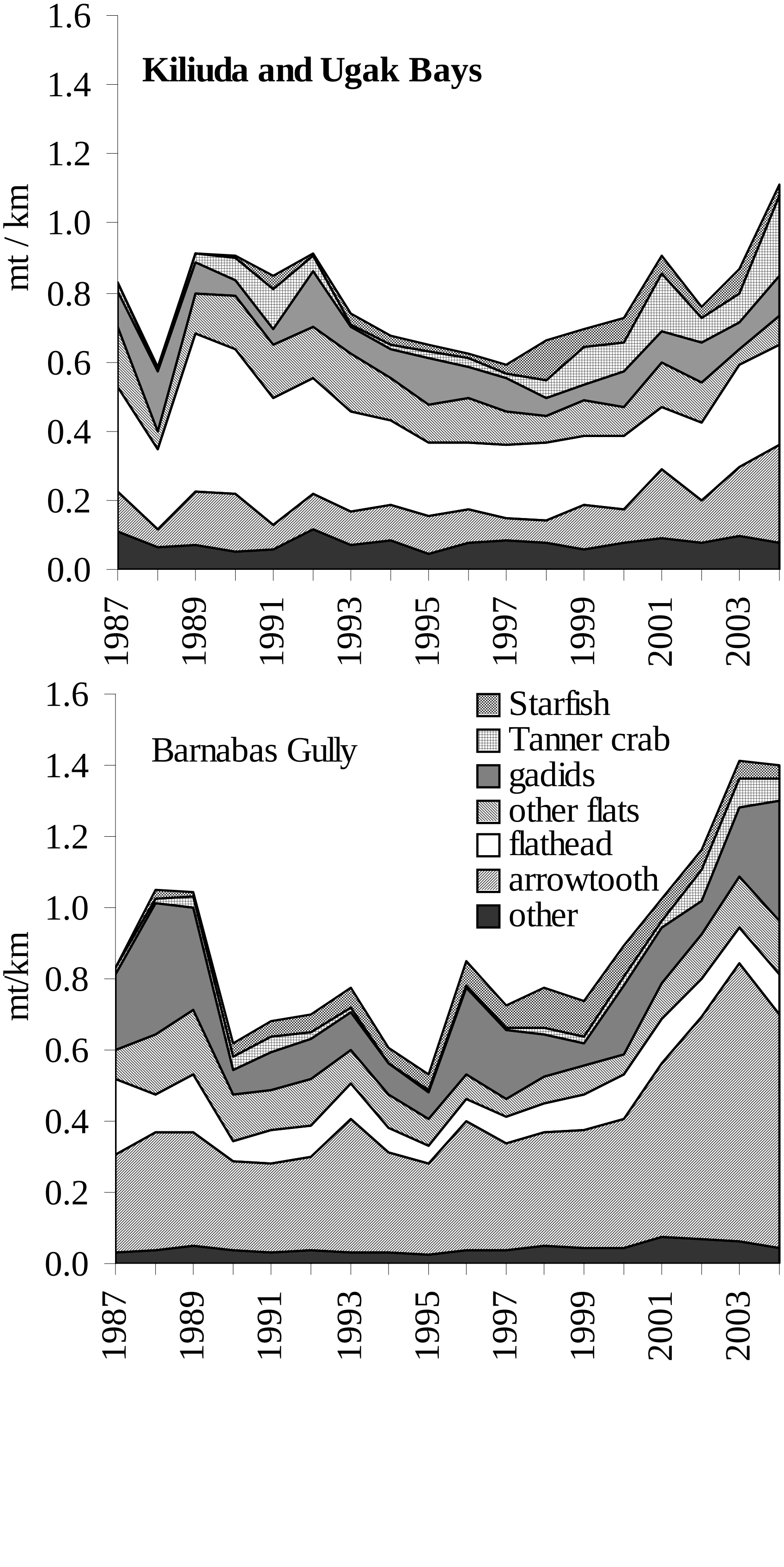


Figure 84. Adjoining trawl stations on the east side of Kodiak Island used to characterize nearshore (dark gray) and offshore (light gray) trawl survey results with the 100m contour indicated.

Arrowtooth flounder are a main component of both the offshore and bay catches (Figure 85). In 2004, arrowtooth flounder catches in Ugak and Kiliuda Bays equaled those of flathead sole which had been the main catch in most recent years. In Barnabas Gully, arrowtooth flounder catches declined but still remain at historically high levels. Gadid catches (80% walleye pollock) doubled in Barnabas Gully to the highest catch rates since 1988. The cause of these shifting catch rates is unknown.


Kiliuda and Ugak Bays
mt / km
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1987
1989
1991
1993
1995
1997
1999
2001
2003
Barnabas Gully
mt/km
Starfish
Tanner crab
gadids
other flats
flathead
arrowtooth
other

Gulf of Alaska Small Mesh Trawl Survey Trends

Contributed by Paul J. Anderson, Kodiak Fisheries Research Center, 301 Research Court, Kodiak, Alaska 99615; (907) 486-3915; email: pj.anderson@usa.net

Summary of the Data Series: Small-mesh trawl surveys for shrimp were conducted by the National Marine Fisheries Service (NMFS) and the Alaska Department of Fish and Game (ADF&G) from 1953 to 2003. Over 90% of survey tows were conducted in May - October. Sampling areas were designated by early exploratory surveys that had the purpose of locating commercial quantities of shrimp. Early surveys had shown that shrimp concentrate in relatively deep locations in the inshore bays and gullies of the GOA (Ronholt 1963). Consequently, most survey tows were restricted to depths greater than 55 m. After 1971 survey strata were designed for all known major shrimp concentrations in the central and western GOA. Random tow sampling locations within each stratum were selected for each survey from 1972 to present. Prior to 1972, trawls were conducted with a variety of small-mesh gear having different catch efficiencies. From 1972 onward, ADF&G and NMFS standardized methods and used "high-opening" trawls with 32 mm stretched-mesh throughout (Anderson 1991). Catch per unit effort (CPUE) was calculated as kg caught per km trawled. Between 1953 and 2003, 9,412 trawls covering 18,068 km were conducted. Annual effort averaged 250 trawls per year (range: 22-775).

The Gulf of Alaska (GOA) marine ecosystem undergoes periodic changes in trophic structure which have become known as regime shifts. Analysis of 50 years of small mesh trawl sampling in the GOA showed changes in species abundance linked to changing oceanographic parameters (Piatt and Anderson 1996, Anderson et al. 1997, Anderson and Piatt 1999, Anderson 2000). The extent and degree of these changes are documented and will become important in determining future strategies for management of the marine ecosystem. Analysis of the historic data is a first step in gaining an appreciation for the rapid and abrupt change that occurred in the marine species complex. The data from small-mesh shrimp trawl cruises provides an opportunity to review long-term changes in the composition of forage species and other epibenthic fish and invertebrates from 1953 to the present.

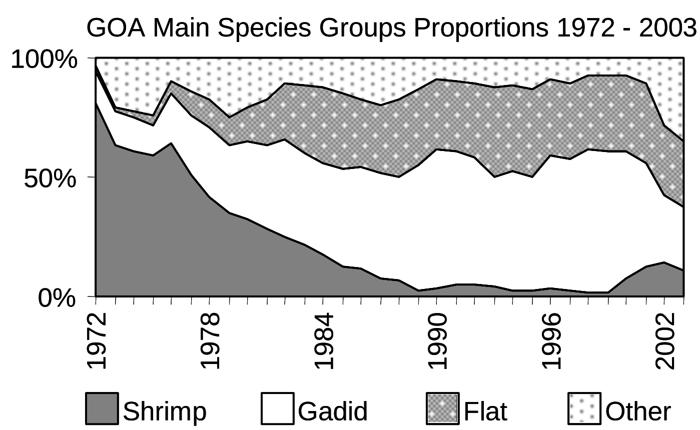


Figure 86. Small-mesh trawl survey porportional catch composition of main species groups in the Gulf of Alaska 1972 - 2003. Shrimp (all Pandalid shrimp species); Flat (all flatfish species); Gadid (all cod species and walleye pollock); Other (all other species combined).

Recent data indicate the GOA went through a relatively brief period of community restructuring after 1999, which now appears to have halted. Most of the recent data in the database came from the ADF&G small mesh survey in 2001 (96 tows), 2002 (108 tows), and 2003 (138 tows) (Ruccio 2003, Jackson 2003, Jackson 2004). These surveys were primarily concentrated around Kodiak Island and the adjacent Alaska Peninsula area. This area did show changes occurring in the species community composition (Figure 86). However additional surveys conducted by NMFS to the west along the Alaska Peninsula (Pavlof Bay in 2001- 2003) and by ADF&G in 2002 west of 158° W showed none of the composition shifts evident in the Kodiak area. This spatial partitioning in changing community structure needs to be studied and better understood. The changes in the Kodiak area were striking, and suggest that community composition oscillates between two systems, one dominated by cod and some flatfish species and another dominated by shrimp, forage fish, and possibly over time other crustaceans, such as commercial species of crab.

Further in depth analysis of the data will be needed to discern possible spatial patterns that may exist. Complementary surveys will be continued in the fall of 2004 by ADF&G. Results from this continuing survey series will be used to improve estimates of long-term species abundance trends and community structure.

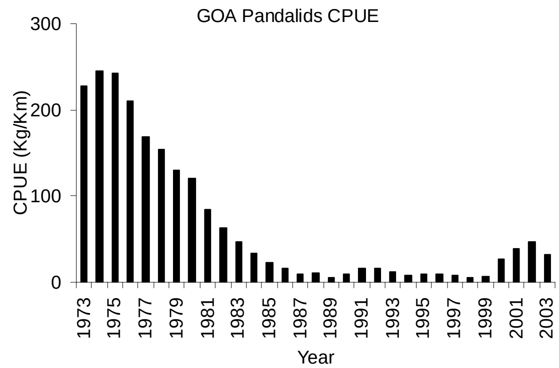


Figure 87. Three-year average CPUE (kg per km trawled) of all Pandalid shrimp species combined in the GOA small mesh survey 1973 - 2003.

Selected Species Index

Pandalid Shrimp

Pandalid shrimp, as a species group, are an important component of the boreal marine ecosystem in the Gulf of Alaska (GOA). Pandalid shrimp occupy a central position in the trophic structure of the northeast Pacific where they constitute the main prey of many fish species and in turn prey on the zooplankton community. They also occupy all depths of the water column from the benthos to near surface. Consequently, changes in their abundance and population dynamics directly reflect changes occurring within other trophic levels throughout the water column. Proportions of shrimp in survey catches were found to be negatively correlated (r = -0.72) with water column temperature (Anderson 2000). Climate change as manifested by changes in water column temperature has an immediate effect on lower trophic levels of boreal marine ecosystems and rapid pandalid shrimp population changes are one of the first indicators that community structure is changing.

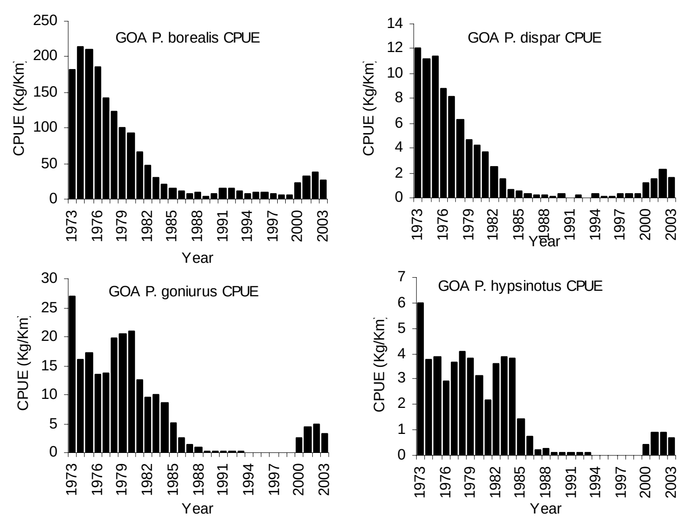


Figure 88. Three-year average CPUE (kg per km trawled) of all *Pandalus borealis*, *P. goniurus*, *Pandalopsis dispar*, and *Pandalus hypsinotus* in the GOA small mesh survey 1973 - 2003.

Abundance of all Pandalid shrimp temporarily increased after 1998 in the GOA (Figure 87). Average catch per tow for all Pandalid shrimp combined increased to over 75 kg/km in 2001, then declined to 38.5 kg/km in 2002, and further declined in 2003 to 25.7 kg/km (Jackson 2003, 2004). Relative Pandalid shrimp abundance at these levels last occurred in survey results nearly twenty years ago in the early 1980s. Shallow water species, *P. goniurus* and *P. hypsinotus*, are restricted to only a few sampled locations, but showed increases in overall abundance in 2001. These species have again shown signs of declining abundance in 2003 (Figure 88). *Pandalus goniurus* declined from 7.9 kg/km in 2001 to 0.9 kg/km in 2003. *Pandalus hypsinotus* has declined to less than 0.01 kg/km in 2003 overall catch rate. Species with a greater depth distribution, *P. borealis* and *Pandalopsis dispar* are showing declines in abundance but not to the degree of the shallow species.

Analysis of length-frequency data from the various populations sampled in the past several surveys has provided clues to the mechanism responsible for this rapid population recovery. Strong size modes were evident in 2001 and 2002 at approximately 15 mm of carapace length (CL) (1+ or 2+ age class; Anderson 1991). Strong year-classes of *Pandalus borealis* produced in 1999 and 2000 are directly responsible for the greater abundance of shrimp observed in the 2001 and 2002 surveys. In 2003, average CL was 17.2 mm (3+ age class; Anderson 1991). Weak recruitment of early age class shrimp since 2002 has resulted in lower abundance observed for the 2003 survey. Results indicate that shrimp are good integrators of the current state of the marine environment in the GOA.

Recent changes in shrimp populations are directly linked to colder conditions as indicated by the PDO (http://jisao.washington.edu/pdo/PDO.latest) between July 1998 and July 2002. Sustained strong recruitment of Pandalid shrimp will require a continued shift to colder ocean conditions (Anderson 2000). Along with favorable oceanographic conditions to allow strong recruitment of shrimp there will also need to be declines in predation pressure. These principle factors play a central role in determining future pandalid population trends and governing trends in other species abundance as well.

Smelts

Smelts in the family Osmeridae are schooling fishes that spawn on beaches (capelin) or are anadromous (eulachon and rainbow smelt) and spawn in rivers that drain into the GOA. All three of these species are routinely captured in the small-mesh trawl survey. After spawning these fishes move offshore into deeper waters. During the late summer surveys they are found frequently near bottom and are vulnerable to capture by our small-mesh sampling gear. Capelin is relatively wide-spread throughout the survey area. Eulachon distribution however, is more concentrated in the GOA. The highest abundance of eulachon is found in the Shelikof Strait region. Eulachon are also more numerous in bays along the Alaska Peninsula and west side of Kodiak Island (Figure 89).

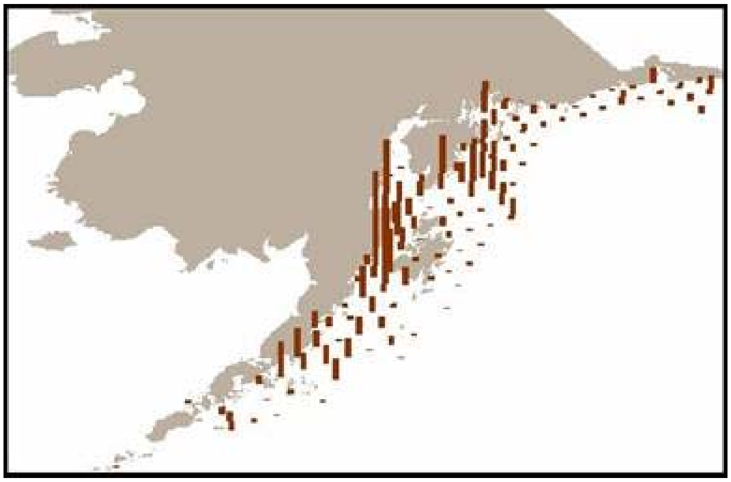


Figure 89. Long-term eulachon relative density and distribution pattern in the GOA from 1953 - 2003. Eulachon density is averaged over 50 kilometer square blocks in the GOA (map produced by Claire Armistead). Data includes RACEBASE long-term data set and all bottom trawls, both small-mesh and other larger meshes.

Osmerids as a group increased to 2 kg/km in 2001 and to over 7 kg/km in 2003 (Figure 90). This is the highest relative abundance level of total osmerids measured since 1980 when 19 kg/km was caught. Average eulachon catch was 1.9, 6.7, and 7.2 kg/km in the 2001, 2002, and 2003 surveys, respectively. The latest survey abundance is the highest level observed for eulachon in the last 30 years. Recent ocean conditions have been optimal for juvenile survival. A major recruitment event of juvenile eulachon was evident in the size frequency data collected in 2002. A strong size mode at around 8 cm FL in 2002 and 11mm FL in 2003 was evident in many sampling locations (Jackson 2003, 2004) (Figure 90). These small size modes of eulachon in small-mesh trawl survey catches are seldom observed. Capelin remained at relatively low levels of less than 0.1 kg/km, yet this was the highest relative abundance measured since 1989 when they were caught at an average of 0.12 kg/km.

Capelin still remain well below their historic peak abundance of 16.8 kg/km in 1980 in the GOA (Figure 90).

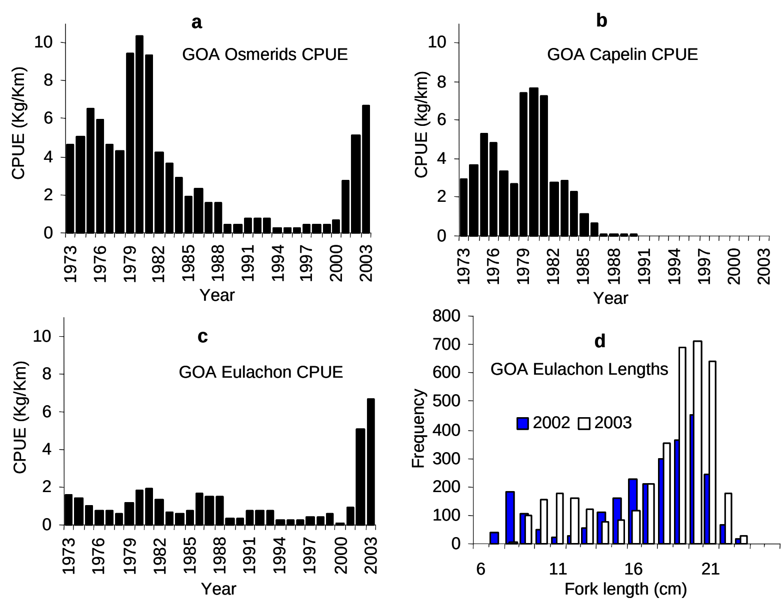


Figure 90. Three-year average CPUE (kg per km trawled) of all osmerids (a), capelin (b), and eulachon (c), and eulachon fork lengths (cm) from 2002 and 2003 (d) in the GOA small mesh trawl survey, 1973-2003.

Other Forage Fish

Pacific sandfish, *Trichodon trichodon*, is a near shore forage fish that spawns during winter in the GOA. Hatching of larvae occurs in the following winter, after eggs incubate for about one-year. Pacific sandfish have shown recovery in recent GOA surveys. Pacific sandfish was present in 18% and 26% of survey tows in 2002 and 2003. Overall the abundance was measured as 3.4, 2.3, and 3.1 kg/km in 2001, 2002, and 2003 respectively (Figure 91). These are some of the highest observed abundances of this species during the past 30 years. Many of the fishes observed have been juveniles and small adults, which leads to the conclusion there has been locally strong recruitment for this species in the survey area since 1999.

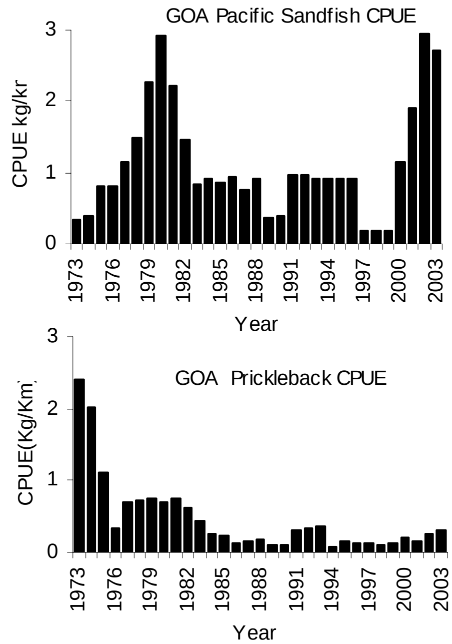


Figure 91. Three-year average CPUE (kg per km trawled of Pacific sandfish and longsnout prickleback in the GOA small mesh survey, 1973-2003.

Longsnout prickleback, *Lumpenella longirostris*, is a benthic forage fish that is an important component of small-mesh trawl catches. This species has a wide distribution pattern within the survey strata, but overall density is not usually very high. This species has significantly declined in the GOA from a peak abundance of over 3 kg/km observed in 1973 (Figure 91). Catch rates in1995 indicated the lowest abundance recorded in the time-series at less than 0.01 kg/km. Longsnout pricklebacks have gradually recovered in recent years and the catch rate observed in the 2003 survey was 0.44 kg/km, this was the highest density observed for this species since 1992 in the GOA small mesh survey.

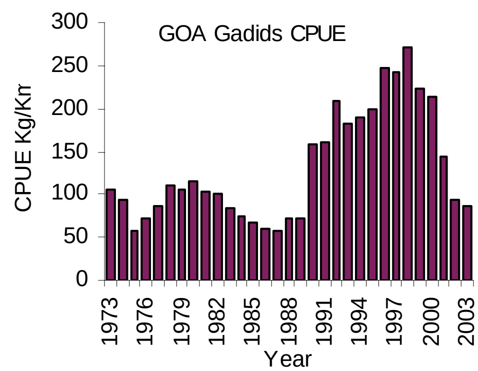


Figure 92. Three-year average CPUE (kg per km trawled of all gadid species in the GOA small mesh survey, 1973-2003.

Gadids

Gadids in the context of this report include all cod and cod-like species. Relative abundance of all gadids has declined since 1998 to the lowest abundance in this survey series since 1990. All gadids combined declined from 111.8 kg/km in 2001 to 83 kg/km in 2003 (Figure 92). In contrast, juvenile walleye pollock, (< 20 cm FL), are at high relative abundances of 11.4, 2.6, and 3.0 kg/km in 2001, 2002, and 2003 catches. The 2001 juvenile pollock abundance level was the highest observed since 1983 when 10.2 kg/km were captured. Larger walleye pollock (> 20 cm FL) and Pacific cod showed the lowest abundance since 1990. Pacific cod abundance declined to12.3 and 7.8 kg/km in 2001 and 2002, and averaged 8.7 kg/km in 2003. Most cod were larger than 60 cm FL. Pacific tomcod, *Microgadus proximus*, have gradually increased during the past several years to 0.75 kg/km, the highest relative abundance observed in the past ten years. Gadids and particularly Pacific cod are major predators of pandalid shrimp (Albers and Anderson 1985, Yang 2004) and forage fish. Overall declines in cod abundance and predation are probably responsible for at least a part of the species composition changes that have recently occurred in the GOA.

Pleuronectids

Flatfish abundance, as a group, did not vary significantly from recent surveys (Figure 93). The abundance of all flatfish combined was 121, 94, and 74 kg/km in 2001, 2002, and 2003 surveys, respectively. Arrowtooth did show increases in abundance to 44.8, 31.4, and 30.3 kg/km in 2001, 2002, and 2003, respectively, some of the highest CPUE recorded for this species in the last thirty years. The majority of the arrowtooth measured from the last three surveys had FL of less than 40 cm. Since arrowtooth flounder, especially those less than 40 cm FL, are known predators of pandalid shrimp (Yang and Nelson 2000, Yang, 2004) these observations are important in determining future species abundance trends. Flathead sole abundance has generally decreased since 1993, but was still above the 1973-to-present average in 2002 and 2003 (Figure 93). Abundance of yellowfin sole in 2002 and 2003 was low and was similar to estimates in years prior to 1978.

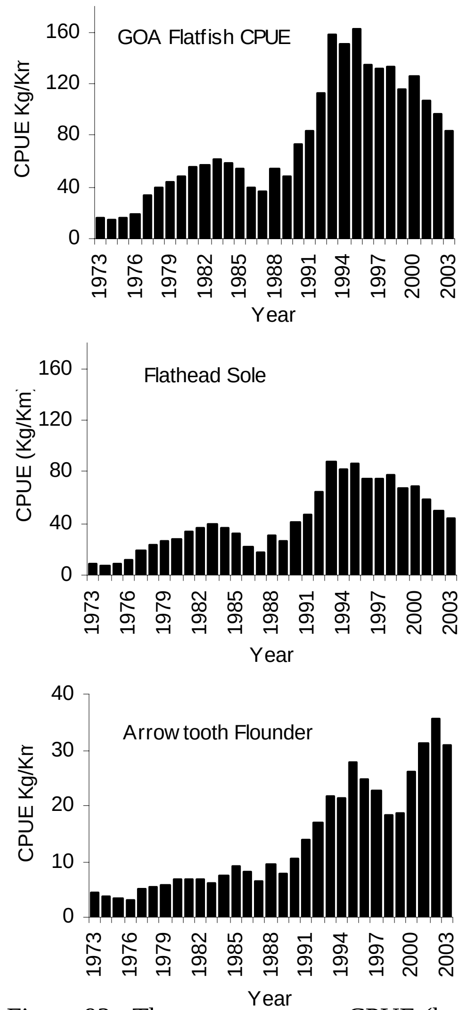


Figure 93. Three-year average CPUE (kg per km trawled) of all flatfish species, flathead sole, and arrowtooth flounder in the GOA small mesh trawl survey, 1973-2003.

Jellyfish

Gelatinous zooplankton or jellyfish frequently occur in dense aggregations in the GOA and can consume commercially important fish and crustacean larvae (Purcell 1985, Purcell and Sturdevant 2001). The gear used in this survey samples this group well and the jellyfish are often in good condition enabling easy species identification. Overall jellyfish population abundance of all species has remained historically high in the sampling region (Figure 94). In 2003 *Cyanea* sp. was the leading component of this group with an overall catch rate of 12.7 kg/km trawled while total group abundance was 13.9 kg/km. Other species captured were *Aurelia* sp., *Aequorea* sp., *Chrysaora* sp., and Ctenophora sp. These other species and those that could not be identified made up less than 10% of the jellyfish biomass in 2003.

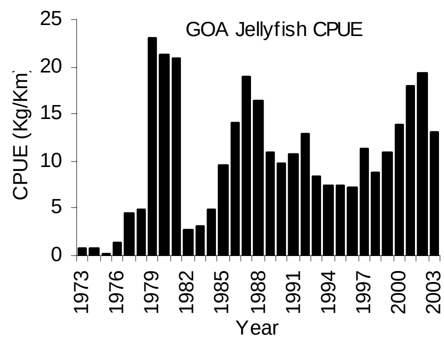


Figure 94. Three-year average CPUE (kg per km trawled) of jellyfish in the GOA small mesh trawl survey, 1973-2003.

Bering Sea Crabs
Contributed by Bob Otto and Jack Turnock, Alaska Fisheries Science Center

An annual NMFS trawl survey is conducted in the Eastern Bering Sea to determine distribution and abundance of crabs and dimersal fishes. Crab population abundance indices are determined using an 'area-swept' method in a stratified systematic sampling design. Current crab abundances are low (Figure 95), and of six crab fisheries included in the FMP, 2 are open, 4 are closed, and 4 are considered overfished. Rebuilding plans are in place for all overfished stocks.

BRISTOL BAY RED KING CRAB.
The mature biomass of Bristol Bay red king crab was highest in1980, declined and has remained relatively low since 1983. The total mature biomass of crabs has remained above 50% of the MSY biomass and, therefore, the stock is not considered overfished. Abundance of legal and pre-recruit males increased by 10 % in 2004, whereas, the number of mature females decreased by ca 9%.

PRIBILOF ISLANDS RED KING CRAB.
Mature biomass of Pribilof Island red king crab was well below 50% MSY in the 1980's but has been higher than the 50% MSY since 1991 and is not considered overfished. Apparent abundance of large male crabs decreased by ca 62% in 2004 while that of mature females decreased by ca 62%. No pre-recruit males were captured. Although not considered overfished, the fishery for remains closed because of considerable uncertainty as to population abundance and due to concerns of unacceptable levels of incidental catch of severely depressed of blue king crab in the same district.

PRIBILOF ISLANDS BLUE KING CRAB.
Blue king crab in the Pribilof Islands area have been considered overfished since mature biomass fell below the 50% MSY in 2002. Abundance of mature biomass continued to decrease in 2004 and is now the lowest on record. Little or no recruitment is apparent in the population which has been declining continuously since 1995. Continued warm conditions in the Islands' waters may be contributing to the decline.

ST. MATTHEW ISLAND BLUE KING CRAB. Blue king crab in the area of St. Matthew Island are also considered overfished. The population has declined steeply since 1998. Legal and pre-recruit male abundances decreased by 11% and 33% respectively in 2004. Indices of female crab abundances are not considered meaningful due to their preference for inshore, rocky, hence untrawlable habitat.

EASTERN BERING SEA TANNER CRAB.
The Eastern Bering Sea tanner crab population was high in the early 1980's and from 1988-1992. The population has been low since then and currently continues to decrease due to low recruitment. The mature biomass is below 50% MSY, therefore the stock is considered overfished and the fishery has been closed since1996. In 2004, the abundance indices for legal males (-28%) and mature females (-29%) decreased, while that of pre-recruit males increased (+25%)

EASTERN BERING SEA SNOW CRAB.
The mature biomass of Eastern Bering Sea snow crab was moderate to high in the early 1980's and from 1987-97. The biomass has declined sharply from 1998 to 1999 and the stock is considered overfished. In 2004, the abundance index for commercial sized males (+2%) and pre-recruit males (+3.6%) increased very slightly, while that for mature females increased more substantially (+25%). A small fishery (ca 9,500 t) will be allowed in January 2005 under the terms of the rebuilding plan.

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

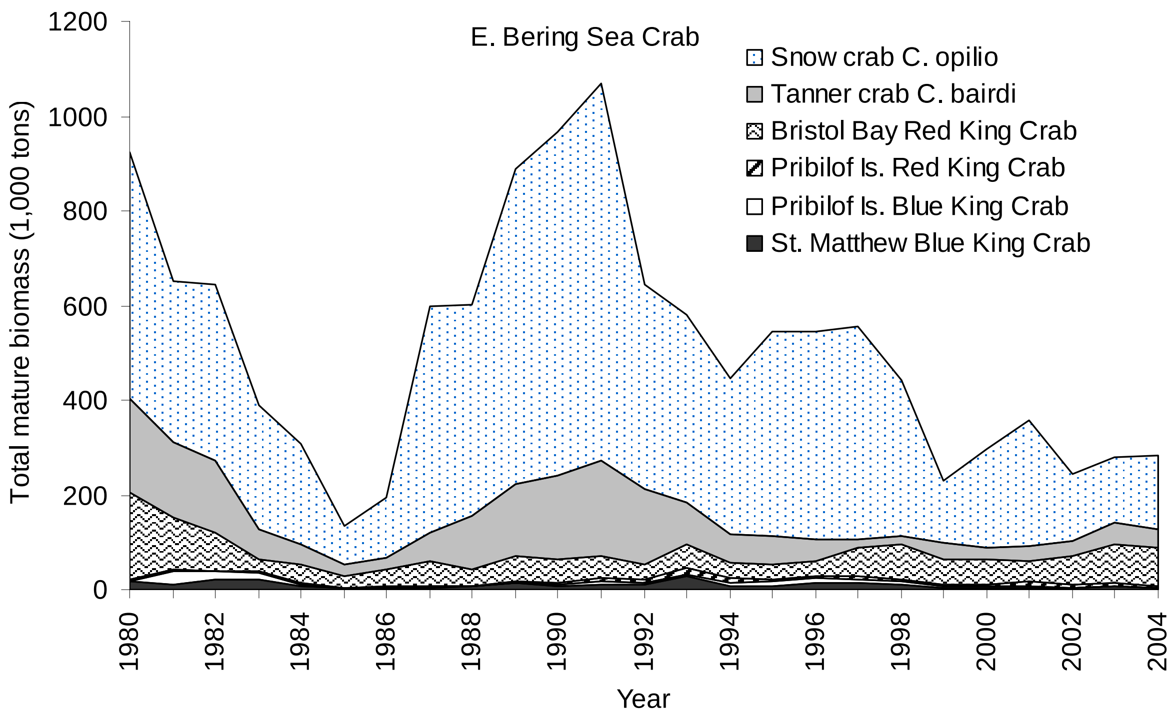


Figure 95. Total mature biomass of Eastern Bering Sea crab populations, 1980-2004.

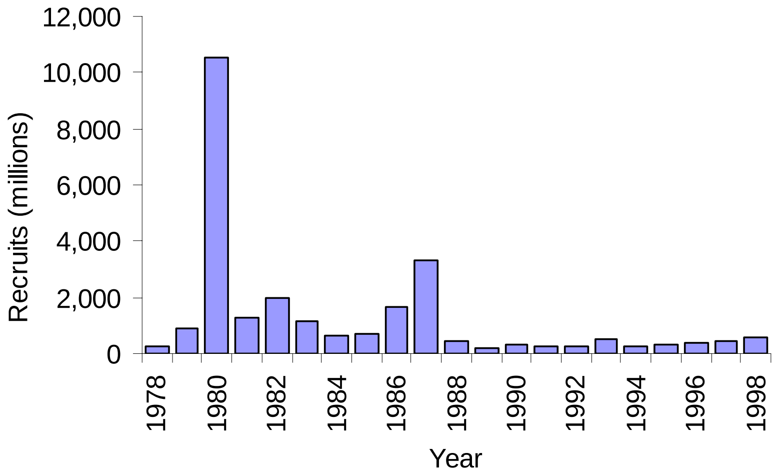


Figure 96. Snow crab recruitment from 1978 to 1998 in millions of crabs that are 25 mm to 50 mm in carapace width and lagged by 5 years (to fertilization year).

Stock-recruitment relationships for Bristol Bay red king crabs

Jie Zheng, ADF&G, Juneau, Alaska, email: jie_zheng@fishgame.state.ak.us

Results from a 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.

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. 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 = 0.53) was used to describe the density-dependent relationship and the autocorrelated Ricker curve (R^2 = 0.45) was used to depict the autocorrelation effects (Figure 97). The recruitment trends of Bristol Bay red king crabs may partly relate to decadal shifts in physical oceanography: all strong year classes occurred before 1977 when the Aleutian Low was weak. The largest year class during the last 20 years, the 1989 brood year, was also coincidental with the weak Aleutian Low index during 1989-1991.

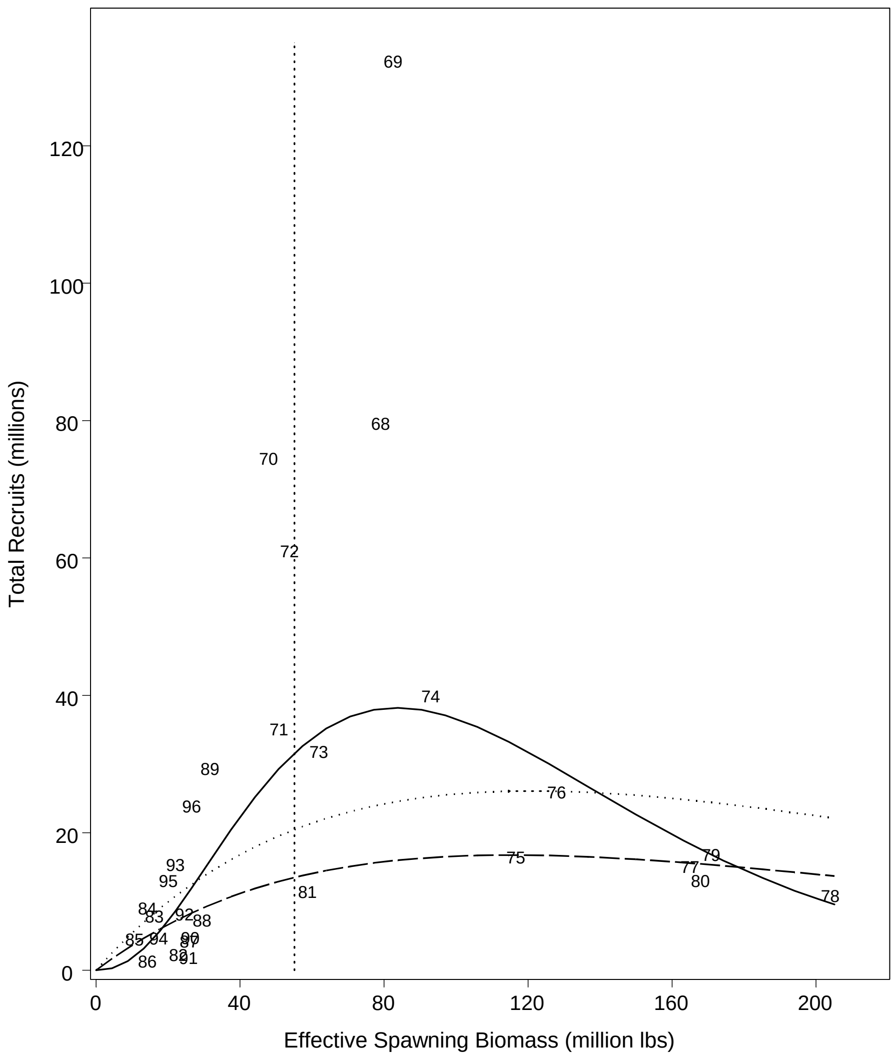


Figure 97. Relationships between effective spawning biomass and total recruits at age 7 (i.e., 8-year time lag) for Bristol Bay red king crabs. Numerical labels are brood year (year of mating), the solid line is a general Ricker curve, the dotted line is an autocorrelated Ricker curve without υ_t values (equation 2), and the dashed line is a Ricker curve fit to recruitment data after 1974 brood year. The vertical dotted line is the targeted rebuilding level of 55 million lbs effective spawning biomass.

Miscellaneous Species – Gulf of Alaska

Contributed by Eric Brown, Alaska Fisheries Science Center

A variety of non-target species are seen in the RACE bottom trawl survey in the Gulf of Alaska. It is possible that the survey may provide information about possible relative abundance changes for some of these species. Some initial results at summarizing these trends are shown (Figure 98). This survey is not designed to assess these organisms and further detailed examinations of these results are needed to assess whether there are meaningful trends.

The starfish and eelpout groups commonly occur in survey trawl catches with starfish being a magnitude of abundance higher than eelpouts. In 2003, eelpouts had highest historical abundance in the central and eastern GOA but decreased in the western GOA. Poachers occur occasionally at very low abundance levels. Their apparent large increase in abundance observed in 1993 (Western GOA) was the result of two unusually "large" catches of 11 and 15 kg. Trends in abundance of the jellyfish group may be difficult to interpret since much of the catch may occur higher in the water column as the trawl is being set or retrieved.

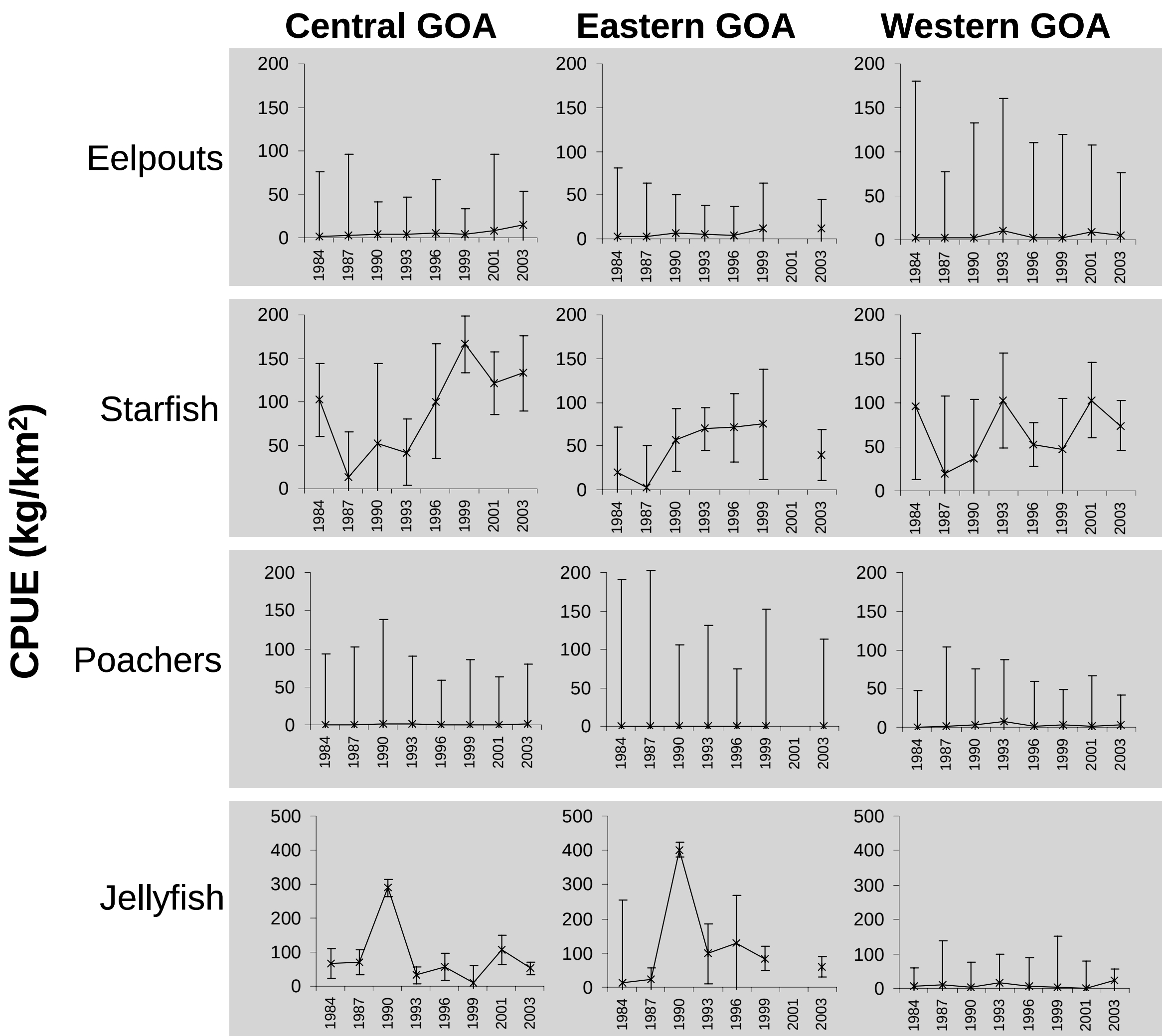
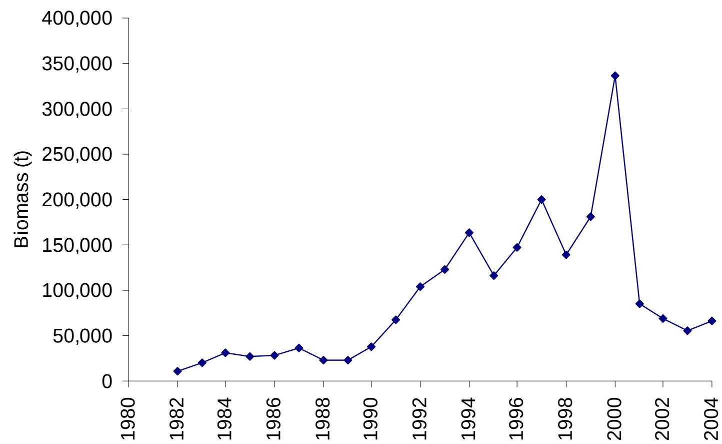


Figure 98. Catch per unit effort of miscellaneous species per unit area in the central, eastern, and western GOA, in bottom trawl surveys conducted between 1984 and 2003. 95% confidence intervals are shown.

Jellyfish – Eastern Bering Sea
Contributed by Gary Walters, Alaska Fisheries Science Center

The time series of jellyfish caught as bycatch in the annual Bering Sea bottom trawl survey was updated for 2004 (Figure 99). The trend for increasing abundance that began around 1989 reported by Brodeur et al. (1999) did not continue in 2001-2004. In fact, the 2001-2004 catches decreased dramatically and were close to levels seen in the 1980's and early 1990's. The overall area biomass index for 2004 is 66,358 t. It is unknown whether this decline is due to a change in availability or actual abundance.



Miscellaneous species - Eastern Bering Sea
Contributed by Gary Walters, Alaska Fisheries Science Center

Three species of eelpouts are predominant on the eastern Bering Sea shelf: marbled eelpout (*Lycodes raridens*), wattled eelpout (*L. palearis*) and shortfin eelpout (*L. brevipes*). Total CPUE of this group appeared higher in the early 1980's than in the late 1980's to the present (Figure 100). Although lower, CPUE appears to be relatively stable in the recent time period. Further analyses are needed to examine CPUE trends at the species level. The CPUE of poachers, likely dominated by sturgeon poacher (*Podothecus acipenserinus*), was low in the early 1980's but increased in the late 1980's to the mid-1990's. CPUE appears to be lower in recent years and may be returning to levels seen in the early 1980's (Figure 100). Echinoderms on the shelf mainly consist of purple-orange seastar (*Asterias amurensis*), which is found primarily in the inner/middle shelf regions, and common mud star (*Ctenodiscus crispatus*), which is primarily an inhabitant of the outer shelf. CPUE values for this group on the shelf appear to be higher from the mid-1980's to the present than in the early 1980's. More research on the life history characteristics of non-target species is required to understand the possible reasons for these CPUE trends.

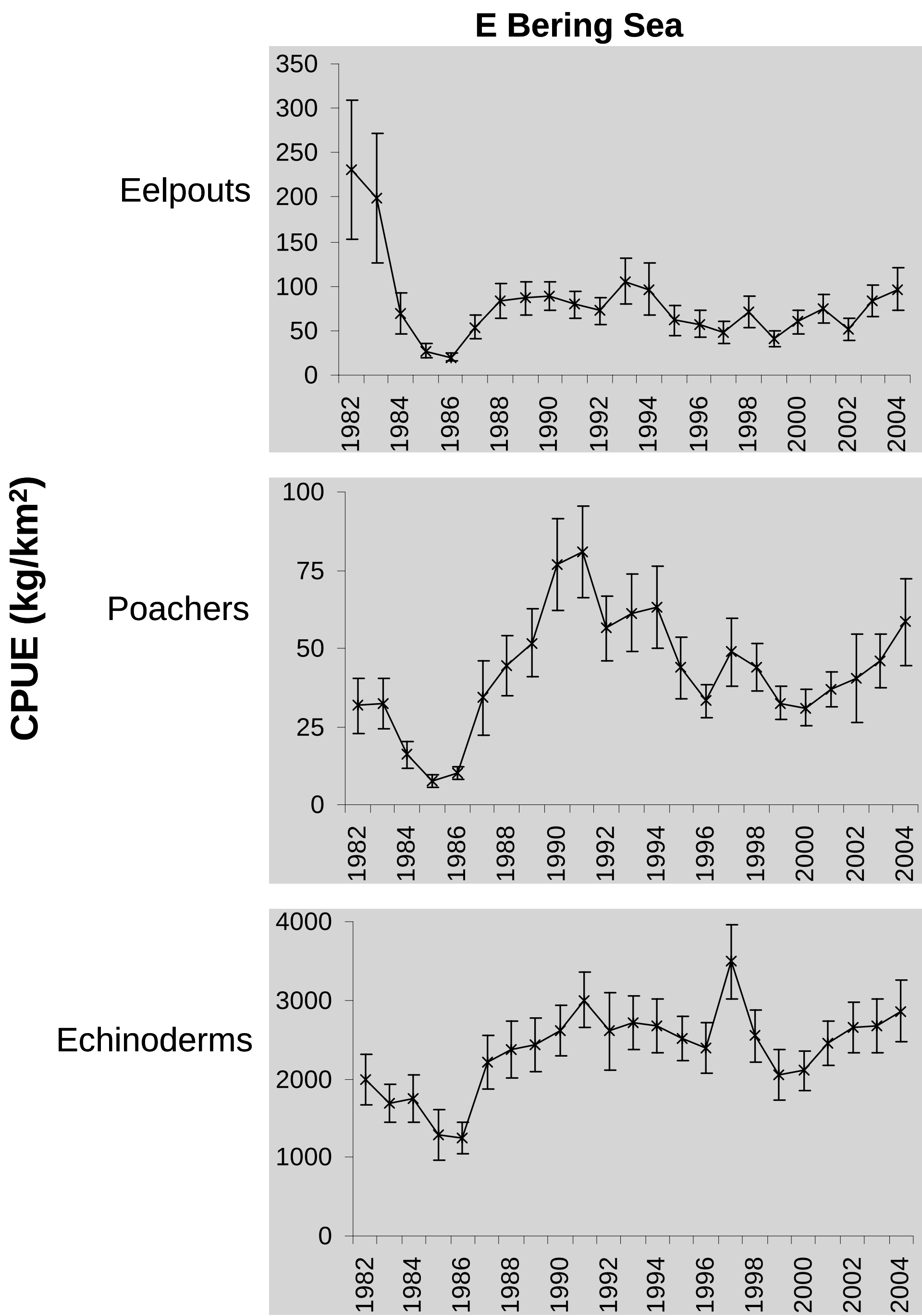


Figure 100. CPUE of miscellaneous species caught in the eastern Bering Sea summer bottom trawl survey, 1982-2004. 95% confidence intervals are shown.

Miscellaneous Species – Aleutian Islands
Contributed by Eric Brown, Alaska Fisheries Science Center

A variety of non-target species are seen in the RACE bottom trawl survey in the Aleutian Islands. It is possible that this survey may provide information about possible relative abundance changes in some of these species. Some initial results at summarizing these trends are shown (Figure 101). This survey is not designed to assess these organisms and further detailed examinations of these results are needed to assess whether there are meaningful trends.

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

The 2004 survey showed an increase in abundance of eelpouts in all areas except the southern Bering Sea. Eelpout catches in all areas were the highest catches since at least 1991. Starfish catches in 2004 increased relative to 2002 in the western AI and southern BS and decreased in the central and eastern AI. Catches of poachers in 2004 showed a continued decreasing trend in all areas since the high catches in 2000 and 2002. In 2004, jellyfish catch rates increased dramatically and represented the highest or the second highest catches on record in all areas.

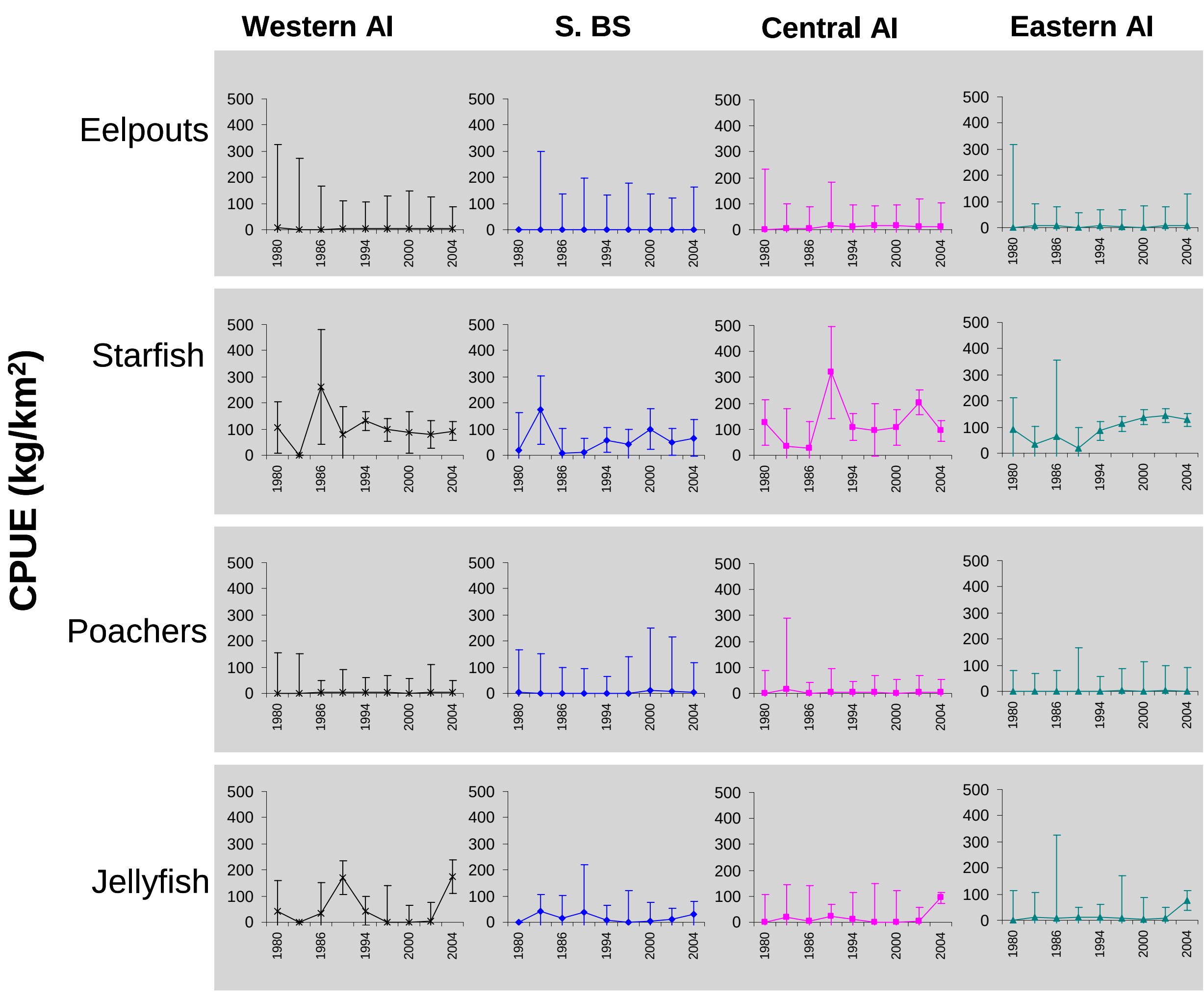


Figure 101. Catch per unit effort of miscellaneous species per unit area in the western Aleutian Islands (AI), southern Bering Sea (BS), central AI, and eastern AI, in bottom trawl surveys conducted between 1980 and 2004. 95% confidence intervals are shown.

Grenadiers in Alaska
by David M. Clausen (ABL) and Sarah Gaichas (REFM - AFSC)

INTRODUCTION

Grenadiers (family Macrouridae) are deep-sea fishes related to hakes and cods that occur world-wide in all oceans (Eschmeyer et al. 1983). Also known as "rattails", they are especially abundant in waters of the continental slope, but some species are found at abyssal depths. At least seven species of grenadier are known to occur in Alaskan waters, but only three are commonly found at depths shallow enough to be encountered in commercial fishing operations or in fishery surveys: giant grenadier (*Albatrossia pectoralis*), Pacific grenadier (*Coryphaenoides acrolepis*), and popeye grenadier (*Coryphaenoides cinereus*) (Mecklenburg et al. 2002). Of these, giant grenadier has the shallowest depth distribution and the largest apparent biomass, and hence is by far the most frequent grenadier caught in Alaska. Because of this importance, this report will emphasize giant grenadier, but it will also discuss the other two species. The purpose of the report is to provide an initial synopsis of biological, fishery, and survey information on these three grenadier species in Alaska. At present, no such synopsis is available, and it is particularly needed for the following reasons: 1) due to their abundance on the continental slope, grenadiers (especially giant grenadier) have an important role in the slope ecosystem; 2) giant grenadier are taken in large numbers as bycatch in longline fisheries; and 3) although there is no current directed fishery for grenadiers in Alaska, the potential exists for the development of a targeted fishery.

BIOLOGICAL INFORMATION

Geographic and Depth Range

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

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

[a]Mecklenburg et al. 2002
[b]Tuponogov 1997
[c]Matsui et al. 1990
[d]Figure 102, this report; see also discussion in "Survey Information" section
[e]Sasaki and Teshima 1988

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

Size

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

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

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

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

Maximum weight of an individual giant grenadier in a recent Bering Sea trawl was 43.5 kg[1]. The following length-weight relationship has been computed for giant grenadier in the Gulf of Alaska (Britt and Martin 2001) based on data collected in a 1999 trawl survey:

W is weight in grams and PAFL is in mm:
males, $W = 6.033 \times 10^{-4}(PAFL^{2.723})$, $n = 22$
female, $W = 2.327 \times 10^{-5}(PAFL^{2.500})$, $n = 45$
combined sexes, $W = 6.193 \times 10^{-4} (PAFL^{2.729})$, $n = 67$

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

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

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

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[1] G. Hoff, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. August 2004.

Age and Growth

Recent age information for Macrouridae species suggests that most are very long-lived. For example, the roundnose grenadier, *Coryphaenoides rupestris*, an important commercial species in the Atlantic, is thought to live up to 70 years (Merrett and Haedrich 1997). Aging studies of giant and Pacific grenadier also indicate that these fish are long-lived.

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

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

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

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

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

Life History, Habitat, and Ecological Relationships

Very little is known about the life history of giant grenadier. No fecundity studies have been done. The spawning period is thought to be protracted and may even extend throughout the year (Novikov 1970). Small, juvenile fish less than ~15-20 cm PAFL are virtually absent from bottom trawl catches (Novikov 1970; Ronholt et al. 1994; Hoff and Britt 2003), and juveniles may be pelagic in their distribution. Novikov (1970) states that sexual maturity is reached at about 56 cm TL (= 14 cm PAFL), when the fish assume a more benthic existence, but he gives no data as to how this value was determined or to which sex it applies. Bottom trawl studies indicate that females and males have different depth distributions, with females inhabiting shallower depths than males. For example, both Novikov (1970) and Britt and Martin (2001) found that nearly all fish <700 m depth were female, and the Novikov study was based on trawl sampling throughout the year. Presumably, some vertical migration of one or both sexes must occur for spawning purposes; Novikov (1970) speculates that females move to deeper water inhabited by males for spawning. Stock structure and migrational patterns of giant grenadier in Alaska are unknown, as no genetics studies have been done, and the fish cannot be tagged because all individuals die due to barotrauma when brought to the surface. One study in Russian waters, however, used indirect evidence to conclude that seasonal feeding and spawning migrations occur of up "to several hundred miles" (Tuponogov 1997).

The habitat and ecological relationships of giant grenadier are likewise little known and uncertain. Clearly, adults are often found in close association with the bottom, as evidenced by their large catches in bottom trawls. However, based on a study of the food habits of giant grenadier off the U.S. west coast, Drazen et al. (2001) concluded that the fish feeds primarily in the water column. Most of the prey items found in the stomachs were meso- or bathypelagic squids and fish, and there was little evidence of benthic feeding. The squids were primarily gonatids, and identifiable fish included viperfish, deep sea smelts, and myctophids. The study noted that the tissue composition of giant grenadier also suggests a midwater component to their lifestyle, as the muscle tissue of the fish is ~92% water, which would help maintain buoyancy during off bottom excursions. This hypothesis about the tendency of the fish to feed off bottom is supported by observations of sablefish longline fishermen, who report that their highest catches of giant grenadier often occur when the line has been inadvertently "clotheslined" between two pinnacles, rather than set directly on the bottom[2]. Furthermore, Drazen et al. (2001) conclude that giant grenadier is "at the top of the food web on the upper continental slope, and because of (its) abundance, may exert significant pressure on …prey populations". One study of giant grenadier food habits in the Aleutian Islands also found, similar to the Drazen et al. (2001) study, that the primary items consumed were squid and myctophids (Yang 2003).

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

Most of the information on Pacific grenadier life history, habitat, and ecological relationships is based on studies off the U.S. west coast. Fecundity of Pacific grenadier was reported to be 23,000-119,000 eggs for one study off Oregon (Stein and Pearcy 1982). Ripe females in this study were collected in April, September, and October. Although very few larvae and juveniles have been captured, they are apparently pelagic, as they have been caught in midwater plankton nets and trawls (Matsui et al. 1990). The juveniles settle to the bottom at a TL of ~80 mm (Stein and Pearcy 1982). Masui et al. (1990) indicate that length at maturity appears to be ~65 cm TL (= 22.8 cm PAFL) for females and ~50 cm TL (= 16.9 cm PAFL) for males. These values seem surprisingly high when one considers the average size of this species, and Stein and Pearcy (1982) report a much smaller size at maturity for females of 46 cm TL (= 15.3 cm PAFL). In contrast to giant grenadier, sexes of Pacific grenadier do not appear to be segregated by depth, and ratio of males to females is around 1:1 (Stein and Pearcy 1982: Hoff and Britt 2003). No research has been done on stock structure or migrations of Pacific grenadier. Adult Pacific grenadier are believed to mostly bottom oriented, but a few have been caught "thousands" of m

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

off bottom (Meckenburg et al. 2002). A food study of this species off the U.S. west coast supports the hypothesis that the fish are more benthic in their habitat than are giant grenadier (Drazen et al. 2001). Smaller Pacific grenadier (<20 cm PAFL) in particular fed more on bottom organisms such as polychaetes, cumaceans, mysids, and juvenile tanner crabs (*Chionoecetes* sp.). Larger individuals tended to consume a higher percentage of pelagic prey items such as squid, fish, and bathypelagic mysids, but there was still evidence of epifaunal prey and sediments in their stomachs. The study found that there was a significant difference in diet between Pacific and giant grenadier, which suggests that these species may occupy different ecological niches in the continental slope environment.

Life history, habitat, and ecological information on popeye grenadier is virtually nil. Males were found to be more common than females in a trawl survey of the eastern Bering Sea slope in 2002 (Hoff and Britt 2003). One of the reasons for the lack of information on popeye grenadier is that they are very infrequently caught on longlines, probably because of their small size. For example, a total of only 8 popeye grenadier were caught in a 2003 longline survey in Alaska that extensively sampled the continental slope[3]. This means that longline experiments or surveys are not a useful data source for this species.

Natural Mortality Estimates

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

FISHERY INFORMATION

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

Currently in the northeastern Pacific, the only directed grenadier fishery is for Pacific grenadier off California and Oregon. This fishery began around 1990, and catches as high as 1,500 mt

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

were taken in 1996 (Andrews et al.1999). Although the product recovery ratio for Pacific grenadier is relatively low because of its long, tapered body shape, the meat is firmly textured and has been rated as having a fairly good flavor (Matsui et al. 1990). The same study reported that giant grenadier flesh was rated very poorly because of its watery, soft texture. The only known fishery for grenadier in Alaska was an attempt to process longline-caught giant grenadier for surimi at the port of Kodiak in 1998[4]. This small effort was apparently unsuccessful, as it ended in 1999. Because of the large biomass of giant grenadier on the continental slope, however, research to develop marketable products from this species is ongoing (Crapo et al. 1999), and the possibility remains that fishermen may find a way to market them at some future date.

Although there has been almost no directed fishing for or retention of grenadiers in Alaska, grenadiers are taken as bycatch in other targeted fisheries and then discarded at sea. None of the discarded grenadiers survive, as the pressure difference experienced by the fish when they are brought to the surface from deep water invariably causes death.

To determine whether the grenadier bycatch in Alaska is sufficiently high to be of management concern or a risk to stock abundance, an estimate of this bycatch is necessary. At present, all species of grenadier in Alaska are classified as "non-specified species" under the North Pacific Fishery Management Council's (NPFMC) fishery management plans, so there are no limitations on catch or retention, no reporting requirements, and no official tracking of grenadier catch by management. Thus, we had to devise our own method for estimating catches of grenadiers based largely on data from the Alaska Fishery Science Center's Fishery Observer Program. This method essentially was an attempt to simulate the catch estimation algorithm used by the NMFS Alaska Regional Office in what was formerly called their "blend catch estimation system". For details of our methodology, see Gaichas (2002). Results of our grenadier catch estimations are shown in Tables 10 and 11. It should be noted that portions of the data in these tables were previously presented in NPFMC Stock Assessment and Fishery Evaluation Reports (Gaichas 2002; Gaichas 2003). Unfortunately, the data have to be presented as "grenadiers, all species combined", because observers were not instructed to identify individual grenadier species[5]. Also, one important caveat is that the catch estimates for the Bering Sea and Aleutian Islands (BSAI) may be more accurate than those for the Gulf of Alaska (GOA). In our catch estimation process, we assume that grenadier catch aboard observed vessels is representative of grenadier catch aboard unobserved vessels. This is a possible problem because observer coverage in the BSAI fisheries is considerably higher than those in the GOA. In general, smaller vessels fish in the GOA, especially in longline fisheries, and many of these vessels are not required to have observers, which could introduce a bias into the GOA estimates.

The estimated annual catches of grenadier in Alaska have been substantial in recent years (Table 10). Total annual catches have ranged between ~4,000-8,000 mt in the BSAI, and between ~10,000-15,000 mt in the GOA. To put these catches in perspective, the total annual sablefish

[4] J. Ferdinand, National Marine Fisheries Servide, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. September 2004.

[5] This problem will be corrected for observations of giant grenadier in the 2005 fishery. Observers will be instructed to note catches of giant grenadier (an easy species to identify), although catches of Pacific and popeye grenadier will still be lumped together.

catch in Alaska in the years 1996-2001 ranged from about 13,600 to 17,600 mt (Sigler et al. 2003). Thus, more grenadier were caught and discarded in these years than the amount of sablefish taken. The overwhelming majority of the grenadier catch (>90%) in each region and each year was apparently taken by longline gear, and the rest was mostly caught by bottom trawl (Table 10).

Most of the grenadier catch in the GOA has been taken in the sablefish fishery, whereas in the BSAI, it has come from both the sablefish and the Greenland turbot fishery (Table 11). The sablefish and Greenland turbot fisheries in Alaska are predominately longline fisheries, which explains the large percentage of grenadier taken in longline gear that is shown in Table 10. Besides the sablefish and Greenland turbot fisheries, other targeted fisheries that have taken grenadier in much smaller amounts include fisheries for deepwater flatfish, Pacific cod, and Pacific ocean perch in the GOA, and for Pacific cod and Pacific ocean perch in the BSAI. Also, data presented in Gaichas (2002) and Gaichas (2003) for 2000-2002 in the BSAI indicate that in the Aleutian Islands, most of the grenadier catch comes from the sablefish fishery, but in the eastern Bering Sea is taken predominately in the Greenland turbot fishery.

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

1. As indicated in Table 11, most of the grenadier catch in Alaska comes from the sablefish fishery. Although there are no data that summarize the depth distribution of this fishery, sablefish abundance in Alaska is usually low in depths >1,000 m[6], and it is likely that little or no commercial effort for sablefish occurs at these depths. Instead, the fishery is probably focused at depths of 400-800 m, where longline surveys have generally found the highest catch rates of sablefish (Zenger and Sigler 1992). Bottom trawl and longline surveys all show that very few Pacific and popeye grenadier are found shallower than 800 m deep, whereas giant grenadier are abundant in these depths (see "Survey Information" section in this report). Hence, we can use this indirect evidence to conclude that giant grenadier are the predominate species in the grenadier catch.

2. As indicated in Table 10, nearly all the grenadier catch is taken by longline gear. As mentioned previously, very few popeye grenadier are caught on longlines because of the small size of these fish. Therefore, we can rule out popeye grenadier as a significant component of the grenadier catch.

SURVEY INFORMATION

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

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

Trawl Surveys

There have been many NMFS trawl surveys in the eastern Bering Sea (EBS), Aleutian Islands (AI), and GOA since 1979, but relatively few have extended deep enough on the continental slope to yield meaningful biomass estimates for grenadier. For example, several surveys of the AI and GOA have sampled only to 500 m; thus, they barely entered the abundant depth range of giant grenadier and were well above the depths inhabited by Pacific and popeye grenadier. Giant grenadier biomass estimates for those surveys that have extended to 800 m or deeper are listed in Table 12. Prior to the early 1990's, it is believed that survey scientists did not always correctly identify Pacific and popeye grenadier in AI and GOA surveys, so biomass estimates for these species in these surveys have not been included in this report. Also, the earlier Bering Sea surveys (1979-1991) usually identified grenadiers only to the level of family, and it is these combined estimates that are listed in Table 12.

The biomass estimates indicate that sizeable populations of giant grenadier are found in each of the three regions surveyed, but the survey time series are too intermittent to show any trends in abundance. Highest estimates of giant grenadier biomass in each region were 669,000 mt in the EBS (2004), 601,000 mt in the AI (1986), and 386,000 mt in the GOA (1999). In the EBS, the biomass estimates for 1979-1991 appear to be unreasonably low compared to the biomass estimates in 2002 and 2004. Given the apparent longevity and slow growth of giant grenadier, it is unlikely that its biomass could have increased nearly six-fold from 74,000 mt in 1991 to 426,000 mt in 2002. The EBS slope surveys in 2002 and 2004 are considered to be better than their predecessors because they were the only ones specifically designed to sample the continental slope, they trawled deeper water (to 1,200 m) that encompassed more of the depth range of grenadiers, and they had good geographical coverage in all areas[7]. Also, in comparison to the steep and rocky slopes of the AI and GOA, the EBS slope is much easier to sample with a bottom trawl, which means a trawl survey in the latter region may yield more reliable results. Therefore, the biomass estimates in the EBS in 2002 and 2004 may be the most valid of any of the surveys in Table 12.

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

Results of the more recent trawl surveys in the EBS and GOA can be examined to determine the comparative biomass of the three grenadier species (Table 13; Figure 102). In the GOA in 1999, giant grenadier was by far the most abundant species and comprised ~94% of the aggregate grenadier biomass. Next in abundance was popeye grenadier, followed by Pacific grenadier. In the EBS surveys in 2002 and 2004, giant grenadier also greatly predominated, with 89% and 93% of the aggregate biomass, respectively. Similar to the GOA, popeye grenadier was second in biomass, followed by Pacific grenadier. Popeye grenadier biomass was considerably larger in both EBS surveys than in the GOA survey, which may be partially due to the fact that the EBS

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

surveys sampled deeper water to 1,200 m, whereas the GOA survey only went to a maximum depth of 1,000 m.

The recent trawl surveys also provide information on the depth distribution of grenadiers in the EBS and GOA (Figure 102). The surveys indicated that in both regions, giant grenadier accounted for nearly all the grenadier biomass at depths less than ~600-700 m, whereas Pacific and popeye grenadier did not become moderately abundant until deeper depths. The 2002 EBS survey showed giant grenadier biomass peaking at depths 400-1,000 m, and then dropping substantially at the 1,000-1,200 m depth stratum. The 1999 GOA survey was generally similar and indicated biomass of giant grenadier was relatively high at depths 300-1,000 m. However, because the GOA survey did not extend beyond 1,000 m, the abundance of giant grenadier in these deeper GOA waters is unknown.

Results of the trawl surveys emphasize the important ecological role of giant grenadier in Alaskan waters. In a ranking of all species caught in the 1999 GOA trawl survey, giant grenadier was the fifth most abundant species in terms of CPUE, after arrowtooth flounder, Pacific ocean perch, walleye pollock, and Pacific halibut (Britt and Martin 2001). It should be noted that this survey covered both the continental shelf and slope; if we consider just the slope deeper than 400 m, giant grenadier was the number one species in CPUE. Likewise, the EBS surveys in 2002 and 2004 (which sampled only the slope) both ranked giant grenadier first in biomass among all species caught (Hoff and Britt 2003; footnote[8]).

Longline Surveys

Longline surveys of the continental slope off Alaska have been conducted annually since 1979 (Sigler et al. 2003). The primary purpose of the surveys is assessment of sablefish abundance, and the standard depth sampled is 200-1,000 m. An index of relative biomass, called the "relative population weight" (RPW), is computed for all the major species caught in the survey. However, RPW values for giant grenadier are only available for the years since 1990[9]. Other measures of giant grenadier abundance in the surveys have been computed for the years 1979-1989, including catch-per-unit-effort values and an index of abundance by number, called "relative population number". These data for the surveys before 1990 are presented in Sasaki and Teshima (1988) and Zenger and Sigler (1992), but will be not be discussed in this report.

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

[8] G. Walters, National Marine Fisheries Servide, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. October 2004.
[9] C. Lunsford, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, AK 99801. Pers. commun. July 2004.

The RPWs provide a standardized time series of annual abundance for giant grenadier in the GOA for the period 1990-2004 and an intermittent series in the eastern AI and EBS (Table 14). The survey was expanded from the GOA into the eastern AI in 1996 and to the EBS in 1997, but these latter two regions have only been sampled in alternating years since. Therefore, the time series is much less complete for the eastern AI and EBS. In the GOA, definitive trends in RPW are difficult to discern. Generally, however, RPW decreased in the first three years to a low of 800,000, then increased to a high in 1997 of 1,420,000, and finally diminished again to a low of 900,000 in 2004. A rigorous analysis of the data will be required to determine whether the trends are statistically valid, such as the methods used by Sigler and Fujioka (1988) to analyze changes in the survey's RPWs for sablefish. The RPW values in Table 14 also indicate that giant grenadier are particularly abundant in the eastern AI; in 2000, 2002, and 2004, RPWs in this region were equal to or greater than those in the GOA, even though area of the slope is much larger in the GOA.

Giant grenadier catch rates in the surveys can be used to examine the geographic distribution of abundance in more detail (Table 15). Highest catch rates are consistently seen in the eastern AI, Shumagin and Chirikof areas, and Bering areas 3 and 4, which are located NW of the Pribilof Islands. In the GOA, there appears to be a definite decline in catch rates as one progresses from the west (Shumagin area) to the east (Southeast area). The 1999 GOA trawl survey also showed a similar trend and found very low catch rates and biomass estimates in the eastern GOA (Britt and Martin 2001).

Average weight of giant grenadier in the longline surveys was largest in the EBS, intermediate in the eastern AI, and smallest in the GOA (Table 16). A comparison of the average length of giant grenadier between the 1999 GOA trawl survey (Britt and Martin 2001) and the 2002 EBS trawl survey (Hoff and Britt 2003) also showed that giant grenadier were larger in the EBS. Average weight in the GOA longline surveys has shown a marked decline in the years since 1993; in 1993, the average weight was 4.92 kg, whereas in 2004 it was only 3.91 kg. Further analysis is needed to determine if this decrease is due to a decline in the numbers of large fish, an ongoing recruitment of smaller fish, or a combination of these factors.

The relative biomass of giant grenadier in the GOA increased with depth, according to an average of the RPWs in the last three longline surveys (Figure 103). RPW was relatively high for each of the three deepest strata sampled in the survey: 401-600 m, 601-800 m, and 801-1,000 m, with the peak at 801-1,000. These data indicate that additional sampling needs to be done at depths >1,000 m to determine where the abundance of giant grenadier begins to decline. The data also suggest that an unknown and perhaps significant portion of the giant grenadier population in the GOA may reside in depths beyond 1,000 m that are not currently surveyed. These depth results are similar to those depicted in Figure 102 for the 1999 GOA trawl survey, which also showed a large biomass of giant grenadier extending to at least 1,000 m.

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

CONCLUSIONS

Of the three common species of grenadier in Alaska, only giant grenadier appears to warrant management concern at present. Concern for the other two species, Pacific and popeye grenadier, could only arise if fishing operations develop in the future at depths >1,000 m, where nearly all the population of these two species live. Survey information indicates that giant grenadier are the most abundant fish on the continental slope at depths 400-1,000 m in all surveyed areas of Alaska except the eastern Gulf of Alaska. As such, they have a significant role in the slope ecosystem and are important predators in this habitat. Although there is no directed fishery for giant grenadiers in Alaska, substantial numbers are taken as bycatch and discarded in the sablefish and Greenland turbot longline fisheries. Estimated annual catches of giant grenadier in Alaska may have ranged between 13,000 mt and 21,000 mt in the years 1997-2001. The large biomass of giant grenadier in Alaska may be able to support this level of catch, but the reported longevity and slow growth of this species makes it susceptible to overfishing. Furthermore, a high proportion of the catch is likely female because mostly female giant grenadier live at the depths where the commercial fishery operates. Disproportionate removal of females by the fishery could put stocks of giant grenadier at greater risk. One possible mitigating factor that may protect giant grenadier from overfishing is that a substantial portion of its population may inhabit depths >1,000 m, where they are safe from any fishing pressure. These deep waters would act as a *de facto* reserve to replenish giant grenadier removed by the fishery in shallower water. Further analyses of fishery and survey data for giant grenadier are needed, as well as additional biological studies, to better determine the population dynamics of this species.

Table 10. Estimated commercial catch (mt) of grenadier (all species combined) in the eastern Bering Sea and Aleutian Islands and Gulf of Alaska, 1997-2002, by gear type. (n.a. = data not available).

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

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

Table 11. Estimated commercial catch (mt) of grenadier (all species combined) in the eastern Bering Sea/Aleutian Islands and Gulf of Alaska, 1997-1999, by target fishery.

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

Table 12. Estimated biomass (mt) of giant grenadier in NMFS trawl surveys in Alaska that sampled the upper continental slope.

Year	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska
1979	91,500[a]	-	-
1980	-	313,480	-
1981	90,500[a]	-	-
1982	104,700[a]	-	-
1983	-	349,538	-
1984	-	-	169,708
1985	107,600[a]	-	-
1986	-	600,656	-
1987	-	-	135,971
1988	61,400[a]	-	-
1989	-	-	-
1990	-	-	-
1991	73,520[a]	-	-
1992	-	-	-
1993	-	-	-
1994	-	-	-
1995	-	-	-
1996	-	-	-
1997	-	-	-
1998	-	-	-
1999	-	-	386,294
2000	-	-	-
2001	-	-	-
2002	426,397	-	-
2003	-	-	-
2004	668,615	-	-

[a]Estimates are for all species of grenadiers combined

Notes and data sources:

a) Eastern Bering Sea: Depths sampled were to 1,000 m in 1979, 1981, 1982, and 1985; to 800 m in 1988 and 1991; and to 1,200 m in 2002 and 2004. Data sources: 1979 to 1988, Bakkala et al. (1992); 1991, Goddard and Zimmerman (1993); 2002, Hoff and Britt (2003); 2004, G. Walters, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115. Pers. commun. September 2004.
b) Aleutian Islands: Depths sampled were to 900 m in each survey. Data source: Ronholt et al. (1994).
c) Gulf of Alaska: Depths sampled were to 1,000 m in each survey. Data sources: 1984 and 1987, data on the Alaska Fisheries Science Center's trawl survey database, available from the National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle, WA 98115-0070; 1999, Britt and Martin (2001).

Table 13. Comparative biomass estimates (mt) for the three common grenadier species in recent NMFS trawl surveys in Alaska that sampled the upper continental slope.

Region	Year	Giant grenadier	Pacific grenadier	Popeye grenadier
Gulf of Alaska	1999	386,294	8,240	16,260
Bering Sea	2002	426,397	2,461	50,329
Bering Sea	2004	668,615	4,004	44,497

Table 14. Giant grenadier relative population weight, by region, in NMFS longline surveys in Alaska, 1990-2004. Dashes indicate years that the eastern Bering Sea or eastern Aleutian Islands were not sampled by the survey. Gulf of Alaska values include data only for the upper continental slope and do not include continental shelf gullies sampled in the surveys.

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

[a]Aleutian Islands east of 180^{o} west longitude.

Table 15. Giant Grenadier catch rates (number caught per 100 hooks), by area, in NMFS longline surveys in Alaska, 1990-2004. Dashes indicate areas or years in the Bering Sea and Aleutian Islands that were not sampled by the survey. Overall catch rates for combined areas or years are not available at this time.

Area	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Bering 4	-	-	-	-	-	-	-	26.1	-	22.3	-	8.0	-	13.3	-
Bering 3	-	-	-	-	-	-	-	27.0	-	23.0	-	14.5	-	26.5	-
Bering 2	-	-	-	-	-	-	-	10.7	-	7.7	-	7.0	-	7.2	-
Bering 1	-	-	-	-	-	-	-	1.9	-	0.2	-	1.6	-	1.3	-
NE Aleutians	-	-	-	-	-	-	12.8	-	10.2	-	17.8	-	21.0	-	25.3
SE Aleutians	-	-	-	-	-	-	22.8	-	25.3	-	28.2	-	27.9	-	24.6
Shumagin	22.1	21.8	19.4	24.2	25.5	30.1	21.5	27.9	31.6	24.4	24.7	26.5	28.3	26.6	27.6
Chirikof	22.1	17.8	19.3	21.8	20.4	28.4	27.4	28.3	17.1	22.2	21.0	24.4	15.4	26.6	16.7
Kodiak	10.4	8.4	6.5	7.6	10.9	13.8	16.1	16.9	11.7	17.5	13.4	13.1	11.6	15.4	8.2
W Yakutat	5.8	4.3	3.6	5.9	3.9	6.0	4.5	9.8	7.7	8.8	9.1	8.7	3.4	7.6	4.9
E Yakutat	2.4	3.2	2.3	3.3	2.0	4.0	4.1	3.2	4.1	3.9	3.3	3.6	4.6	5.1	3.8
Southeast	1.4	1.4	1.8	1.6	1.7	2.8	2.4	2.6	3.6	5.5	4.3	5.2	4.8	3.2	2.6

Table 16. Average weight (kg) of giant grenadier caught in NMFS longline surveys in Alaska, by region, 1990-2004.

Year	Eastern Bering Sea	Eastern Aleutians	Gulf of Alaska
1990	-	-	4.53
1991	-	-	4.62
1992	-	-	4.42
1993	-	-	4.92
1994	-	-	4.70
1995	-	-	4.49
1996	-	4.64	4.50
1997	4.95	-	4.37
1998	-	4.93	4.33
1999	4.72	-	4.34
2000	-	4.93	4.53
2001	5.62	-	4.12
2002	-	4.64	4.12
2003	5.15	-	3.94
2004	-	4.34	3.91
Mean	5.04	4.68	4.38

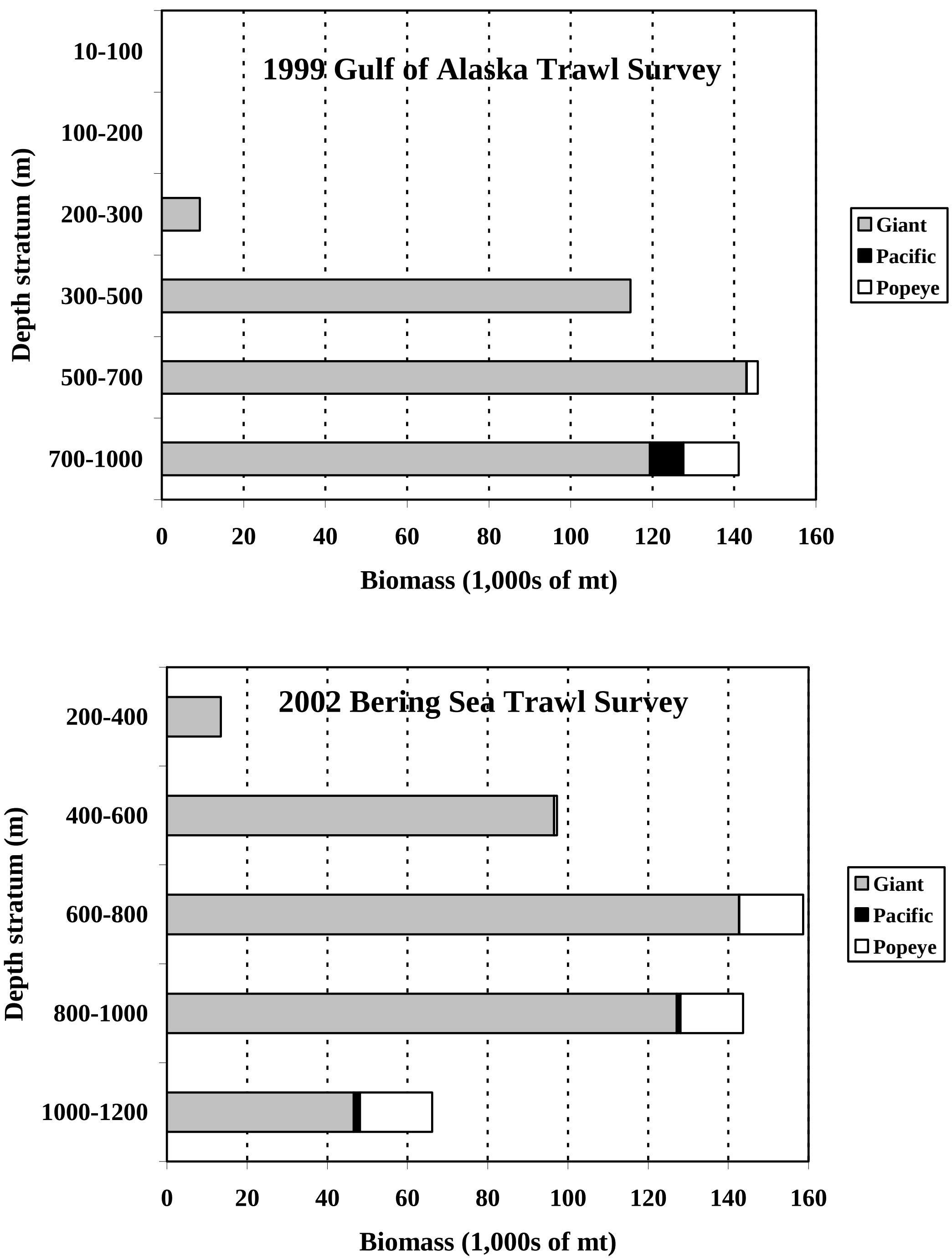

Figure 102. Depth distribution of giant, Pacific, and popeye grenadier biomass estimates in the 1999 Gulf of Alaska trawl survey and 2002 eastern Bering Sea slope trawl survey. Note: depth strata shown for each survey are not the same because the surveys had different stratification schemes for depth.

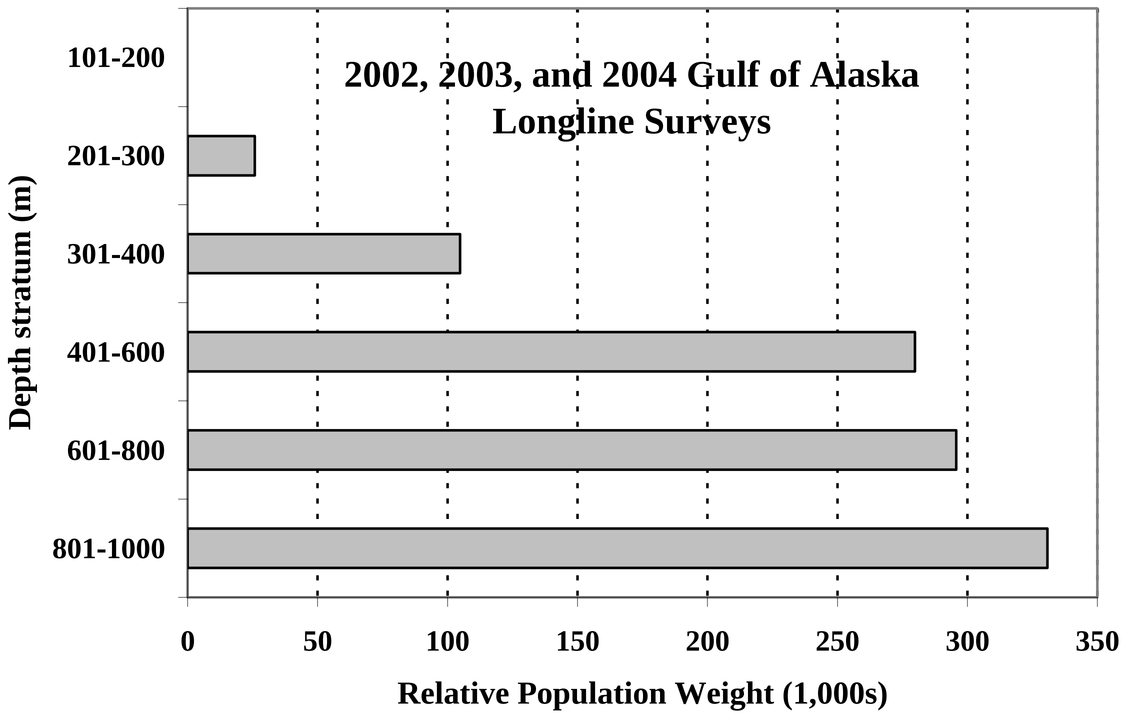

Figure 103. Depth distribution of giant grenadier relative population weight in the 2002, 2003, and 2004 longline surveys of the Gulf Alaska. Values shown are averages of the three surveys and do not include continental shelf gullies sampled in the surveys.

Marine Mammals

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

Descriptions of the range, habitat, diet, life history, population trends and monitoring techniques of marine mammals in the Gulf of Alaska and Bering Sea were provided in previous Ecosystem Considerations Chapters (Livingston 2001, 2002, Boldt 2003).

The text below summarizes an update of the status and trends for three pinniped species that are currently of particular concern and thought to have the most significant interactions with Alaskan groundfish fisheries, either because of direct takes or diet overlap. A general discussion of recent abundance surveys for large cetaceans is presented as well. A summary table of the best estimates regarding the status of all stocks of marine mammals in Alaskan waters through 2003 is provided.

PINNIPEDS

Steller sea lion (*Eumetopias jubatus*)

In November 1990, the NMFS listed Steller sea lions as “threatened” range-wide under the U.S. Endangered Species Act (55 Federal Register 49204, November 26, 1990) in response to a population decrease of 50% - 60% during the previous 10 – 15-year period. Several years later, two population stocks were identified, based largely on differences in genetic identity, but also on regional differences in morphology and population trends (Bickham et al. 1996, Loughlin 1997). The Western Stock, which occurs from 144°W long. (approximately at Cape Suckling, just east of Prince William Sound, Alaska) westward to Russia and Japan, was listed as “endangered” in June 1997 (62 Federal Register 24345, May 5, 1997). The Eastern Stock, which occurs from Southeast Alaska southward to California, remains classified as threatened. Population assessment for Steller sea lions is currently achieved by aerial surveys of non-pups and on-land pup counts.

An aerial survey of the endangered Western Stock of Steller sea lions in Alaska (from Cape St. Elias, 144°W to Attu Island, 172°E) was conducted by NMFS in June 2004. This was the first complete survey conducted using medium format, vertical photogrammetric techniques. In previous years, counts of adult and juvenile (non-pup) sea lions were made from 35 mm slides shot obliquely (from the side windows) of aircraft. Based on comparison surveys, counts made from medium format photographs are approximately 3-4% higher than those from 35 mm slides because of the resolution of the film and the orientation of the photograph.

In 2004, there were a total of 28,730 non-pup Steller sea lions counted on the 262 sites surveyed in the range of the western stock. NMFS monitors the population at a series of ‘trend’ sites that have been consistently surveyed since the mid-1980s. The 2002 counts were made from 35 mm slides as opposed to the medium format photographic technique first used in 2004. Subtracting the 3-4% increase due to film format differences, NMFS estimates that the western Steller sea lion population increased approximately 6-7% from 2002 to 2004. This is similar to the rate of increase observed between 2000 and 2002 when standard 35mm slide techniques were used (Figure 104).

There were regional differences in the trends observed between 2002 and 2004. Trend site counts increased between 2002 and 2004 in the three Aleutian Islands sub-areas (Western, Central and Eastern) and in the western Gulf of Alaska, from the Shumagin Islands through Unimak Pass (Figures 104 and 105). However, in the eastern portion of the range of the western Steller sea lion population, trend site counts remained stable (near Prince William Sound in the eastern Gulf of Alaska) or decreased (around Kodiak Island in the central Gulf of Alaska).

A slightly different pattern of trends is revealed when a longer time series of sub-area counts since 1989 are examined (Table 17). Steller sea lion non-pup counts in the center of the range of the western stock (the western Gulf of Alaska and Eastern Aleutian Islands from the Shumagin Islands through the Islands of Four Mountains) remained relatively stable from 1989-2004, showing oscillations around a mean. To the west, sea lion numbers decreased through the mid-1990s in both the Central and Western Aleutian Islands. Trend site counts stabilized at the 1998 level in the Central Aleutians, but continued to decline in the Western Aleutians through 2002 followed by a small increase between 2002 and 2004. To the east, trend site counts decreased sharply in both the Central and Eastern Gulf of Alaska through 1998. Since then, counts increased in the Eastern Gulf of Alaska, but continued to decline, at a slower rate, in the Central Gulf of Alaska. NMFS, along with its research partners in the North Pacific, is exploring several hypotheses to explain these trends, including climate or fisheries related changes in prey quality or quantity, and increases in the rate of predation by killer whales.

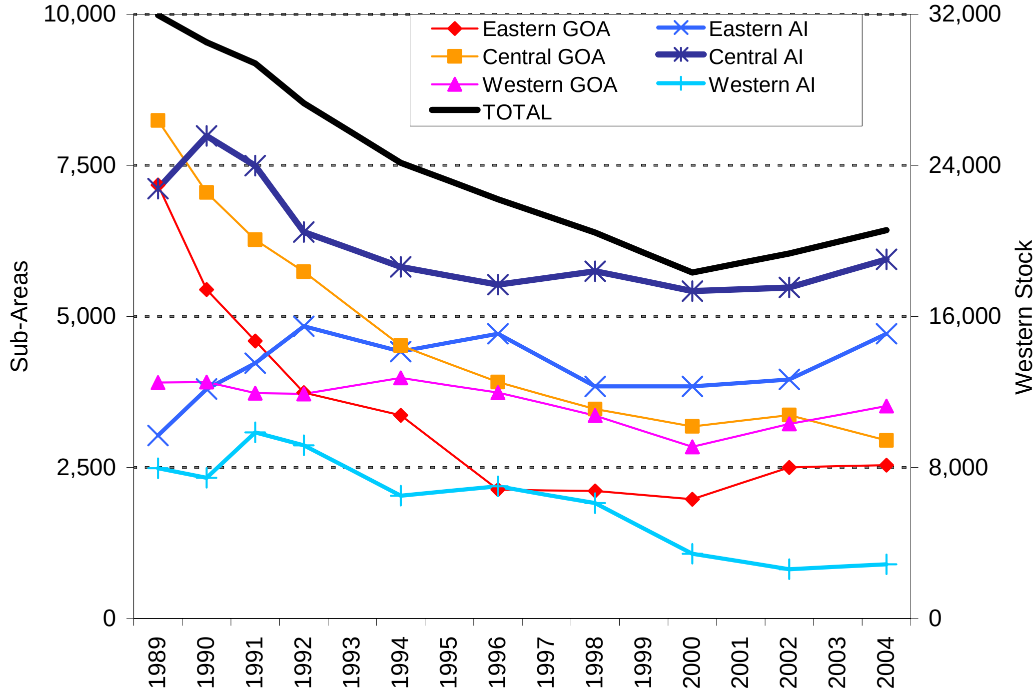

Figure 104. Counts of non-pup (adult and juvenile) Steller sea lions on rookery and haulout trend sites in the range of the western population from 1989-2004. Counts are aggregated by sub-area (left axis) in the Gulf of Alaska (GOA) and Aleutian Islands (AI) and for the entire western Alaskan population (TOTAL; right axis). Surveys in 1989-2002 used 35 mm oblique slides, while the 2004 survey used medium format vertical photographs. Counts in 2004 displayed above have been reduced 3.5% from the actual count to account for the format differences (see text).

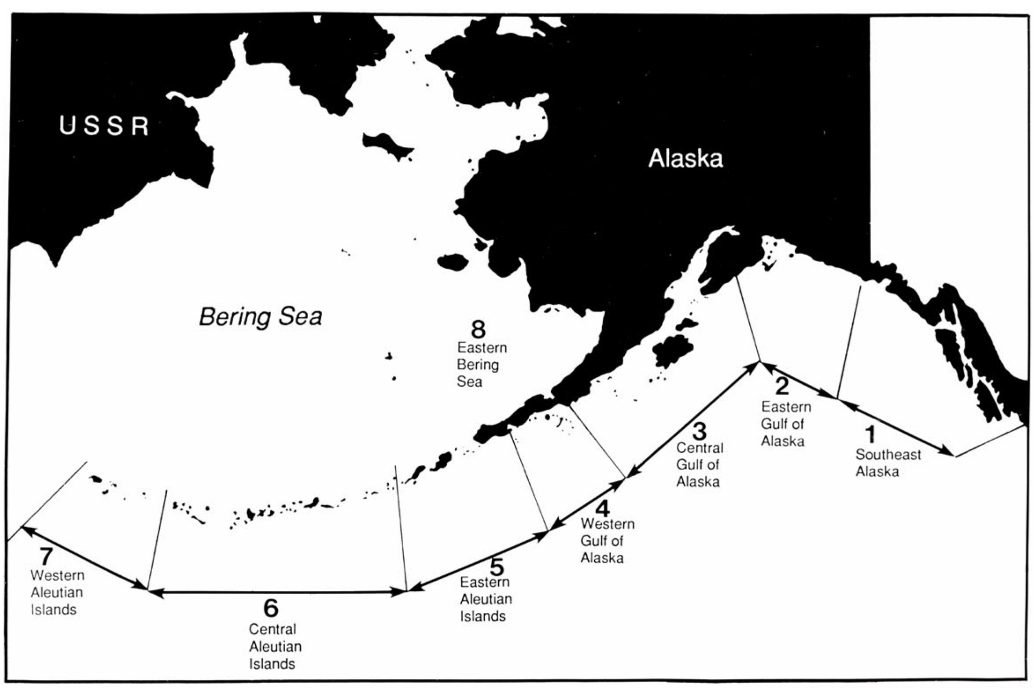

Figure 105. Map of Alaska showing areas within the range of the western Steller sea lion (subareas 2-7) surveyed in 2004.

Table 17. Counts of adult and juvenile (non-pup) Steller sea lions observed at rookery and haulout trend sites in six subareas of Alaska during June and July aerial surveys from 1989 to 2004, including overall percentage changes between 2002 and 2004, 2000 and 2002, and 1991 and 2004, and estimated annual rates of change from 1991-2004. Counts in 1989-2002 were made visually or from 35 mm slides shot obliquely out the side windows of aircraft. Counts in 2004 were made from medium format photographs shot vertically over rookery and haulout sites. Comparison studies suggest that counts from medium format photographs are approximately 3-4% greater than from 35 mm photographs. Both the corrected (20041) and uncorrected (20042) subarea trend site counts in 2004 are listed. Corrected 2004 counts were used to compute percentage changes and annual rates of change.

	Gulf of Alaska			Aleutian Islands			Western
Year	Eastern	Central	Western	Eastern	Central	Western	Stock
1989	7,175	8,243	3,908	3,032	7,114	2,486	31,958
1990	5,444	7,050	3,915	3,801	7,988	2,327	30,525
1991	4,596	6,270	3,732	4,228	7,496	3,083	29,405
1992	3,738	5,739	3,716	4,839	6,398	2,869	27,299
1994	3,365	4,516	3,981	4,419	5,820	2,035	24,136
1996	2,132	3,913	3,739	4,715	5,524	2,187	22,210
1998	2,110	3,467	3,360	3,841	5,749	1,911	20,438
2000	1,975	3,180	2,840	3,840	5,419	1,071	18,325
2002	2,500	3,366	3,221	3,956	5,480	817	19,340
2004[1]	2,540	2,948	3,517	4,714	5,944	899	20,563
2004[2]	2,632	3,055	3,645	4,885	6,160	932	21,309
<u>Percentage Changes</u>							
2002-2004	1.6%	-12.4%	9.2%	19.2%	8.5%	10.1%	6.3%
2000-2002	26.6%	5.9%	13.4%	3.0%	1.1%	-23.7%	5.5%
1991-2004	-44.7%	-53.0%	-5.7%	11.5%	-20.7%	-70.8%	-30.1%
<u>Annual Rates of Change 1991-2004</u>							
Annual Change	-4.7%	-5.6%	-1.4%	-0.6%	-1.5%	-10.6%	-3.1%
Upper 95%	-0.2%	-3.7%	0.4%	1.4%	0.2%	-7.3%	-1.5%
Lower 95%	-9.2%	-7.5%	-3.2%	-2.5%	-3.2%	-13.8%	-4.8%
P[3]	**0.0446**	**0.0004**	0.1032	0.4993	**0.0752**	**0.0002**	**0.0037**

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

Northern fur seal (*Callorhinus ursinus*)

The northern fur seal ranges throughout the North Pacific Ocean from southern California north to the Bering Sea and west to the Okhotsk Sea and Honshu Island, Japan. Breeding is restricted to only a few sites (i.e., the Commander and Pribilof Islands, Bogoslof Island, and the Channel Islands) (NMFS 1993). During the breeding season, approximately 74% of the worldwide population is found on the Pribilof Islands in the Bering Sea (NMFS 1991, 1993). Two separate stocks of northern fur seals are recognized within U.S. waters: an Eastern Pacific stock and a San Miguel Island stock.

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

Based on counts conducted during August 2004, it is estimated that 122,803 (SE = 1,290) pups were born on St. Paul Island and 16,876 (SE = 239) pups were born on St. George Island (Tables 18 and 19). The observed pup mortality rates of 3.27% on St. Paul Island and 2.46% on St. George Island were relatively low, and similar to estimates obtained in 2002. The 2004 pup production estimate for St. Paul Island is 15.7% less than the estimate in 2002 and 22.7% less than the estimate in 2000. The 2004 pup production estimate for St. George Island is 4.1% less than the estimate in 2002 and 16.4% less than the estimate in 2000. Estimated pup production has declined at 6.4% per year (SE = 0.78%, P = 0.01) on St. Paul Island, and at 4.6% per year (SE = 0.45%, P = 0.01) on St. George Island, from the estimated pup production in 1998 (Figure 106). Estimated pup production on the two islands, as a whole, has declined at 6.2% per year (SE = 0.58%, P = 0.01) since 1998. The 2004 pup production estimate on St. Paul Island is comparable with the level observed in 1918, while the St. George pup production estimate is below the level observed in 1916. During the time period of 1916 to 1918, the northern fur seal population was increasing at approximately 8% per year following the cessation of extensive pelagic sealing.

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

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

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

Table 19. Numbers of northern fur seal, *Callorhinus ursinus*, pups born on St. George Island, Alaska in 2004. Estimates are shown on numbers alive at the time of shearing, counts of dead pups, estimates of pups born, standard error of estimate (SE), and estimates of pup mortality rate (%).

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

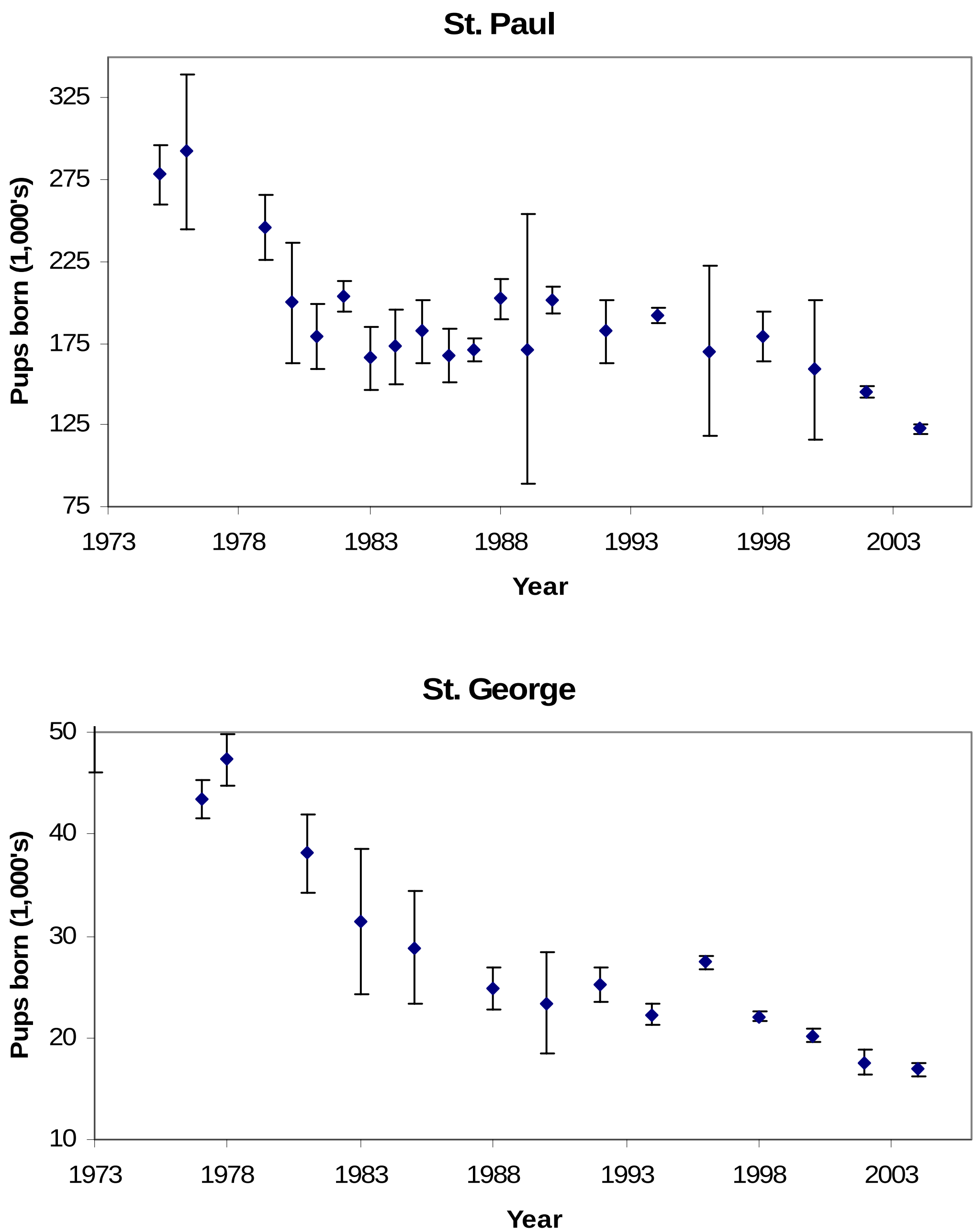

Figure 106. Northern fur seal pups born on the Pribilof Islands 1975-2004. Error bars are approximate 95% confidence intervals.

Harbor Seal (*Phoca vitulina*)

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

Statewide abundance

The National Marine Mammal Laboratory (Alaska Fisheries Science Center) conducted aerial surveys of harbor seals across the entire range of harbor seals in Alaska. Each of five survey regions was surveyed between 1996 - 2000, with one region surveyed per year (Boveng et al. 2003; Simpkins et al. 2003). The current statewide population estimate for Alaskan harbor seals is 180,017 (Table 20). This estimate, however, is believed to be low because it is based on incomplete coverage of terrestrial sites in Prince William Sound and of glacial sites in the Gulf of Alaska and the Southeast Alaska regions.

Table 20. Provisional regional and statewide population estimates for Alaskan harbor seals (subject to revision as part of analyses that are currently underway).

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

Southeast Alaska Stock Abundance

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

Gulf of Alaska Stock Abundance

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

Bering Sea Stock Abundance

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

CETACEANS

Wide-scale distribution surveys of large cetaceans have been conducted opportunistically for many years in Alaskan waters, with periodic short-term focus on estimating the abundance of specific populations or species. However dedicated surveys to determine the abundances of all observed cetaceans in Alaskan waters have only recently been made (Moore et al. 2002). Line transect surveys conducted during the summers of 2001-2002 indicated that two of three species of large whales regularly observed throughout the cruises were abundant in some portion of their range within former whaling grounds off coastal waters of the Aleutian Islands (Zerbini et al. 2004). The vicinity of the Aleutian Islands and Alaska Peninsula dominated as major whaling grounds in the North Pacific Ocean. Numerous stocks of large whales were extensively exploited, to the point of depletion, into the late 20th century including the North Pacific right whale (*Balaena japonica*), blue whale (*Balaenoptera musculus*), fin (*Balaenoptera physalus*), sei (*Balaenoptera borealis*), humpback (*Megaptera novaeangliae*), and sperm whales (*Physeter macrocephalus*) and to a lesser degree minke whales (*Balaenoptera acutorostrata*). The recent findings of the two summer survey conducted by Zerbini et al. (2004) are that humpback whales were abundant in historical whaling grounds north of the eastern Aleutian Islands, and fin whales were abundant in one of two primary whaling areas, Port Hobron, south of the Alaska Peninsula. Minke whales were abundant during both cruises with concentrations in the eastern Aleutian Islands. Distribution patterns and areas of concentrations of humpbacks, fins, and minkes were similar overall between study years and agreed with distributions reported by other research efforts conducted across the Aleutians during this time (Sinclair et al. submitted). Similar to the findings of other surveys, no sightings of either blue or North Pacific right whales were observed in either cruise indicating the continued depleted status of these species (Zerbini et al. 2004). However, it is of note that sightings of blue whales have been confirmed in other areas. Observations of blue whales in the Gulf of Alaska were recorded on July 15-16, 2004. Three individuals of this endangered species were seen about 100-150 miles southeast of Prince William Sound. These are the first documented sightings in the Gulf of Alaska in the past three decades.

POTENTIAL CAUSES OF DECLINES IN MARINE MAMMALS

Direct Take/Fishery Interactions - Observable interactions between marine mammals and fisheries are generally restricted to direct mortality in fishing gear. In the absence of understanding the effect of individual takes upon the population as a whole, interpretation of the significance of removal of individuals is limited to a simple accounting of the number of individual animals killed. Based on counts of animals reported taken incidentally in fisheries up through 2003 (Angliss and Lodge 2004), none of the marine mammal incidental mortality estimates for Alaskan groundfish fisheries exceeded the potential biological removal (PBRs) (Hill and DeMaster 1999; Table 21). However, it should be noted that a number of stocks of marine mammals are incidentally killed in commercial fisheries activities (Table 21). Killer whales, humpback whales, and Steller sea lions have levels of mortality which may cause some federally-managed commercial fisheries to change categories in the List of Fisheries. While there are many fisheries that overlap within the range of depleted and endangered marine mammal stocks, few overall are observed, and the rate of coverage is low. Reliable estimates of PBRs for a number of stocks (i.e. harbor seals) are limited by the absence of updated population data. As it is acquired, stock assessment data will be used to evaluate the progress of each fishery towards achieving the goal of zero fishery-related mortality and serous injury of marine mammals, as outlined in the Marine Mammal Protection Act (MMPA) (Public Law 103-238, 1994).

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

Competition may also exist where marine mammal foraging areas and commercial fishing zones overlap. Female northern fur seals from the Pribilof Islands forage extensively at distances greater than 81 nm (150 km) from the rookery (Robson 2001), placing them within range of commercial groundfish vessels displaced by Steller sea lion conservation zone restrictions.

Indirect Competition - More difficult to identify are the indirect effects of competition between marine mammals and fisheries for prey resources. Such interactions may limit foraging success through localized depletion (Lowe and Fritz 1997), destabilization of prey assemblages (Freon et al. 1992, Nunnallee 1991, Laevastu and Favorite 1988), or disturbance of the predator itself. Compounding the problem of identifying competitive interactions is the fact that biological effects of fisheries may be indistinguishable from changes in community structure or prey availability that might occur naturally.

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

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

Most scientists agree that the 1976/77 regime shift dramatically changed environmental conditions in the BSAI and GOA (Benson and Trites 2000). However, there is considerable disagreement on how and to what degree these environmental factors may have affected both fish and marine mammal populations. Some authors suggest that the regime shift changed the composition of the fish community resulting in reduction of prey diversity in marine mammal diets (Sinclair 1988, Sinclair et al. 1994, Piatt and Anderson 1996, Merrick and Calkins 1996). Some suggest the overall biomass of fish was reduced by about 50 percent (Merrick et al. 1995, Piatt and Anderson 1996). Others suggest that the regime shift favored some species over others, in part because of a few years of very large recruitment and overall increased biomass (Beamish 1993, Hollowed and Wooster 1995, Wyllie-Echeverria and Wooster 1998).

Hunt et al. (2002) proposed that the pelagic ecosystem in the southeastern Bering Sea alternates between bottom-up control in cold regimes and top-down control in warm regimes. In their proposed Oscillating Control Hypothesis, Hunt et al. (2002) hypothesized that when cold or warm conditions span over decades, the survival and recruitment of piscivorous vs. planktivorous fishes are variably affected (Hunt et al. 2002) along with the capacity of fish populations, (and arguably, apex predator populations) to withstand commercial fishing pressures.

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

SUMMARY OF INFORMATION ON ALASKA MARINE MAMMAL STOCKS

Table 21. This summary table of Alaska marine mammal stocks includes estimates of fishery mortality and native subsistence harvest levels up through 2003. New estimates of PBR based on the 2004 population surveys of northern fur seals and Steller sea lions are not yet available. Fishery mortality is expressed as an annual average for the time period 1998-2003.

Species	Stock	N (est)	CV	C.F.	CV C.F.	Comb. CV	N(min)	0.5 Rmax	F(r)	PBR	Fishery mort.	Subsist mort.	Status
Baird's beaked whale	Alaska	n/a					n/a	0.02	0.5	n/a	0		NS
Bearded seal	Alaska	n/a					n/a	0.06	0.5	n/a	1	6,788	NS
Beluga whale	Beaufort Sea	39,258	0.229	2	n/a	0.229	32,453	0.02	1	649	0	177	NS
Beluga whale	E. Chukchi Sea	3,710	n/a	3.09	n/a	n/a	3,710	0.02	1	74	0	60	NS
Beluga whale	E. Bering Sea	18,142	0.24	3.09	n/a	0.24	14,898	0.02	1	298	1*	164	NS
Beluga whale	Bristol Bay	1,888	n/a	3.09	n/a	0.2	1,619	0.02	1	32	1*	15	NS
Beluga whale	Cook Inlet	386	0.087			0.087	359	0.02	0.3	2.2	0	0	S
Bowhead whale	W. Arctic	9,860	0.124			0.124	8,886	0.02	0.5	89	0.2	58	S
Cuvier's beaked whale	Alaska	n/a					n/a	0.02	0.5	n/a	0	0	NS
Dall's porpoise	Alaska	83,400	0.097			0.097	76,874	0.02	1	1,537	37.5	0	NS
Fin whale	NE Pacific	n/a					n/a	0.02	0.1	n/a	0.8	0	S
Gray whale	E. N. Pacific	26,635	0.1006			0.1006	24,477	0.0235	1	575	8.9	97	NS
Harbor Porpoise	SE Alaska	10,947	0.242	1.56*	0.108[+]	0.274	8,954	0.02	0.5	90	3*	0	NS
Harbor porpoise	Gulf of Alaska	30,506	0.214	1.37[+]	0.066[+]	0.304	25,536	0.02	0.5	255	25	0	NS
Harbor porpoise	Bering Sea	47,356	0.223	1.337[+]	0.062[+]	0.3	39,328	0.02	0.5	393	2	0	NS
Harbor seal	SE Alaska	37,450	0.026	1.74	0.068	0.073	35,226	0.06	1	2,114	36	1,749	NS
Harbor seal	Gulf of Alaska	29,175	0.023	1.5	0.047	0.052	28,917	0.06	0.5	868	36	791	NS
Harbor seal	Bering Sea	13,312	0.062	1.5	0.047		12,648	0.06	0.5	379	31	161	NS
Humpback whale	W. N. Pacific	394	0.084			0.084	367	0.02	0.1	0.7	0.8	0	S
Humpback whale	Cent.N. Pacific	4,005	0.095			0.095	3,698	0.02	0.1	7.4	4.2	0	S
	CNP-SEAK feeding area	961	0.12			0.12	868	0.02	0.1	3.5	2.2	0	
Killer whale	E. N. Pacific N. resident	723	n/a				723	0.02	0.5	7.2	1.4	0	NS
Killer whale	E. N. Pacific transient	346	1				346	0.04	0.04	2.8	0.6	0	NS
Minke whale	Alaska	n/a					n/a	0.02	0.5	n/a	0	0	NS
North Pacific right whale	E. N. Pacific	n/a					n/a	0.02	0.1	n/a	0	0	S
Northern fur seal	E. North Pacific	888,120		4.475	n/a	0.2	751,754	0.043	0.5	16,162	16	1,132	S
Pacific white-sided dolphin	Cent.N. Pacific	26,880					26,880	0.02	0.5	n/a	4	0	NS
Ribbon seal	Alaska	n/a					n/a	0.06	0.5	n/a	1	193	NS
Ringed seal	Alaska	n/a					n/a	0.06	0.5	n/a	0	9,567	NS
Sperm whale	N. Pacific	n/a					n/a	0.02	0.1	n/a	0.4	0	S
Spotted seal	Alaska	n/a					n/a	0.06	0.5	n/a	3	5,265	NS
Stejneger's beaked whale	Alaska	n/a					n/a	0.02	0.5	n/a	0	0	NS
Steller sea lion	E. U. S.	31,028					31,028	0.06	0.75	1,396	3.7**	2	S
Steller sea lion	W.U. S.	34,775					34,775	0.06	0.1	209	25.9	176	S

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

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

** = this does not include intentional take in British Columbia

+ = There are two correction factors involved in the estimation of harbor porpoise abundance. One factor is 2.96 (CV = 0.18), which corrects for availability bias, and is used for all three estimates for Alaska harbor porpoise stocks following Laake et al. (1996). The correction factor included in this table corrects for animals missed on the trackline. Because this number differed for different stocks, the factor is included in the summary table.

Seabirds

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The 2004 seabird section provides information on incidental catch estimates, colony trend data for select seabird colonies, and a review of other work being completed. Readers interested in a discussion of seabird foraging and effects of food limitations on seabird populations should refer to the extensive information provided in the 2000 Ecosystem chapter (NPFMC 2000). Readers interested in fishery/seabird geographical overlap can rely on the discussion provided in the 2002 chapter (NPFMC 2002).

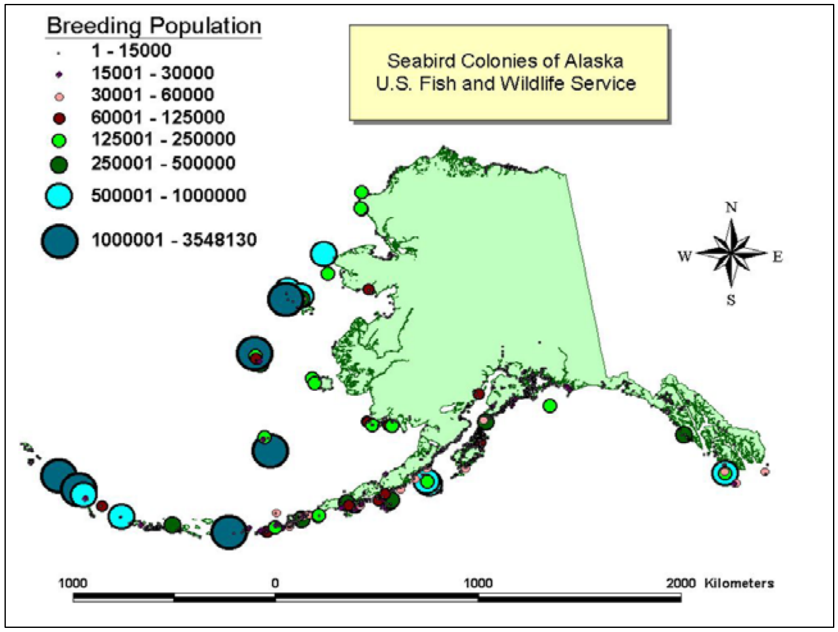
The U.S. Fish & Wildlife Service (USFWS) is the lead Federal agency for managing and conserving seabirds and is responsible for monitoring distribution, abundance, and population trends. The U. S. Geologic Survey – Biological Resources Division (USGS-BRD) plays a critical role in seabird research in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

Distribution

Pelagic

The pelagic distribution of seabirds in Alaskan waters has not been examined in recent years. Comparisons to historical information, especially that of the OCSEAP surveys completed in the 1970's, and to current fishing effort cannot be made given current data gaps. Recent efforts to address this information gap have included the implementation of stationary seabird surveys on longline and trawl fisheries research vessels. This program was initiated in 2002 by the Washington Sea Grant Program in collaboration with the International Pacific Halibut Commission, the Alaska Department of Fish and Game, and NMFS to complete "bird-feeder" type surveys on charter vessels conducting halibut and sablefish surveys. Counts of seabird abundance were performed after each set was brought aboard and within a standardized area astern. Data collected in 2002 were reported (Melvin et al. 2004), as will the 2003 information. In 2004 the program was expanded from longline charter vessels to groundfish charters operated by the Alaska Fisheries Science Center. The opportunity to develop a line-transect seabird survey program on platforms of opportunity is currently being explored.

Colonies



(Not updated from 2003). The sizes of seabird colonies and their species composition differ among geographic regions of Alaska (Figure 107), due to differences in marine habitats and shoreline features (Stephensen and Irons 2003). In the southeastern GOA, there are about 135 colonies, and they tend to be small (<60,000 birds, and often <5,000). Exceptions are two colonies with 250,000-500,000 birds at Forrester and St. Lazaria Islands. Along the coast of north-central Gulf of Alaska (GOA), colonies are generally small but number over 850 locations, with larger colonies at the Barren and Semidi Island groups. Moving west along the Alaska Peninsula (with 261 colonies) and throughout the Aleutians (144 colonies), colonies increase in size, and include several with over 1 million birds and two with over 3 million birds. Large colonies of over 3 million birds are also found on the large islands of the Bering Sea (BS). Relatively few colonies are located along the mainland of the BS coast, and colonies along the Chukchi and Beaufort Seas are small and dispersed.

Trends in Abundance and Productivity

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

Some seabirds are highly clustered into a few colonies, and 50 % of Alaska's seabirds nest in just 12 colonies, 10 of which are in the EBS (Stephensen and Irons 2003). The USFWS and USGS-BRD monitor selected colonies on rotating schedules, described in detail in Dragoo et al. (2003) (see also, NPFMC 2002). Discussion of factors that influence seabird populations was presented in the 2002 Ecosystems chapter (NPFMC 2002). For detailed summaries of seabird chronology, breeding success and population trends for species at specific sites refer to Dragoo et al. (2003), which includes data up to 2001. Below, we summarize data presented in Dragoo et al. (2003), with a focus on broad regional trends, using each species x site as a sample (Figures 108-110).

Overall, breeding chronology (Figure 108) was early or typical in 2001 for most regions and species. Exceptions were later than average dates for storm-petrels in southeast Alaska (SEAK) and for puffins in the southwest BS (SWBS). A trend of earlier breeding in seabirds has been noted throughout the North Pacific, and may be linked to climate changes affecting spring plankton blooms (Root et al. 2003). If plankton blooms are too early, it may result in a mismatch between prey and seabirds, which can affect seabird breeding success (Bertram et al. 2001).

Seabird productivity in 2001 (Figure 109) was variable throughout regions and among species. Dragoo et al. (2003) noted that in most cases, plankton feeders (storm-petrels and auklets) had average or below average reproductive success, whereas diving piscivores (cormorants, murres, murrelets, rhinoceros auklets and puffins) had average or above average productivity. However, there was considerable variability even within feeding guilds. In general, lower than average productivity was more prevalent in the Chukchi, southeast BS (SEBS), and SWBS. In the SWBS in particular, 52 % of the samples (n = 27) had below average breeding success. In the GOA, productivity was above average, while SEAK was more variable. Notably, black-legged kittiwakes (surface-feeding piscivores), one of the most frequently monitored species, had below average productivity in 9 of 10 sites stretching from the Chukchi Sea to the southern BS, yet they did well at all 4 sites in the GOA/SEAK (Gulf of Alaska/Southeast Alaska). Murres, also piscivorous but able to dive to 100 m, were successful at a few sites in the BS, but also did better in the GOA/SEAK.

Changes in seabird populations (Figure 110) are less subject to annual fluctuations, since adults are long-lived and usually return to the same breeding colony. Because changes observed in a single year may not be meaningful, Dragoo et al. (2003) describe population trends by exponential regression models, with inclusion of 2001 data. Through 2001, populations of fulmars and petrels (primarily surface-feeding on invertebrates) were stable or increasing at all sites. Cormorants (nearshore diving piscivores), declined in 9 of 11 samples, however, cormorants sometimes shift nesting locations, so population trends at a given site are difficult to interpret (Dragoo et al. 2003). Other piscivores showed variable trends. Regionally, declining seabird populations were most prevalent in the SEBS (which includes the Pribilof Islands) and GOA (Figure 110). The highest proportion of increasing trends occurred in the SWBS (9 of 18 samples). In the N. Bering / Chukchi and in SEAK, most populations were stable or increasing.

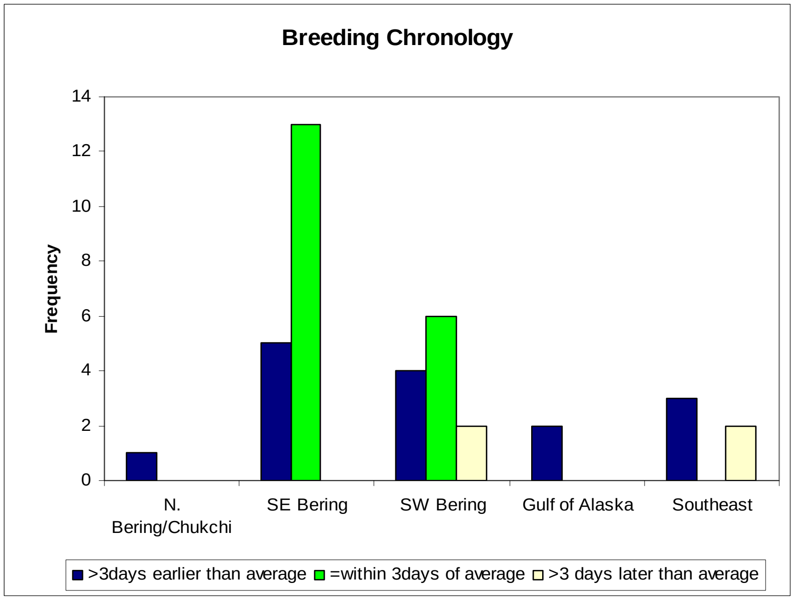


Figure 108. Seabird breeding chronology for species monitored at selected colonies in Alaska in summer 2001. Frequency is the number of samples (species x site) for each region, showing earlier than average, average, or later than average dates for breeding. Chronology usually used hatch dates. Data are from Table 3 in Dragoo et al. 2003.

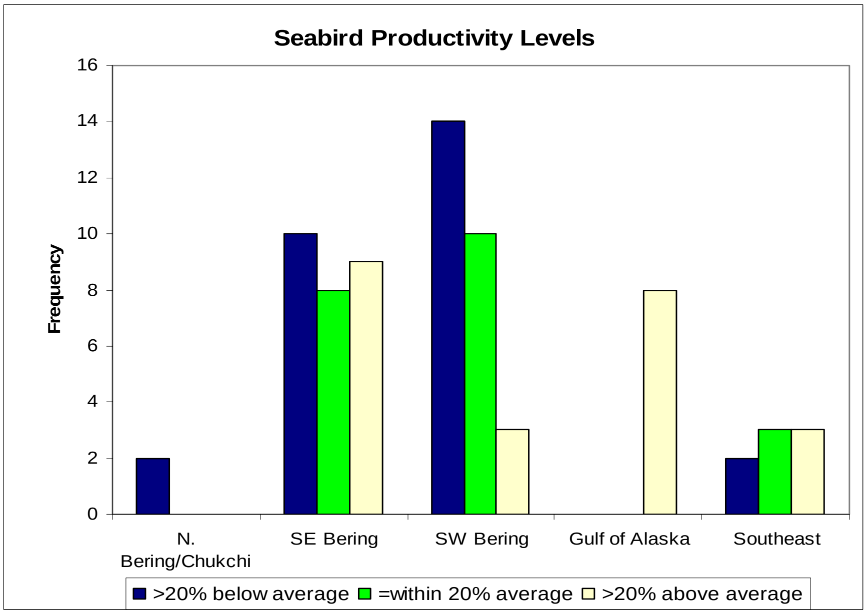


Figure 109. Seabird breeding success for species monitored at selected colonies in Alaska in summer 2001. Frequency is the number of samples (species x site) for each region, showing below average, average, or above average productivity rates. Productivity was usually expressed as chicks fledged per egg (but see individual reports referenced in Dragoo et al. 2003 for variants). Data are from Table 4 in Dragoo et al. 2003.

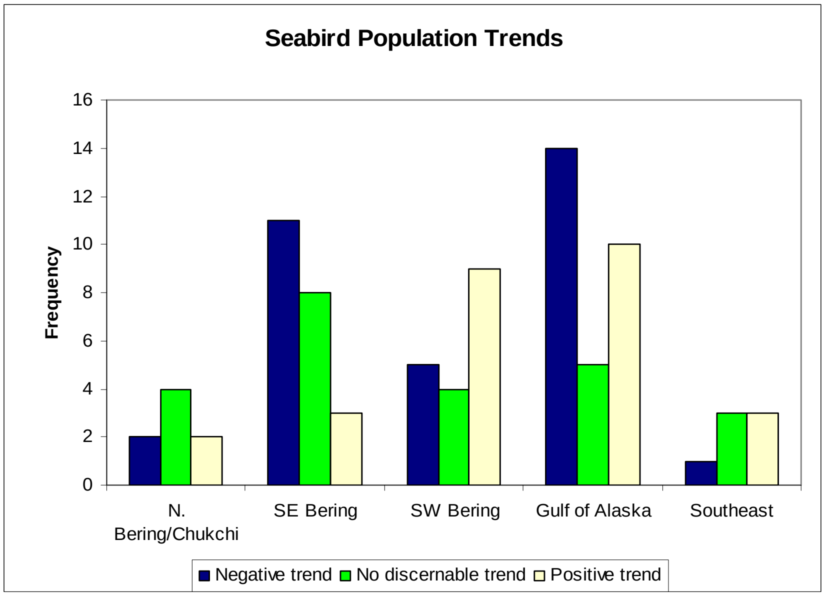


Figure 110. Seabird population trends for species monitored at selected colonies in Alaska in summer 2001. Frequency is the number of samples (species x site) for each region, showing negative trends, no statistically significant trend, or positive trends in population, derived from exponential regression models for samples with multiple years of data. Data are from Table 4 in Dragoo et al. 2003.

Ecosystem Factors Affecting Seabirds

<u>Food Availability</u>

Seabird foraging and effects of food limitations on seabird populations were addressed in the 2000 Ecosystem chapter (NPFMC 2000). A comprehensive review has not been completed since then. Factors affecting food availability for seabirds include (1) forage fish availability and spatial/temporal changes due to ecosystem effects, (2) commercial fishery removals of forage fish, either through directed catch or bycatch, (3) enhancements to forage fish stock and availability due to commercial fishery removal of predators, and (4) provisioning of food to seabirds through discard and offal from commercial fisheries. We are unaware if a model of these factors has been completed for the North Pacific. There are no directed fisheries for forage fish in federal waters off Alaska, and bycatch information is available through observer data. Work is being started at the Alaska Fisheries Science Center (AFSC) to address item 4, which may lay some groundwork to fill knowledge gaps with regard to the other items.

Fishery Interactions

Fisheries bycatch.

This section provides information on trends in seabird bycatch by fishery and by species or species group. The detailed seabird bycatch tables previously reported here will be available through other sources and documents such as the AFSC seabird/fishery interaction website at http://www.afsc.noaa.gov/refm/reem/Seabirds/Default.htm

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

Between 1993 and 2003 the average annual bycatch in the combined BSAI and GOA longline fisheries was 13,551 seabirds (12,619 and 932 respectively). Over this period the average annual bycatch rates were 0.71 and 0.24 birds per 1,000 hooks in the BSAI and in the GOA, respectively. The period previous to 1998 was typified by large inter-annual variation in seabird bycatch, even with the implementation of the first generation of seabird avoidance regulations in 1997 (Figure 111). Beginning in 1998, seabird bycatch has trended downward. In 2002 many freezer-longliners fishing in the BSAI adopted the recommendations from studies completed by Melvin et al. (2001). Paired streamer lines meeting specific performance standards had proven to be very effective in reducing seabird bycatch during this study. NMFS completed revisions to seabird avoidance regulations in February 2004. Among other requirements, vessels larger than 55 feet length over all must use paired streamer lines except in certain weather conditions.

The annual bycatch of seabirds has been substantially reduced to the current numbers of about 5,000 birds (Figure 111). While seabird bycatch increased in 2003 over 2002, the rate remained constant while effort continued an upward trend (Figure 112). Note that a total of 3,835 seabirds were taken in BSAI longline fisheries in 2002. This represents a steady reduction over the last few years, and is a 6-fold decrease in the total number of birds taken from the high of over 24,000 birds in 1998. In the same time frame there has been a 7-fold reduction in the bycatch rate from 0.14 to 0.02 seabirds per 1,000 hooks.

Similar trends occurred in the GOA, although they were not as pronounced (Figure 113). This may in part be due to the already low bycatch rates there, as well as other factors. A similar pattern occurs in the GOA, where a 6-fold decrease in bycatch numbers has occurred from the high of nearly 1,634 birds in 1996 (Figure 113). A very large increase in overall effort in 2003 was matched with a slight increase in overall seabird bycatch in the GOA. However, with steady increases in overall effort each year since 1998, the bycatch has decreased steadily from that high year. This general downward trend in seabird bycatch may continue, given the improved seabird avoidance regulations implemented in early 2004 and efforts undertaken by NMFS, Washington Sea Grant, and industry associations to complete outreach activities and work with vessel owners and operators.

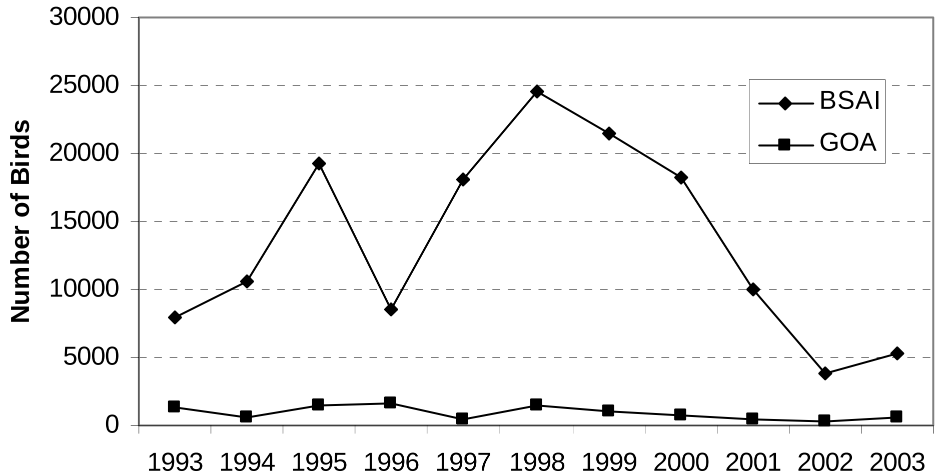


Figure 111. Estimated seabird bycatch in the BSAI and GOA groundfish longline fisheries of the Alaskan EEZ, 1993 to 2003.

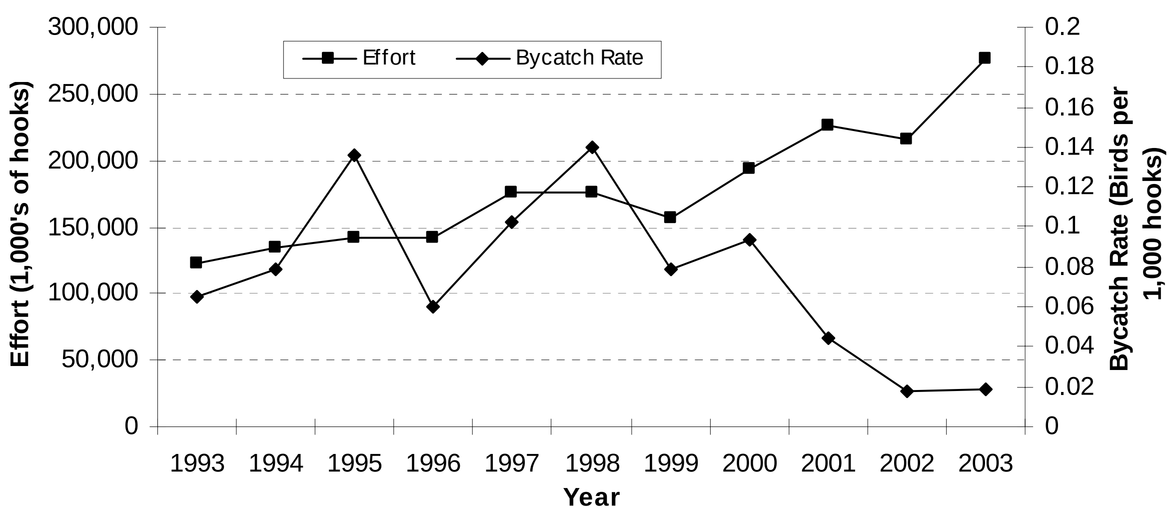


Figure 112. BSAI groundfish longline effort and seabird bycatch rate, 1993 through 2003.

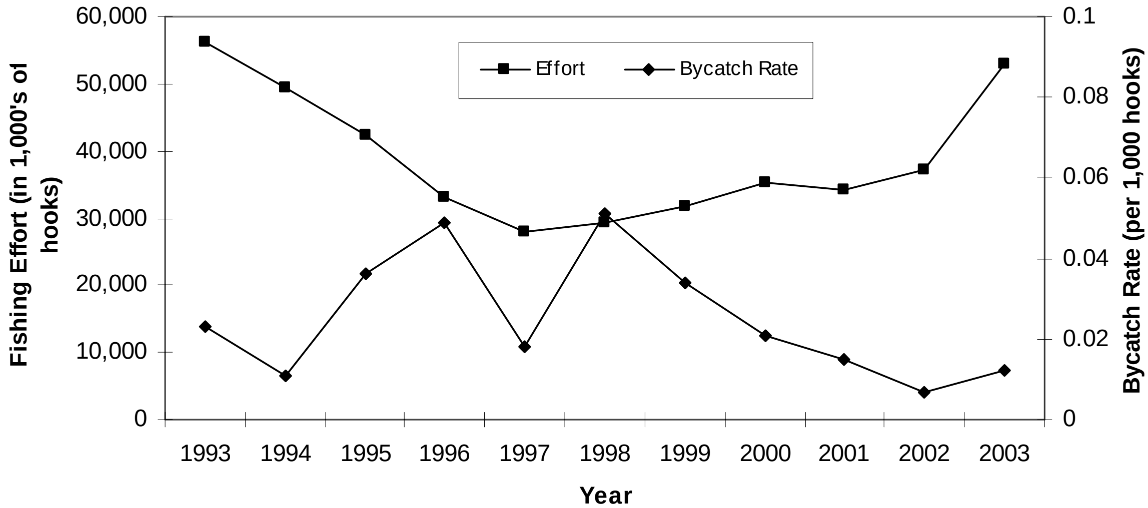


Figure 113. GOA groundfish longline effort and seabird bycatch rate, 1993 through 2003.

Seabird bycatch in the BSAI and GOA longline fleets is linked to a variety of factors that have resulted in large inter-annual variation (Dietrich 2003). Some of these factors include food availability, environmental conditions, breeding success, and population levels. Other factors include fleet or vessel-specific factors and the effectiveness of mitigation measures. Seabird bycatch in 2002 was the lowest recorded for the longline fleet. Efforts by the longline fleet may have contributed substantially to the observed reduction, although no analysis has been completed to ascertain the contribution of various factors. In 2003 seabird bycatch in the BSAI increased by nearly 40% over 2002, while the bycatch rate remained fairly constant (0.019 vs 0.018 in 2002). The increased bycatch was likely due, in part, to a 28% increase in effort. However, other factors may also have been at work, given the reduction in bycatch between 1998 and 2002 of 84% while effort increased over this time by 23%. With the implementation of regulations in 2004, and other activities directed at reducing bycatch the downward trend should continue.

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

Trawl: On trawl vessels only, observers use whole haul, partial haul, or basket sampling to record prohibited species bycatch and determine the species composition of the haul. Observers are often required to use 2 sample types in a single haul, in order to best sample for either of these goals. Observers have been instructed to use the largest sample available when monitoring for seabird bycatch. Unfortunately, that has not always occurred. This would not be a problem for estimation purpose, as observers record their sample size for each species in their sample, except that the great majority of hauls do not have any seabird bycatch. NMFS did not require observers to record the sample size when no birds were observed, so it is unknown which sample size was used to monitor for seabird bycatch in these hauls. Thus, it has been necessary to calculate two alternative sets of estimates of seabird bycatch for trawlers based on the largest (alternative 1) and smallest (alternative 2) sizes of sampling effort recorded for fish species (Figure 114). In each of these two alternative calculation methods, a separate ratio estimator was used to bind the results of the catch ratios and variances of data from the three different sample sizes into arbitrary equal samples which were then inflated upwards to the total catch effort of the NMFS blend program. It is not known which of the 2 estimates is more accurate. Seabird bycatch on trawl vessels probably lies somewhere between them. If the majority of observers had been able to use their largest sample size to monitor for seabird bycatch, as instructed, then the lower of the two estimates more closely represents bycatch on the trawl fleet. This issue has been resolved for data collections beginning in the 2004 season, where the sample size used to monitor for seabirds will be noted whether a bird was taken or not. Estimates are provided for 1998 through 2003 only due to the way the commercial catch data were organized prior to that. Northern fulmars are again the most common species taken, constituting more than 53% of the seabird bycatch.

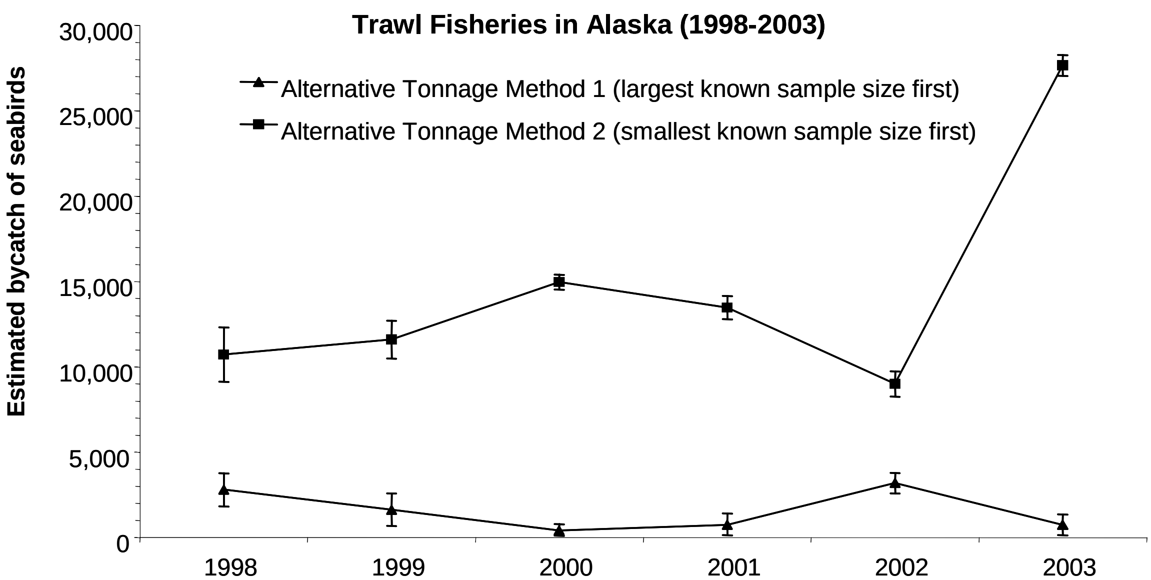


Figure 114. Seabird bycatch in Alaskan groundfish trawl fisheries (combined) using two alternate estimation methods incorporating potential sample sizes used while monitoring for seabirds in observer samples.

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

University of Washington, and the USFWS to determine and test mitigation measures to reduce seabird interactions with trawl sonar transducer cables.

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

Species Composition: Depending on which trawl estimate is used (see above), longline gear accounted for 94% or 65% of the total average annual seabird bycatch while trawl gear accounted for either 6% or 35%. Pot gear accounted for less than 1% in all cases. The higher percentage of trawl bycatch coincides with the alternate trawl estimation methods as described above (Figure 114). Based on the average annual estimates of seabirds observed taken in groundfish longline fisheries from 1993 to 2002, 93 % of the longline seabird bycatch was caught in the BSAI, and 7% in the GOA. Also of note, the bycatch rates in the BSAI are approximately 3 times higher than in the GOA (Figures 112 and 113).

Seabird bycatch trends by species or species groups.

When summarizing overall mortality for each species, all fisheries combined, the numbers are confounded by the need to produce two alternate estimates within the trawl fleet due to the sample size notation issue (see above, Figure 114). Detailed numbers by species or species groups can be found at www.afsc.noaa.gov/refm/seabirds.

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

Laysan Albatross: Laysan albatross bycatch peaked in 1998 at about 2,000 birds and has been decreasing substantially since then to less than 150 birds in 2002 (Figure 115). The rise in Laysan albatross bycatch from 2002 to 2003 was driven both by the BSAI longline bycatch, and by birds taken in the trawl fishery. In the trawl fishery, the 2003 estimated bycatch mortality of Laysan albatross, using the high estimate for the trawl fleet, was 432 birds. The lower trawl estimate yields 365 birds. In 2002 the numbers were 105 and 49, respectively. The cause of this rise in bycatch is currently unknown, but might be attributed to the normal inter-annual variations seen in the past. When analyzed, the 2004 estimates should indicate whether efforts to reduce albatross mortalities through the use of mitigation measures have been successful. Efforts currently underway include implementation of regulations requiring seabird mitigation measures on longliners, coordination with the industry to complete vessel-specific bycatch reduction work, and continued research in both the longline and trawl fisheries on methods to deter birds from interacting with commercial fishing gear. The Laysan albatross population was estimated at 874,000 by BirdLife International (www.birdlife.org) in 2003, but that number includes only breeding pairs. The U.S. Fish and Wildlife Service is currently engaged in a population assessment. A bycatch level of 500 birds per year represents 0.06% of the Birdlife International population estimate. However, Laysan albatross bycatch is not constrained only to the groundfish fisheries in Alaska. They may be taken by demersal halibut and pelagic tuna and swordfish longline fisheries in the North Pacific as well.

Black-footed Albatross: No black-footed albatross have been recorded by observers in the Alaskan trawl fleets from 1998-2004, either within the observer sample or from an interaction with trawl cables. The bycatch of black-footed albatross is from the longline fisheries, and has been extremely variable over time (Figure 116). Most bycatch occurs in the GOA longline fisheries. After a peak of nearly 700 black-footed albatross taken in 1996, the bycatch has undergone a steady downward trend. Numbers rose again in 2003, due to a slight increase in bycatch rates coupled with a larger increase in overall effort in the GOA. Implementation of seabird avoidance regulations and other activities will hopefully reduce black-footed albatross bycatch. The USFWS was petitioned on 28 September 2004 to list the black-footed albatross as endangered under the U.S. Endangered Species Act, citing the decision by the IUCN to classify the species as endangered on the Red List in 2003 (www.redlist.org). World population estimates range from 275,000 to 327,753 individuals (Brooke 2004, NMFS 2004). Bycatch in the Alaskan demersal groundfish fleet represent 0.07% of the lower of these population estimates. Note that the groundfish fishery is only one source of bycatch for this species throughout its range.

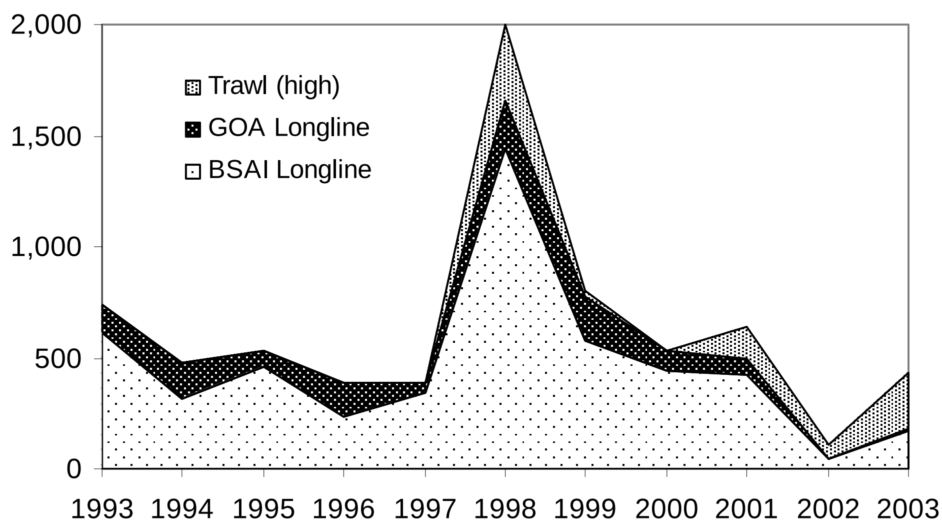


Figure 115. Combined bycatch in Alaskan groundfish fisheries for Laysan albatross, 1993 through 2003. Data for trawl fisheries begins in 1998.

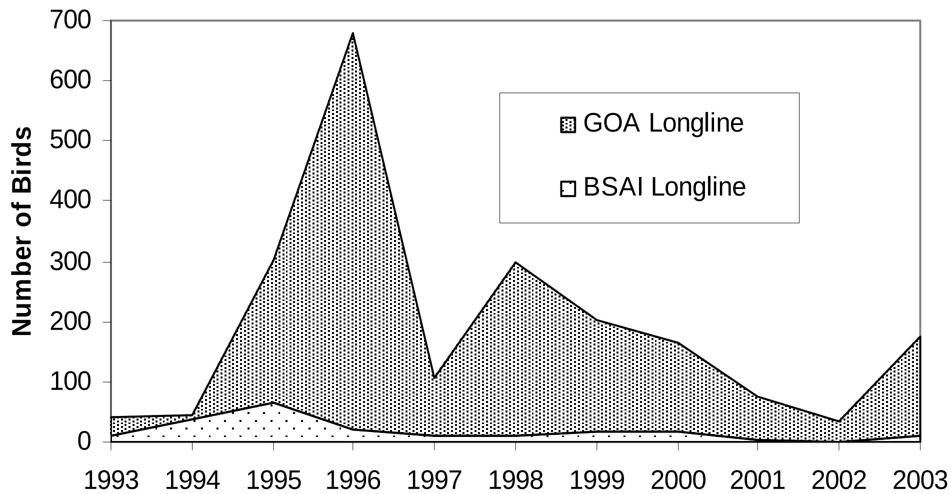


Figure 116. Combined bycatch in Alaskan groundfish fisheries for black-footed albatross, 1993 through 2003.

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

Northern Fulmar: The northern fulmar is the most frequent species taken among all fisheries combined. Discussion of northern fulmar bycatch is especially confounded by the need to provide two sets of possible bycatch numbers for the trawl fleet. Figure 117 a and b represents northern fulmar bycatch combined for all fisheries, with longline and pot represented from 1993 onward and trawl included since 1998. The alternate methods for the trawl fleet are noted by a low estimate (Figure 117a) and a high estimate (Figure 117b). Total bycatch of fulmars in the longline fisheries peaked in 1999 and dropped substantially since, with a slight increase in 2003. Bycatch in the trawl fleet is difficult to judge at this time, given the need to report estimates using these alternate methods. While the higher estimate procedure results in almost 30,000 mortalities, that number should be used with great caution. The actual number may be much lower than that estimate. Additional analyses of these data are necessary. Conversely, those numbers do not include mortalities from interactions with trawl cables. Note also that some components of the trawl industry are working closely with NMFS and Washington Sea Grant to develop mitigation measures for seabirds. The Northern fulmar population was previously estimated at 2.1 million birds by the USFWS in 1998. A bycatch rate of 30,000 birds is 1.4% of this population estimate.

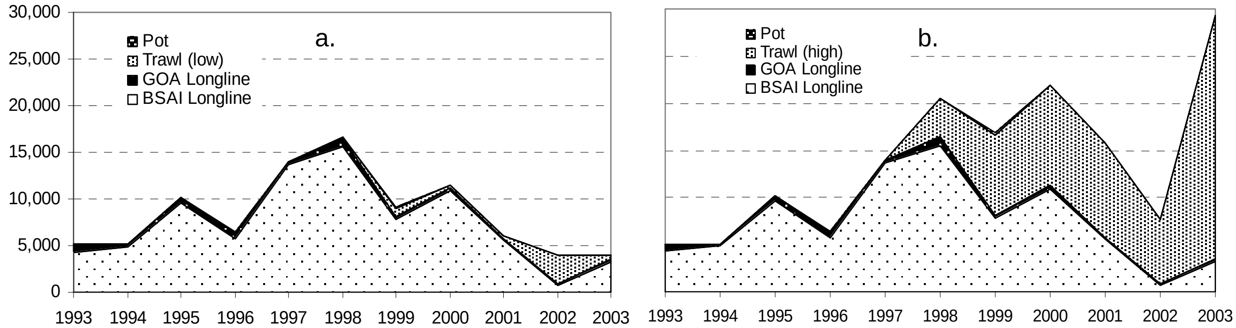


Figure 117. Estimated northern fulmar bycatch in North Pacific groundfish fisheries, using low (a; left side) and high (b; right side) estimation procedures for the trawl fishery. Data from the trawl fishery prior to 1997 are not included.

Shearwater species: Observers are not required to identify sooty and short-tailed shearwaters to species. They record them as unidentified dark shearwater. Other shearwaters occur rarely in the Bering Sea and Gulf of Alaska, so identification materials have not been provided. Any occurrence of shearwaters other than sooty or short-tailed would likely be recorded in one of the unidentified categories. Using the trawl estimation method that results in a higher estimate, the annual average bycatch, 1999 through 2003, from all sources is 1,566. Using the lower estimate from the trawl fleet would yield an average of 482 birds. Total shearwater bycatch peaked at 3,500 in 2001 and has decreased to less than 500 in 2003. These numbers are negligible when compared to population estimates that over 50 million for these two species.

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

Population Effects of Bycatch

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

Competition for food resources

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

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

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

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

Provision of food resources

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

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

Research Needs

Section 4.3.4 of the Alaska Groundfish Fisheries DPSEIS included several research and/or analysis needs identified by scientists currently researching seabirds in the BSAI and GOA ecosystems (NMFS, 2001a). As the information gaps are filled, the view of how seabirds are affected by fisheries may change. Additional research and analysis needs were identified in the NPFMC Science and Statistical Committee (SSC) comments on the DPSEIS, in the Draft: Bering Sea Ecosystem Research Plan (AFSC, 1998) and by other seabird scientists. Table 22 summarizes these research needs and notes the status of efforts. Steps toward addressing many of the identified research needs (Table 22) have been made, although in most cases these are works in progress. Efforts are underway to develop quantitative models to evaluate the potential for population-level impacts of fisheries on seabirds. For fulmars and albatrosses, this effort includes identification of colonies of provenance of birds taken in longline fisheries in Alaska.

Table 22. Research needs identified for seabird ecology and seabird/fishery interactions for groundfish fisheries in Alaska. STAL = Short-tailed albatross; LAAL = Laysan albatross; BFAL = black-footed albatross. NRC = National Research Council.

Category	Research and analysis needs	Current Status	Authors or Contacts
	Quantitative models on population-level impact of bycatch	BFAL model available; pelagic longline fishery	Lewison & Crowder 2003
	Seabird Population Assessments	Preliminary efforts for BFAL & LAAL STAL (unpubl.).	Seivert, USFWS Cochrane and Starfield, USFWS
Population	Assess bycatch mortality at the colony level.	2001-2003: genetic profiling of fulmar populations	Hatch, USGS-BRD, Anchorage.
level effects		2002-2003: Genetic profiling of albatrosses	Walsh, U of Washington
	Quantitative models on impacts of fishery discards & offal.	NRC Fellowship will begin at AFSC in 2004	Fitzgerald & Edwards, NMFS
	Cost/benefit model of mortality and food provisioning	NRC Fellowship will begin at AFSC in 2004	Fitzgerald & Edwards, NMFS
	Seasonal pattern of offal discharge vs seabird energy needs.	None – NRC should lay groundwork for this effort	
	Short-tailed albatross spatial & temporal distribution	2001: Satellite telemetry studies begin on Torishima Island	Balogh, USFWS Anchorage
Distribution		2003: At-sea capture in Alaska.	Balogh, USFWS Anchorage
& fisheries	Pelagic Distribution of Seabirds	N. Pacific Pelagic Seabird Database begun in 2002;	USGS-BRD & USFWS,
		Stationary seabird surveys began in 2002.	WA Sea Grant
		Line transects: need to use platforms of opportunity	
	Examine temporal & spatial scale of seabird aggregations with respect to ephemeral & stable oceanographic features & prey aggregations.	Analysis of data on STAL underway Work on albatrosses available for central & S. Pacific No work specific to Alaska waters completed	Suryan et al., Oregon State U. various publications
	Identify & quantify seabird food items.	Great deal of work completed	Various authors
	Define seabird feeding areas (horizontally & vertically)	Telemetry for STAL only	Suryan et al., Oregon State U.
Food & foraging	Define relationship between feeding and fishing areas.	No comprehensive study.	
	Describe seabird diet during fall through spring months	No comprehensive study.	2002 overview: Kuletz, USFWS
	Examine regional patterns of prey use & trends over time.	Compilation of data from seabird colonies monitored during breeding season are available.	Dragoo et al. 2003, USFWS
	Examine saturation effect from pulsed fisheries	No work has been completed in the North Pacific on seabird's ability to take advantage of offal and discards.	
	Characterize seabird interaction with trawl cables and gear.	Preliminary work with electronic monitoring in 2002 Observer special project implemented in 2004.	Fitzgerald, NMFS
Gear &	Develop mitigation measures to reduce seabird interactions on trawl vessels	Pilot work begins in 2003 and is continuing.	WA Sea Grant, Pollock Conservation Cooperative
mitigation methods	Analysis of multi-year data sets of factors affecting seabird bycatch	Thesis completed on factors affecting seabird bycatch in demersal groundfish longline vessels.	Dietrich University of Washington
	Evaluate effective methods for setting longlines underwater	Various projects, 1999 – ongoing.	Industry, WA Sea Grant, NMFS, and USFWS
	Evaluate integrated weight longlines	Ongoing since 2002	Melvin, WA Sea Grant

Ecosystem or Community Indicators

Alaska Native Traditional Environmental Knowledge of Climate Regimes
By Heather Lazrus, Alaska Fisheries Science Center, Heather.Lazrus@noaa.gov

Alaska Natives who traditionally inhabitant marine ecosystems accumulate a great deal of place-based knowledge about the environment with which they interact through daily observation and experience. Environmental changes associated with successive climate regimes have been recognized and captured by the knowledge systems of Alaska Natives. Traditional environmental knowledge (TEK) is useful to natural resource managers by drawing their attention to environmental changes or by corroborating scientifically described transitions between climate regimes. To illustrate this, a brief qualitative time series organized into three generally accepted climate regimes in the Bering Sea Aleutian Islands (BSAI) region has been constructed with information extracted from the *NOAA Fisheries Alaska Native Traditional Environmental Knowledge Database*.[10] ,[11] It should be noted that the information compiled in the *NOAA Fisheries Alaska Native Traditional Environmental Knowledge Database* was not necessarily elicited in response to specific questions about climatic changes. Additional research is needed to more closely correlate Alaska Native TEK with scientific observations in the BSAI region.

- **1947 – 1975**

In the vicinity of St Lawrence, the early half of the 1900s was characterized by calm weather and predictable ice formation (1). Around Savoonga ice would have begun to solidify by October in the 1930s and 1940s. People's perceptions of winter were largely based on the hunting activities made possible by solid ice formation (16,1). In the mid 1940s the area from Gambell north to Nome appeared to be solid ice (11). Observations, beginning in the later part of this period, of changes in sea ice formation, from solid to increasingly patchy, were understood to affect walrus migration (11). Since the 1960s changes in sea ice may have contributed to observed declines in spotted seal populations (19). Rising sea levels and corresponding coastal erosion became a problem, marking significant changes along the coastline from the 1960s to early 1970s and impacting the harvesting of sculpins (7).

- **1976/1977 – 1988**

Throughout the BSAI region and beginning in the late 1970s, winds increased in frequency and intensity, average temperatures increased, ice melted or moved away from shorelines earlier, and ocean currents seemed to have shifted. These interrelated changes affected coastlines and impacted fishing and hunting practices (5, 16, 17). Both winds and warmer temperatures contributed to delayed ice formation (19). Ice began to remain unstable throughout the cold season and melt earlier and more rapidly in the springtime in the region around Elim (15). While most seal species seemed to be doing well, spotted seal populations began to decline in the 1960s

[10] References in text refer to page numbers of individual observations in Sepez, et al. 2003. 'Physical Environment' *NOAA Fisheries Alaska Native TEK Database*. Unpublished Document accessed through the Alaska Fisheries Science Center Economics and Social Science Research Program, Seattle, WA.
[11] See also Sepez, 2003. 'Ecosystem or Community Indicators' p239. In Jennifer Boldt (ed.) *Ecosystem Considerations* for 2004. Appendix D Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the BSAI and GOA. North Pacific Management Council 605 W. 4th Ave. Suite 306, Anchorage, AK 99501

and 1970s which could be due to young seals becoming stranded when ice melted prematurely (19).

- **1989 – 1998**

Increased westerly winds seemed to be part of a trend in changing wind patterns which contributed to delays in the packing of ice and a delayed freeze, sometimes occurring as late as December (3, 11). Precipitation patterns shifted, with the major snowfalls of the year coming in late winter and early spring (19). Increasingly frequent mild winters and warm springs seemed to correspond with bad seal hunting seasons (22). In 1998 a significant decline of seabird populations which may have been weather-related was observed. Decreases in salmon populations, such as Yukon River salmon, and clams in Mekoryuk Bay, as well as increases in other shellfish were observed during this period (13). Ice formation patterns were delayed during this period when ice was not consistently solidified until early to mid December as opposed to mid October(16). This indicates that sea ice was formed by cold winds and does not contain the nutrients which are important during spring thaws and come from the nutrient-rich sea bottom. Less snow and colder winters were observed, especially in the winter of 1998/1999. Between 1996 and 1998, when spring weather arrived early, reduced sea ice, heightened wave action and subsequent increased sedimentation may have contributed to the poor health of walrus populations and was also detrimental to young, near shore spotted seal populations (19).

Biodiversity as Index of Regime Shift in the Eastern Bering Sea (not updated for 2004)
By Gerald R. Hoff, AFSC

Many investigators have identified events in environmental and biological data from the North Pacific that indicate regime shifts, or reorganizations of the ecosystem at the environmental and biological level. Measurable climate events were identified in the mid-1970s, late 1980s, and the late 1990s that have been correlated with environmental phenomenon including Pacific Decadal Oscillation, El Niño Southern Oscillation, sea ice coverage, and summer time sea surface temperatures. The far reaching effect that climate change has on the ecosystem is not well mapped out, but many studies have shown strong correlations between climate change and recruitment of fish and invertebrates, and plankton production in the North Pacific. Biodiversity indices are robust measures for large ecosystem monitoring and possible indicators of regime shift phenomenon.

Data used for this study was collected by the Groundfish Assessment Program of the Resource Assessment and Conservation Engineering (RACE) Division, which surveys the eastern Bering Sea (EBS) shelf on an annual basis during summer (May-August). Use of biological survey data to monitor regime shifts is possible due to the consistent nature of this multispecies survey.

Biodiversity indices (richness and evenness) were used as indicators for species compositional changes over a 24-year period (1979-2002) and related the trends and changes evident with reported regime shift events in the EBS. Richness and evenness indices use the proportional biomass estimates of each assemblage to estimate a value that reflects the relative number of abundant species in the assemblage (richness) and the distribution of the species proportionalities (evenness).

For this analysis, two species guilds, flatfish and roundfish were identified, where the flatfish guild included all Pleuronectiformes recorded from the EBS survey (11 species or species groups), and the roundfish guild (40 species or species groups) excluding walleye pollock and Pacific cod due to their extremely large biomass. Biodiversity measures were calculated using Ludwig and Reynolds recommendations for species richness and evenness which are considered robust measures and allow the use of biomass estimate proportions for biodiversity indices.

A piecewise model was used to detect a break in the biodiversity time series, indicating a significant ecosystem change had occurred. Two linear models describe the biodiversity trends before and after a break (Figure 118). The data set for richness and evenness for each guild showed a continuous period of change from the late 1970s through the late 1980s, followed by a period of stasis until the present (Figure 118). The diversity indices suggest an event in the 1970s sparked ecosystem changes that were perpetuated into the late 1980s and early 1990s. The event in the late 1980s countered the 1970s event, and the system tended to stabilize at a new level from the early 1990s through 2002.

Biodiversity indices for the EBS fish guilds concur with the timing of a significant climactic event in the late 1980s. This study indicates that survey data can be used as a robust measure of large ecosystem change and corroborates shifts related to climate and environmental changes.

Given the greatly improved species identification levels and standardization now in use on the RACE groundfish surveys, assemblages can be studied which include more fish species and invertebrates. Improved resolution of the species groups may detect more subtle changes in the ecosystem than previously possible.

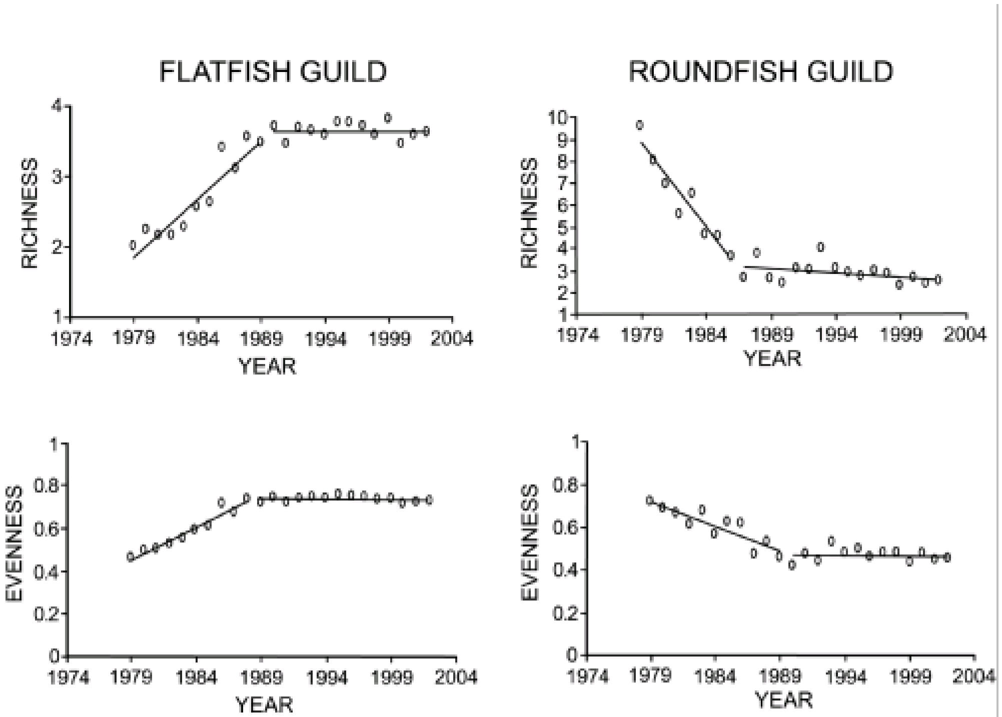


Figure 118. Plots of biodiversity (richness and evenness) indices for two fish guilds (flatfish and roundfish) from the eastern Bering Sea. Biodiversity showed a distinct shift in trends in the late 1980s which corresponds to reported regime shift events.

Combined Standardized Indices of recruitment and survival rate

Contributed by Franz Mueter, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, fmueter@alaska.net

Description of indices: This section provides indices of overall recruitment and survival rate (adjusted for spawner abundance) across the major commercial groundfish species in the Eastern Bering Sea (11 stocks) and Gulf of Alaska (10 stocks). Time series of recruitment and spawning biomass for demersal fish stocks were obtained from 2003 SAFE reports. Recruitment and spawner abundances for salmon and herring stocks were not updated this year. Survival rate (SR) indices for each stock were computed as residuals from a spawner-recruit model. Both a Ricker and Beverton-Holt model were fit to each stock and the model with the best fit (based on the small-sample Akaike Information Criterion) was used to compute the SR index. Each time series of recruitment or SR indices was standardized to have a mean of 0 and a standard deviation of 1 (hence giving equal weight to each stock in the combined index). Recruitment or SR series were lined up by year-class, resulting in matrices of recruitment / SR indices by year with missing values at the beginning and end of many series. A combined standardized index of recruitment (CSI_R) and survival (CSI_{SR}) was computed by simply averaging indices within a given year across stocks. Prior to standardizing the series, missing values in each series were estimated by imputation. Multiple imputations were obtained by bootstrap resampling to estimate the variability in the averaged index that results from filling in missing values. Uncertainty in the stock-specific estimates of R and SR was not accounted for.

Status and trends: The CSI_R suggests that recruitment of demersal species in the Gulf of Alaska and Bering Sea followed a similar pattern with mostly above-average recruitments from the mid- or late 1970s to about 1989, followed by below-average recruitments during the early 1990s (GOA) or most of the 1990s (EBS) (Figure 119). Regime shift transition points are less obvious than in the same indices based on last year's assessments. In particular, evidence for the 1976/77 regime shift is relatively weak. Estimates at the beginning and end of the series were based on only a few stocks and are highly uncertain, but recruitment in the EBS remained mostly below average through 2001, the last year for which data for at least 3 stocks was available. The CSI_{SR} were more variable but showed similar patterns (Figure 119). All CSI values were exceptionally low in 1982 in the EBS (primarily due to low survival / recruitment of flatfishes) and, to a lesser extent, in the GOA. This was followed in both regions by unusually high survival and recruitment indices in 1984, when recruitment of all stocks except flathead sole in the GOA and yellowfin sole in the EBS was above average. Similar to CSI_R, survival rate indices were below average during most of the 1990s in both regions, but the trend in CSI_{SR} was more pronounced in the GOA. Survival rate estimated for the last two years are near the long-term average, but are based on only 3-4 stocks and therefore highly uncertain.

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. 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 strongly correlated between the two regions (CSI_R: r = 0.72; CSI_{SR}: r = 0.65). These variations in productivity are correlated with and may be driven by variations in large-scale climate patterns such as the PDO, which changed sign in 1976/77, and the Victoria pattern, which changed sign in 1989/90.

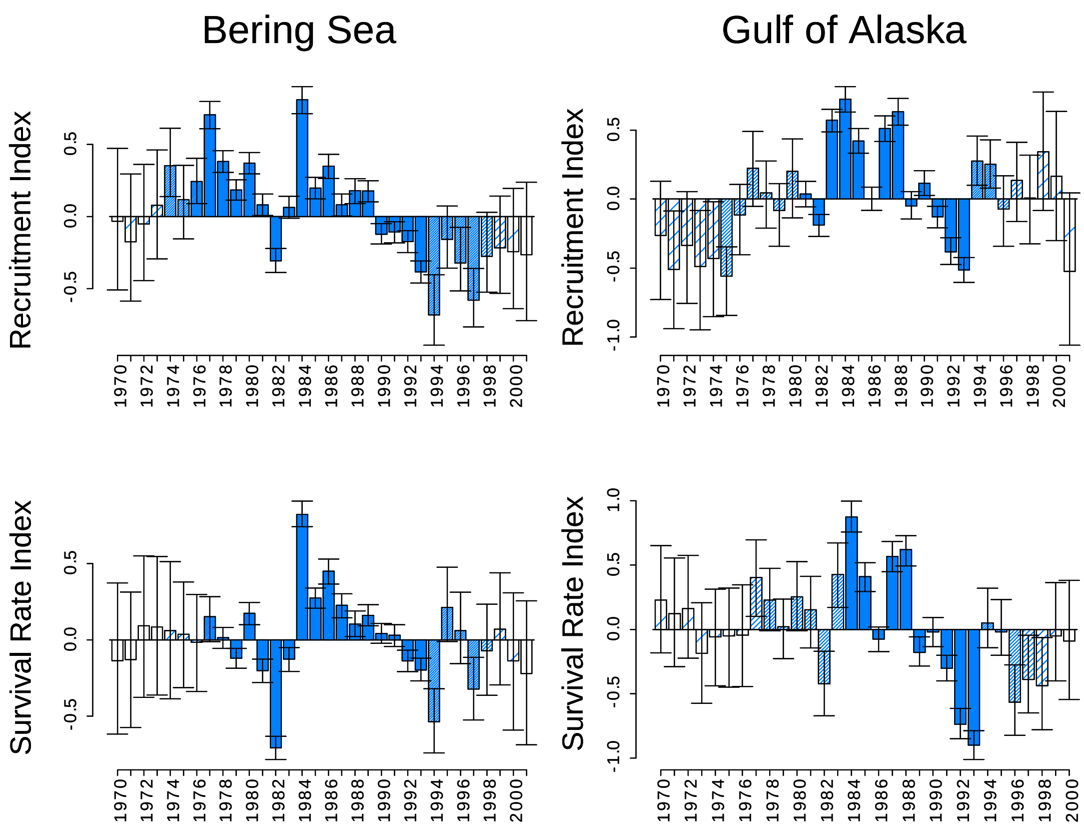


Figure 119. Combined Standardized Indices of recruitment (top) and survival rate (Ricker residuals, bottom) by year class across demersal stocks in the Bering Sea / Aleutian Island region (11 stocks) and in the Gulf of Alaska (10 stocks). Solid blue bars represent years with data for all stocks or stock groups. Lighter shading corresponds to years with more missing stocks. Series were truncated in 1970 and only years with data for at least 3 stocks were included. Bootstrap confidence intervals (95%) depict uncertainty resulting from filling in missing values but assume that survival and recruitment are estimated without error.

Average Local Species Richness and Diversity of the Groundfish Community

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Description of indices: This section provides indices of local species richness and diversity based on standard bottom trawl surveys in the western (west of 147°N) Gulf of Alaska (GOA) and Eastern Bering Sea (EBS). The average number of fish taxa per haul and the average Shannon-Wiener index of diversity (Magurran 1988) by haul were computed based on CPUE (by weight) of each fish species (or taxon). Indices were based on a total of 55 fish taxa in the GOA and 47 fish taxa in the EBS. Taxa were included at the lowest possible taxonomic level, i.e. at a level that was consistently identified throughout all surveys. Indices were computed following Mueter and 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 and time of sampling, area swept, and year.

Status and trends: Average species richness and diversity of the groundfish community in the Gulf of Alaska increased from 1990 to 1999 with both indices peaking in 1999 and sharply decreasing thereafter (Figure 120). Species richness and diversity on the Eastern Bering Sea shelf have undergone significant variations from 1982 to 2003. Species diversity increased from 1983 through the early 1990s, was relatively high and variable throughout the 1990s, and decreased significantly after 2000 (Figure 121).

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. Species diversity is a function of the number of species and their relative abundance in each haul. In the GOA average species diversity followed changes in local richness. In contrast, trends in species diversity in the EBS differed from those in richness. For example, low species diversity in the EBS in 2003 occurred in spite of high average richness, primarily because of the high dominance of walleye pollock, which increased from an average of 18% of the catch per haul in 1995-98 to 30% in 2003. 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.

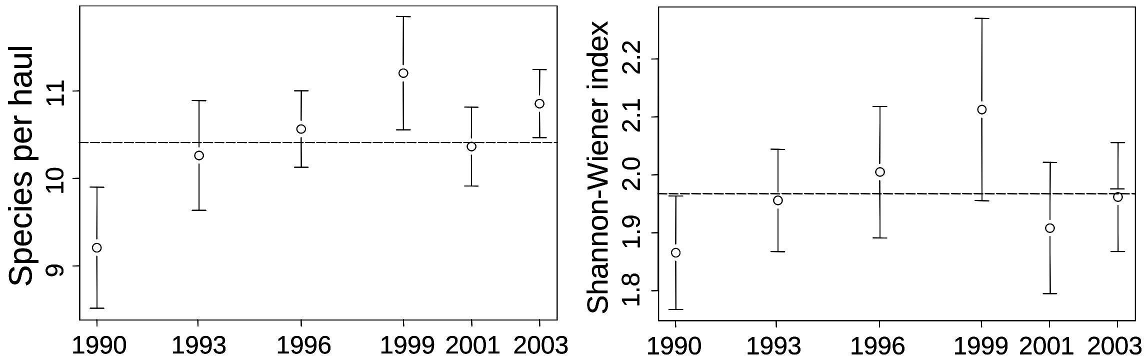

Figure 120. Model-based annual averages of species richness (average number of species per haul), and species diversity (Shannon-Wiener index) in the western Gulf of Alaska, 1990-2003, based on 55 fish taxa collected by standard bottom trawl surveys with 95% confidence intervals. Model means were adjusted for differences in area swept, depth, date and time of sampling, and geographic location among years.

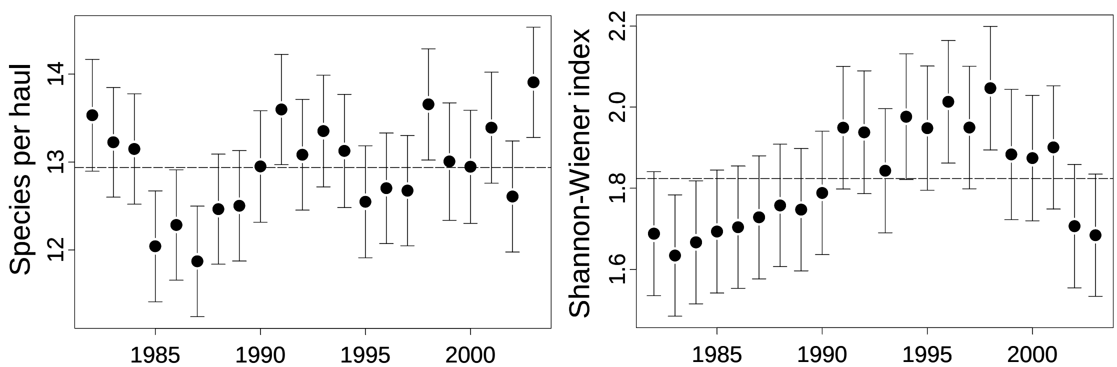

Figure 121. Model-based annual averages of species richness (average number of species per haul), and species diversity (Shannon-Wiener index) in the Eastern Bering Sea, 1982-2003, based on 47 fish taxa collected by standard bottom trawl surveys with 95% confidence intervals. Model means were adjusted for differences in area swept, depth, date and time of sampling, and geographic location among years.

Total Catch-per-unit-effort of all Fish and Invertebrate Taxa in Bottom Trawl Surveys

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Description of index: The index provides a measure of overall abundance of demersal and benthic species. Average catch-per-unit-effort of all fish and invertebrate taxa captured by standardized bottom trawl surveys in the Eastern Bering Sea (EBS) and Gulf of Alaska (GOA) was estimated. Spatial and temporal patterns in total CPUE of all taxa combined were modeled using Generalized Additive Models (GAM) as a function of depth, location, Julian day, time of day (hour), and area swept following Mueter and Norcross (2002). Although catches were standardized to account for the area swept by each haul we included area swept in the model because of differences in catchability of certain taxa with changes in net width (Dave Somerton, Alaska Fishery Science Center, personal communication) and because there was strong evidence that total CPUE tends to decrease with area swept, all other factors being constant. The model for the EBS further included bottom temperatures, which appeared to strongly reduce CPUEs at low temperatures (< 1˚C). At present it is not clear whether this effect is due to actual changes in abundance or temperature-dependent changes in catchability of certain species. Total CPUE over time was computed separately for the eastern and western GOA because of large differences in species composition and because no survey was conducted in the eastern GOA in 2001. We did not estimate CPUE in the GOA for the 1984 and 1987 surveys because a large portion of these surveys used non-standard gear types. Trends in CPUE over time in the eastern GOA were highly uncertain due to large differences in sampling dates among years and are not presented here.

Status and trends: Total survey CPUE in the western GOA first peaked in 1993/96 and decreased significantly between 1996 and 1999 (Figure 122). CPUE increased again from 2001 to 2003, which had the highest observed CPUE value of the time series. Total CPUE in the EBS has undergone substantial variations and peaked in 1993, similar to the GOA (Figure 123). There was an apparent long-term increase in CPUE from 1982-2003 (Generalized least squares regression with first-order autocorrelated errors: slope = 0.014 per year, t = 1.74, P = 0.097). Log-transformed CPUE in the EBS was near the long-term mean from 2000-2002 and, similar to the GOA, increased significantly in 2003.

Factors causing observed trends: Commercially harvested species account for over 70% of the survey catches. Therefore fishing is expected to be a major factor determining trends in total survey CPUE, but environmental variability is likely to account for a substantial proportion of overall variability in CPUE through variations in recruitment and growth. The increase in survey CPUE in the EBS from 2002 to 2003 primarily resulted from increased abundances of walleye pollock and a number of flatfish species (arrowtooth flounder, yellowfin sole, rock sole, and Alaska plaice). The increase in the GOA between 2001 and 2003 was largely due to a substantial increase in the abundance of arrowtooth flounder, which accounted for 43% of the total survey biomass in 2003.

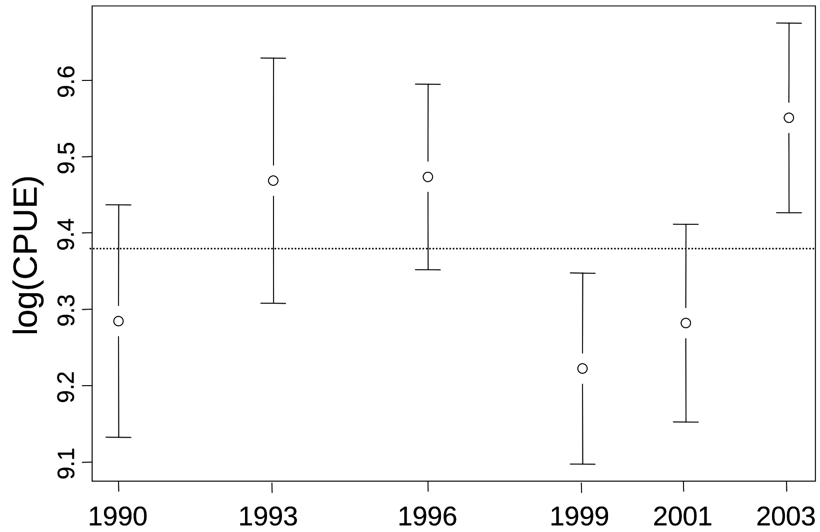


Figure 122. Model-based estimates of total log(CPUE) of all fish and invertebrate taxa captured in bottom trawl surveys from 1990 to 2003 in the western Gulf of Alaska (west of 147˚ W) with approximate 95% confidence intervals. Modeled means were adjusted for differences in depth, day and hour of sampling, area swept and sampling location among years.

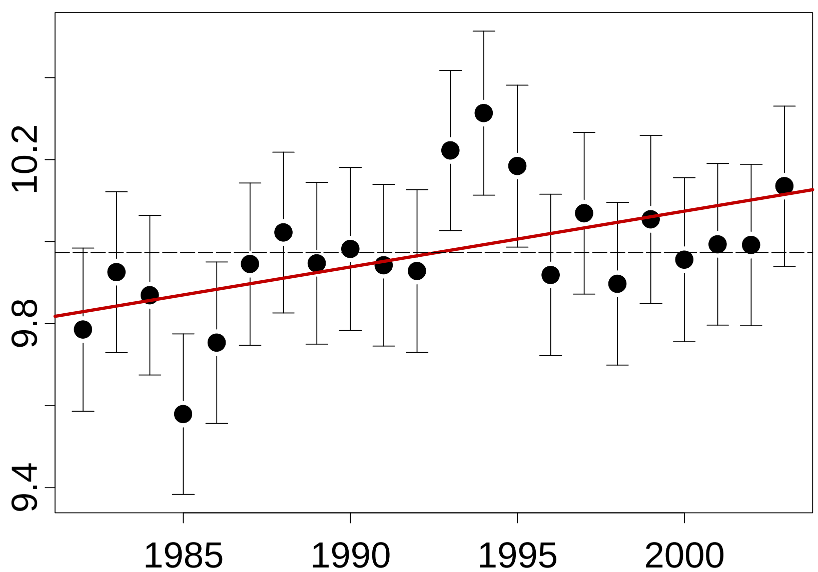


Figure 123. Model-based estimates of total log(CPUE) of all fish and invertebrate taxa captured in bottom trawl surveys from 1982 to 2003 in the Bering Sea with approximate pointwise 95% confidence intervals and long-term linear trend. Estimates were adjusted for differences in depth, bottom temperature, day of sampling, area swept, and sampling location among years.

ECOSYSTEM-BASED MANAGEMENT INDICES AND INFORMATION

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

Ecosystem Goal: Maintain Diversity

Time Trends in Bycatch of Prohibited Species

Contributed by Terry Hiatt and Joe Terry, Alaska Fisheries Science Center

The retention and sale of crab, halibut, herring, and salmon generally is prohibited in the groundfish fishery; therefore, these are referred to as prohibited species. The prohibition was imposed to reduce the catch or bycatch of these species in the groundfish fishery. A variety of other management measures have been used to control the bycatch of these species and data from the groundfish observer program have been used to estimate the bycatch of these species and the bycatch mortality of halibut. Most of the groundfish catch and prohibited species bycatch is taken with trawl gear. The implementation of the halibut and sablefish IFQ programs in 1995 allowed for the retention of halibut in the hook and line groundfish fishery and effectively addressed an important part of the halibut bycatch problem in that fishery, but it also made it very difficult to differentiate between halibut catch and bycatch for part of the hook and line groundfish fishery. Therefore, the estimates of halibut bycatch mortality either for the hook and line fishery or for the groundfish fishery as a whole are not comparable before and after 1995. Estimates of the bycatch of prohibited species other than halibut and estimates of halibut bycatch mortality are presented in Figure 124. 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

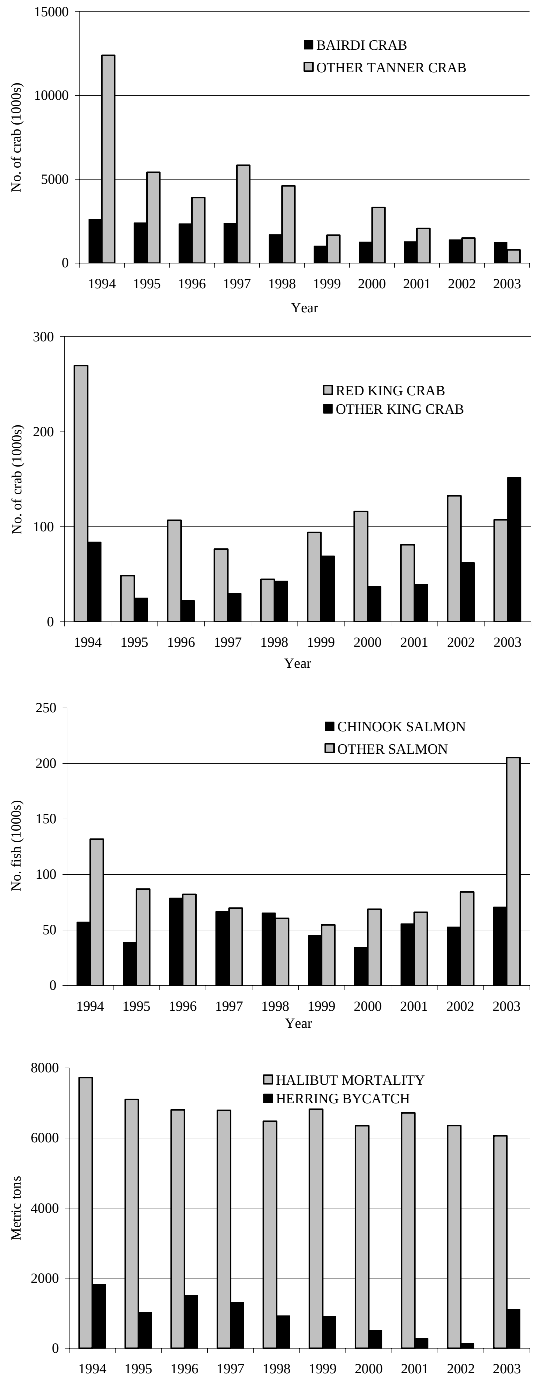


Figure 124. Bycatch of tanner and king crab, salmon, halibut, and herring in groundfish fisheries off Alaska, 1994-2003.

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. Annual estimates for the years 1994-2002 come from NMFS Alaska Region's blend estimates; 2003 estimates are from the Alaska Region's new Catch Accounting System. Between 2002 and 2003, there was an increase in the bycatch of "other king crab" (OKC) and "other salmon" (OS). In 2002, most of the OKC bycatch occurred in the BSAI sablefish pot and BSAI longline Pacific cod fisheries, with about 27% of the total OKC bycatch in each of the two fisheries. In 2003, 94% of the OKC bycatch occurred in the BSAI sablefish pot fishery. In both 2002 and 2003, nearly 95% of the OS bycatch occurred in the BSAI pollock trawl fishery. Part of the increase in bycatch between 2002 and 2003 can be explained by the 33% increase in the overall catch of OS in 2003 compared to 2002. Part of the difference in bycatch of OKC and OS between 2002 and 2003 could be a result of the change to the new catch accounting system.

Time trends in groundfish discards

Contributed by Terry Hiatt and Joe Terry, Alaska Fisheries Science Center

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 125). These decreases are explained by reductions in the discard rates of pollock and Pacific cod that resulted from regulations implemented in 1998 prohibiting discards of these two species. Discards in the Gulf of Alaska have increased somewhat since 1998 but are still lower than amounts observed in 1997, prior to the implementation of the improved retention regulations. Estimates of discards for 1994-2002 come from NMFS Alaska Region's blend data; estimates for 2003 come from the Alaska Region's new 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.

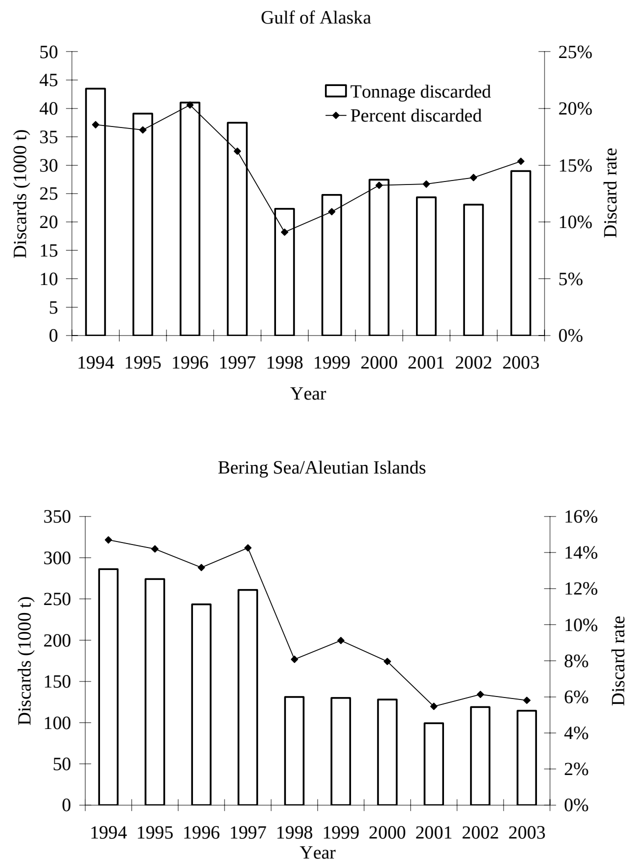
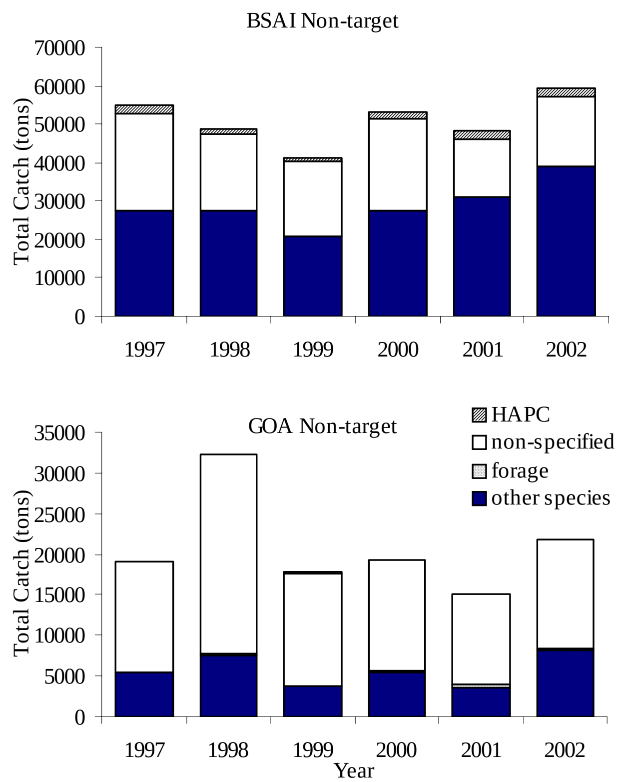


Figure 125. Total biomass and percent of total catch biomass of managed groundfish discarded in the GOA and BSAI areas 1994-2003. (Includes only catch counted against federal TACS).

Time Trends in Non-Target Species Catch (not updated for 2004)
Contributed by Sarah Gaichas and Jennifer Boldt, Alaska Fisheries Science Center

In addition to prohibited and target species catches, groundfish fisheries also catch non-target species (Figure 126). There are four categories of non-target species: 1.) forage species (gunnels, sticheids, sandfish, smelts, lanternfish, sandlance), 2.) non-specified species (grenadiers, crabs, starfish, jellyfish, unidentified invertebrates, benthic invertebrates, echinoderms, other fish, birds, shrimp), 3.) other species (sculpins, unidentified sharks, salmon sharks, dogfish, sleeper sharks, skates, octopus, squid), and 4.) HAPC (seapens/whips, sponges, anemones, corals, tunicates).

In the BSAI, non-target catch was primarily comprised of non-specified and other species categories (Figure 126). Jellyfish, starfish, grenadiers, and other fish dominated the non-specified group and skates, sculpins and squid dominated the other species category. The non-target catch in the GOA also consisted primarily of non-specified and other species categories. Grenadiers were the dominant fish caught in the non-specified category in all years; other fish were also important in 1998. The other species category in the GOA consisted primarily of skates, but also included sculpins, dogfish, and unidentified sharks.



HAPC biota and forage species are also presented in Figure 126, but are small relative to the other categories of non-target catch. HAPC biota catch estimates range from 922 to 2548 t (primarily tunicates) in the BSAI, and from 27 to 46 t, (primarily anemones) in the GOA. Non-target forage catches consist primarily of smelts and range from 24 to 83 t in the BSAI and from 27 to 541 t in the GOA.

Most non-target catch is discarded as well as some target catch. Non-target and target discard estimates are comparable in the GOA. BSAI discards of non-target species are more than double the GOA discards of non-target species. In the BSAI, however, non-target discard estimates are less than one-third of the target discard estimates. It should be noted that although the blend estimates are the best available estimates of discards, they are not necessarily accurate because they are based on visual observations of observers rather than data from direct sampling.

Ecosystem Goal: Maintain and Restore Fish Habitats

Areas closed to bottom trawling in the EBS/ AI and GOA
Contributed by Cathy Coon, NPFMC

Many trawl closures have been implemented to protect benthic habitat or reduce bycatch of prohibited species (i.e., salmon, crab, herring, and halibut) (Table 23 and Figure 127). 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 23. 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 2000 and 2001. For 2001, over 90,000 nm of the EEZ off Alaska was closed to trawling year-round. Additionally 40,000 nm were closed on a seasonal basis. State waters (0-3nm) are also closed to bottom trawling in most areas.

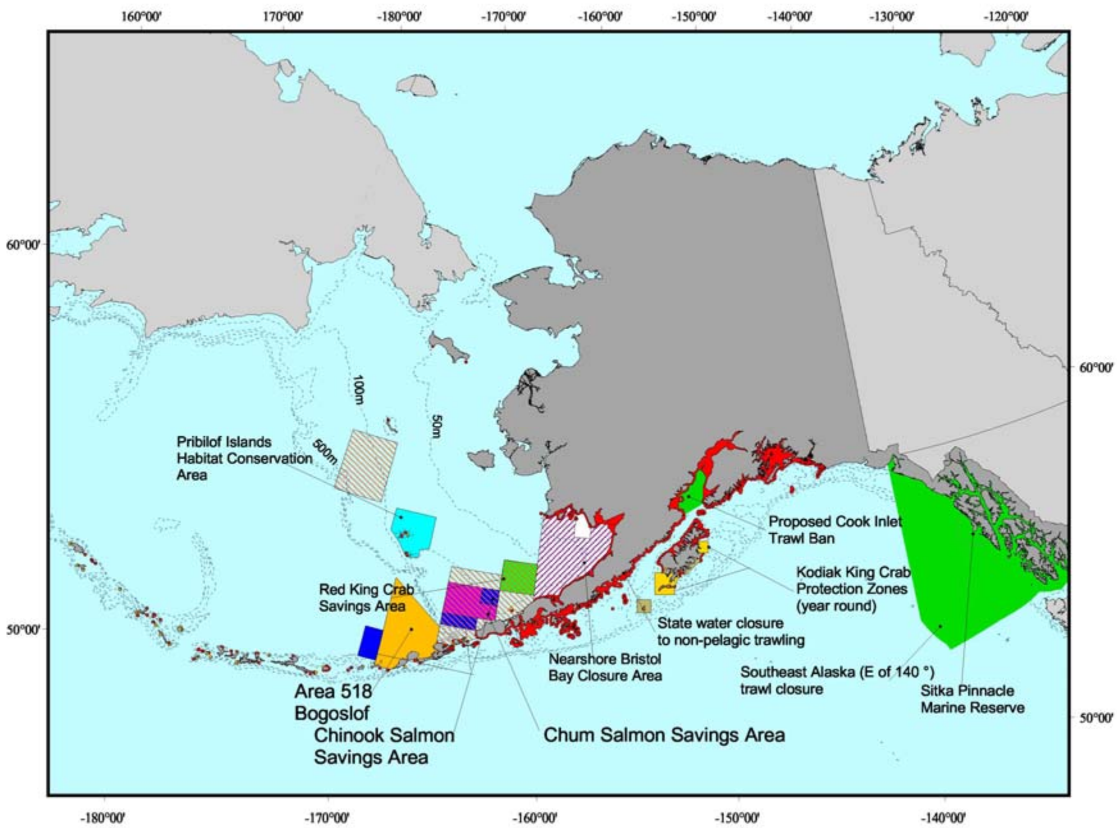


Figure 127. Groundfish closures in Alaska's Exclusive Economic Zone

Table 23. Time series of groundfish trawl closure areas in the BSAI and GOA, 1995-2002

Bering Sea/ Aleutian Islands

Year	Location	Season	Area size	Notes
1995	Area 512	year-round	8,000 nm^2	closure in place since 1987
	Area 516	3/15-6/15	4,000 nm^2	closure in place since 1987
	CSSA	8/1-8/31	5,000 nm^2	re-closed if 42,000 chum salmon in bycatch
	CHSSA	trigger	9,000 nm^2	closed if 48,000 Chinook salmon bycatch
	HSA	trigger	30,000 nm^2	closed to specified fisheries when trigger reached
	Zone 1	trigger	30,000 nm^2	closed to specified fisheries when trigger reached
	Zone 2	trigger	50,000 nm^2	closed to specified fisheries when trigger reached
	Pribilofs	year-round	7,000 nm^2	established in 1995
	RKCSA	year-round	4,000 nm^2	established in 1995; pelagic trawling allowed
	Walrus Islands	5/1-9/30	900 nm^2	12 mile no-fishing zones around 3 haul-outs
	SSL Rookeries	seasonal ext.	5,100 nm^2	20 mile extensions around 8 rookeries
1996	Same closures in effect as 1995			
1997	Same closure in effect as 1995 and 1996, with two additions:			
	Bristol Bay	year-round	19,000 nm^2	expanded area 512 closure
	COBLZ	trigger	90,000 nm^2	closed to specified fisheries when trigger reached
1998	same closures in effect as in 1995, 1996, and 1997			
1999	same closure in effect as in 1995, 1996, 1997 and 1998			
2000	same closure in effect as in 1995, 1996, 1997 ,1998 and 1999 with additions of Steller Sea Lion protections Pollock haulout trawl exclusion zones for EBS, AI **** areas include GOA***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
		No Trawl Atka Mackerel Restrictions	29,000 nm^2	
2001	same closure in effect as in 1995, 1996, 1997 ,1998 and 1999, 2000 with additions of Steller Sea Lion protections Pollock haulout trawl exclusion zones for EBS, AI **** areas include GOA***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
		No Trawl Atka Mackerel Restrictions	29,000 nm^2	
2002	same closure in effect as in 1995, 1996, 1997 ,1998 and 1999, 2000, 2001 with additions of Steller Sea Lion protections Pollock haulout trawl exclusion zones for EBS, AI **** areas include GOA***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
		No Trawl Atka Mackerel Restrictions	29,000 nm^2	
2003	same closure in effect as in 1995, 1996, 1997 ,1998 and 1999, 2000, 2001,2002 including 2002 additions of Steller Sea Lion protections			
2004	same closure in effect as in 1995, 1996, 1997 ,1998 and 1999, 2000, 2001,2002, 2003			

Table 23. continued.

Gulf of Alaska

Year	Location	Season	Area size	Notes
1995	Kodiak	year-round	1,000 nm^2	red king crab closures, 1987
	Kodiak	2/15-6/15	500 nm^2	red king crab closures, 1987
	SSL Rookeries	year-round	3,000 nm^2	10 mile no-trawl zones around 14 rookeries
	SSL Rookeries	seasonal ext,	1900 nm^2	20 mile extensions around 3 rookeries
1996	same closures in effect as in 1995			
1997	same closures as in 1995 and 1996			
1998	same closures as in 1995, 1996 and 1997, with one addition:			
	Southeast trawl	year-round	52,600 nm^2	adopted as part of the license limitation program
		(11,929 nm2 area on the shelf)		
1999	same closures as in 1995, 1996, 1997 and 1998, with two additions:			
	Sitka Pinnacles			
	Marine reserve	year-round	3.1 nm^2	Closure to all commercial gear
	Sea Lion haulouts			
2000	same closures as in 1995, 1996, 1997, 1998 and 1999			
	Pollock haulout trawl exclusion zones for GOA**** areas include EBS, AI***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
2001	same closures as in 1995, 1996, 1997, 1998 and 1999, 2000			
	Pollock haulout trawl exclusion zones for GOA**** areas include EBS, AI***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
2002	same closures as in 1995, 1996, 1997, 1998 and 1999, 2000, 2001			
	Pollock haulout trawl exclusion zones for GOA**** areas include EBS, AI***			
		No trawl all year	11,900 nm^2*	
		No trawl (Jan-June)	14,800 nm^2*	
	Cook Inlet trawl closure: non-pelagic trawl exclusion to address crab bycatch avoidance			
	Year round	nm^2		
2003	same closures as in 1995, 1996, 1997, 1998 and 1999, 2000, 2001, 2002			
2004	same closure in effect as in 1995, 1996, 1997, 1998 and 1999, 2000, 2001, 2002, 2003			

Hook and Line (Longline) fishing effort in the Gulf of Alaska, Bering, Sea and Aleutian Islands

Contributed by Cathy Coon, NPFMC

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 128. This fishery is prosecuted with stationary lines, onto which baited hooks are attached. Gear components include 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 129-131 show the spatial patterns and intensity of longline effort, based on observed data. Spatial changes in fisheries effort may in part be affected by fishing closure areas (i.e. Steller sea lion protection measures) as well as changes in markets and increased bycatch rates of non-target species.

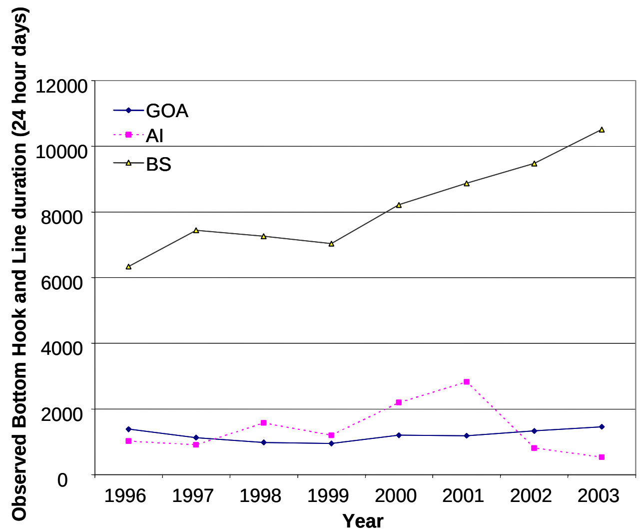


Figure 128. Estimated hook and line time in the Gulf of Alaska, Bering Sea, and Aleutian Islands during 1996-2003.

Bering Sea

For the period 1998-2003, there were a total of 92,635 observed longline sets in the Bering Sea fisheries. Spatial patterns of fishing effort were summarized on a $5km^2$ grid (Figure 129). Areas of high fishing effort were north of False Pass (Unimak Island) as well as the shelf edge represented by the boundary of report areas 513 and 517, as well as 521-533. This fishery occurs mainly for Pacific cod, Greenland turbot, and sablefish.

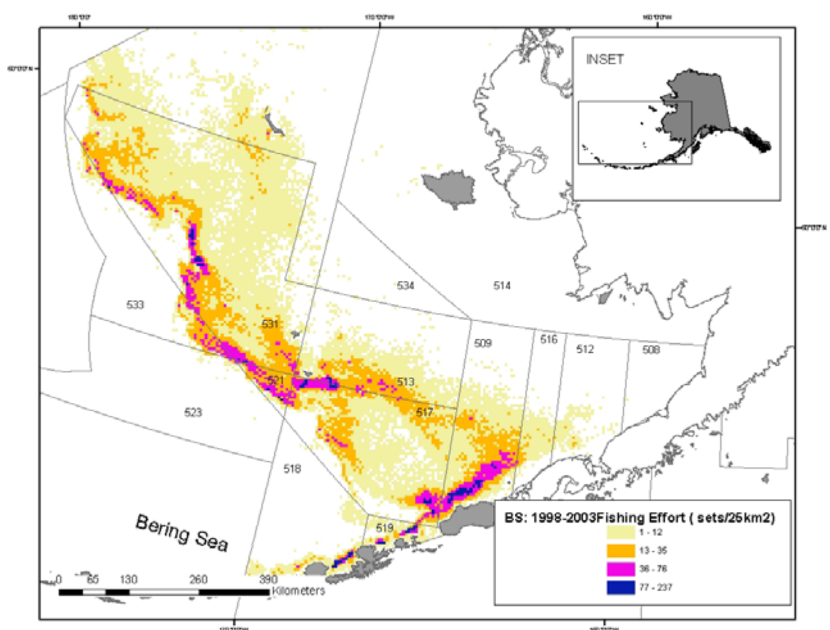


Figure 129. Spatial location and density of hook & line (longline) effort in the Bering Sea 1998-2003.

Aleutian Islands

For the period 1998-2003 there were 15,716 observed hook and line sets in the Aleutian Islands. The spatial pattern of this effort was dispersed over a wide area. Areas of high fishing effort were dispersed along the shelf edge (Figure 130). This fishery occurs mainly for Pacific cod, Greenland turbot, and sablefish. The catcher vessel longling fishery occurs over mud bottoms. In the summer, the fish are found in shallow (45-75 m) waters, but are deeper (90-245 m) 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 275 to 1100 m.

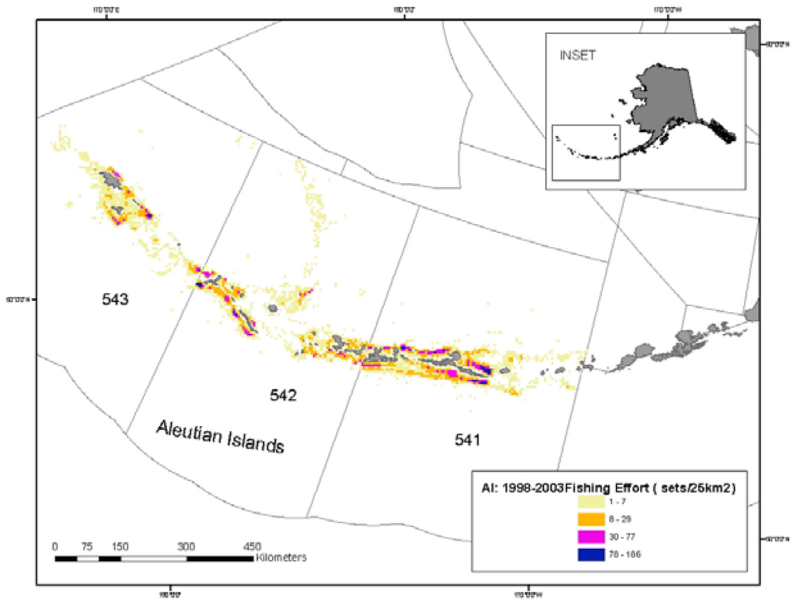


Figure 130. Spatial location and density of hook & line effort in the Aleutian Islands, 1998-2003.

Gulf of Alaska

For the period 1998-2003 there were 11,488 observed hook and line sets in the Gulf of Alaska. Patterns of high fishing effort were dispersed along the shelf (Figure 131). The predominant hook and line fisheries in the Gulf are composed of sablefish and Pacific cod. Southeast Alaska includes a demersal rockfish fishery; the dominant fish caught is yelloweye rockfish (90%), with smaller 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 number of vessels, reduced crowding, gear conflicts and gear loss, and increased efficiency. The cod longline fishery generally occurs in 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 45 m to 255 m.

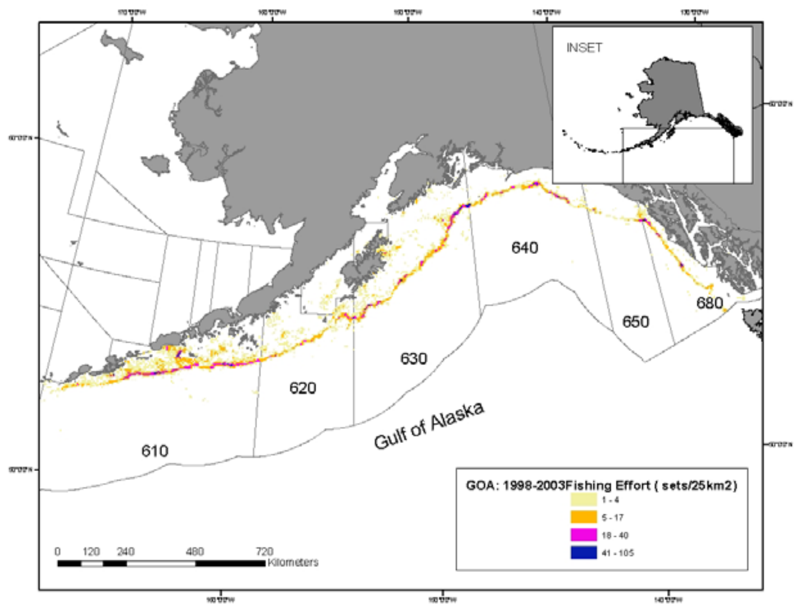


Figure 131. Spatial location and density of hook & line effort in the Gulf of Alaska, 1998-2003.

Groundfish bottom trawl fishing effort in the Gulf of Alaska, Bering Sea and Aleutian Islands

Contributed by Cathy Coon, NPFMC

The amount of effort (as measured by the number of days fished) in bottom trawl fisheries is used as an indicator for habitat effects. Effort in the bottom trawl fisheries in the Bering Sea, Aleutian Islands, and Gulf of Alaska is shown in Figure 132. In general, bottom trawl effort in the Gulf of Alaska and Aleutian Islands has declined as pollock and Pacific cod TACs have been reduced. Effort in the Bering Sea remained relatively stable from 1991 through 1997, peaked in 1997, then declined. Fluctuations in fishing effort track well with overall landing of primary bottom trawl target species, in particular flatfish and to a lesser extent pollock and cod. Since 1999, only pelagic trawls can be used in the Bering Sea pollock fisheries.

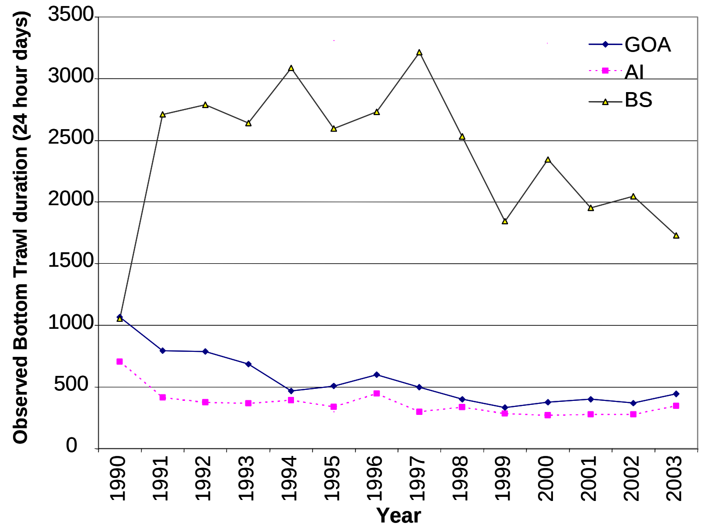


Figure 132. Estimated bottom trawl time in the Gulf of Alaska, Bering Sea, and Aleutian Islands during 1990-2003.

The locations where bottom trawls have been used are of interest for understanding habitat effects. Figures 133-135 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), changes in market, and increased bycatch rates of non-target species. The magnitude of the Bering Sea trawl fishery effort is twice as large as both the Aleutian Islands and Gulf of Alaska efforts combined.

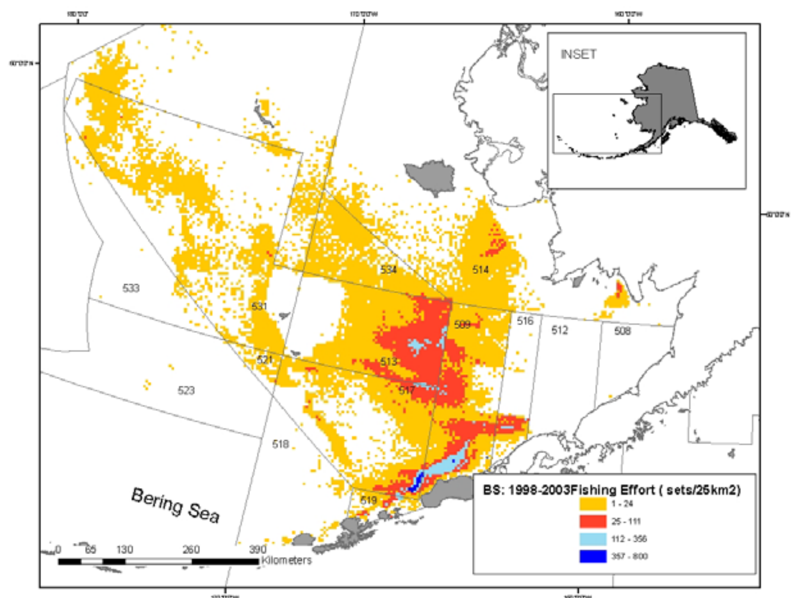


Figure 133. Spatial location and density of bottom trawl effort in the Bering Sea 1998-2003.

Bering Sea

During 1990-2003, there were a total of 259,580 observed bottom trawl sets in the Bering Sea fisheries. In 2003, trawl effort consisted of 111,777 sets which was the low for the 10 year period. Spatial patterns of fishing effort were summarized on a $5km^2$ grid (Figure 133). 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.

Aleutian Islands

For the period 1990-2003 there were 48,103 observed bottom trawl sets in the Aleutian Islands. The spatial pattern of this effort is dispersed over a wide area. During 2003, the amount of trawl effort was 2,544 sets, which was the low for the 10 year period. Areas of high fishing effort are dispersed along the shelf edge (Figure 134). The primary catch in these areas was pollock, Pacific cod, and Atka mackerel. Bottom trawl catch of Pacific Ocean perch was also high in earlier years.

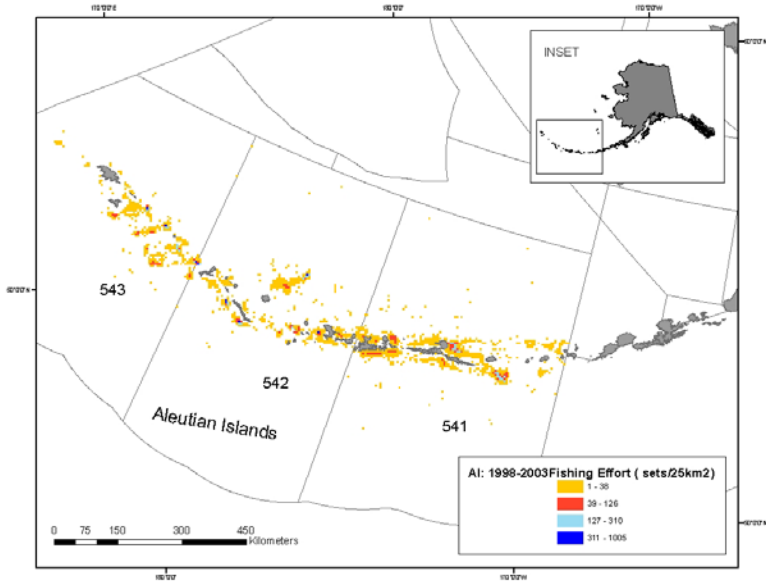


Figure 134. Spatial location and density of bottom trawl effort in the Aleutian Islands, 1998-2003.

Gulf of Alaska

For the period 1990-2003 there were 74,793 observed bottom trawl sets in the Gulf of Alaska. The spatial pattern of this effort is much more dispersed than in the Bering Sea region. During 2000, the amount of trawl effort was 3,443 sets. Areas 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 135). Primary catch in these areas was pollock, Pacific cod, flatfish and rockfish. A larger portion of the trawl fleet in Kodiak is comprised of smaller catcher vessels that require 30% observer coverage, indicating that the actual amount of trawl effort would be much higher since a large portion is unobserved.

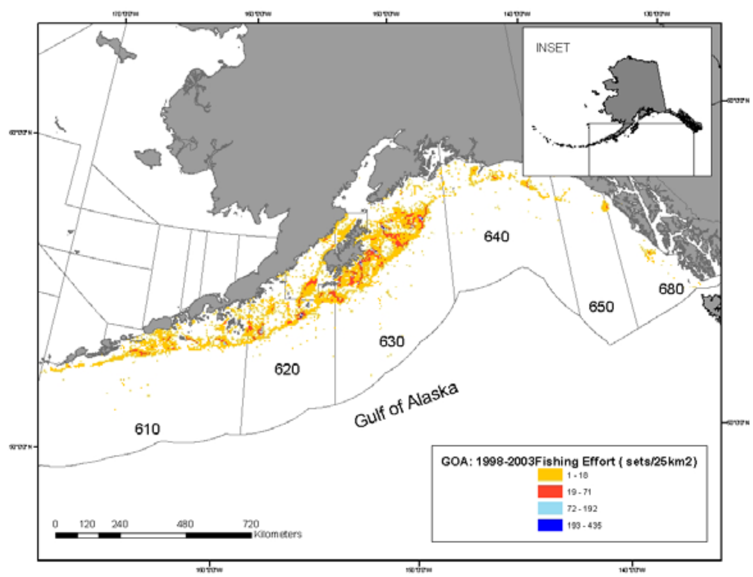


Figure 135. Spatial location and density of bottom trawl effort in the Gulf of Alaska, 1998-2003.

Groundfish pelagic trawl fishing effort in the Eastern Bering Sea

Contributed by Cathy Coon, NPFMC

Fishing intensity in the pelagic trawl fishery in the eastern Bering Sea can be described in either effort (number of hauls) or duration (amount of time net is in the water). Observed duration for the pelagic trawl fisheries is shown in Figure 136. The spatial pattern of fishing effort was summarized on a $5km^2$ grid (Figure 137). Areas of high fishing effort were 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.

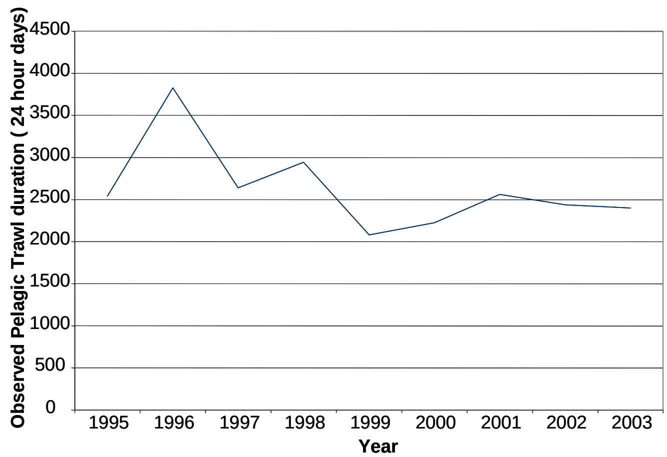


Figure 136. Observed pelagic trawl time in the eastern Bering Sea during 1995-2003.

In 1990, concerns about bycatch and seafloor habitats affected by this large fishery led the North Pacific Fishery Management Council to apportion 88% of TAC to the pelagic trawl fishery and 12% to the nonpelagic trawl fishery (North Pacific Fishery Management Council, 1999). For practical purposes, nonpelagic trawl gear is defined as trawl gear that results in the vessel having 20 or more crabs (*Chionecetes bairdi*, *C. opilio*, and *Paralithodes camstschaticus*) larger than 1.5 inches carapace width on board at any time. Crabs were chosen as the standard because they live only on the seabed and they provide proof that the trawl has been in contact with the bottom.

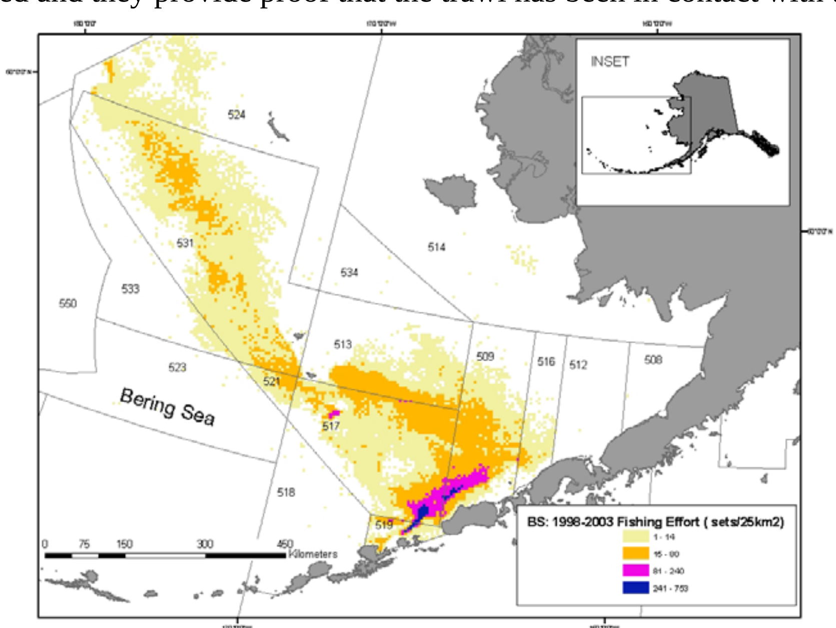
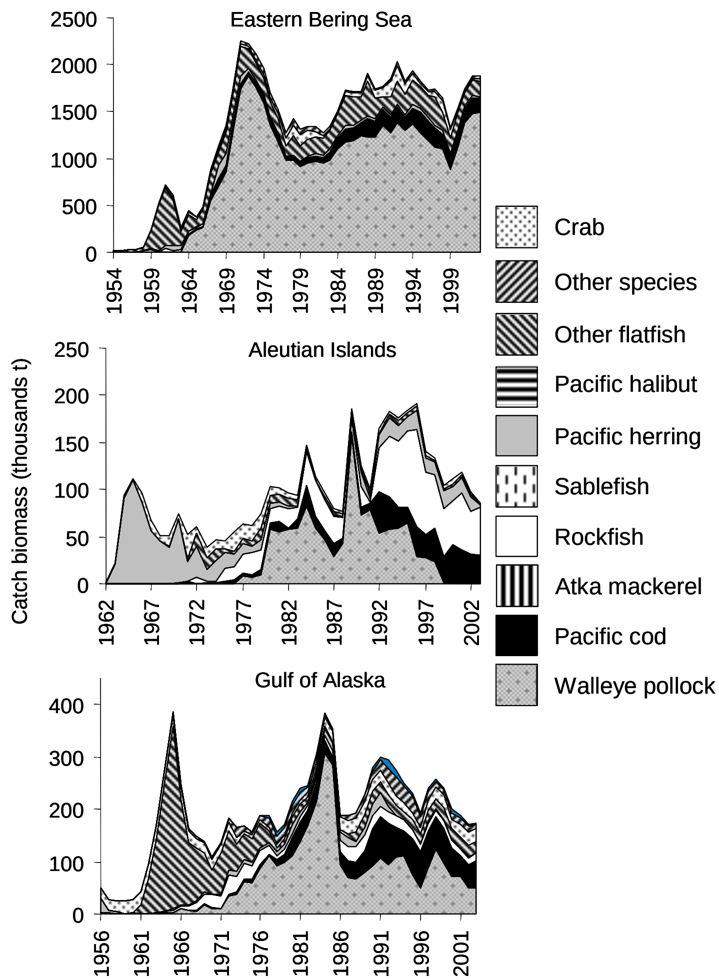


Figure 137. Spatial location and density of pelagic trawl effort in the eastern Bering Sea 1998-2003.

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

Trophic level of the catch

Contributed by Pat Livingston, Alaska Fisheries Science Center



To determine whether North Pacific fisheries were "fishing-down" the food web, the total catch, trophic level of the catch, and the Fishery Is Balanced (FIB) Index (Pauly et al. 2000) in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska areas were determined. Total catch levels and composition for the three regions show the dominance of walleye pollock in the catch from around the 1970's to at least the early 1990's (Figure 137). Other dominant species groups in the catch were rockfish prior to the 1970's in the Aleutian Islands and the Gulf of Alaska, and Atka mackerel in the 1990's in the Aleutian Islands. All these species are primarily zooplankton consumers and thus show alternation of similar trophic level species in the catch rather than a removal of a top-level predator and subsequent targetting of a lower trophic level prey.

Stability in the trophic level of the total fish and invertebrate catches in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska (Figure 139) are another indication that the "fishing-down" effect is not occurring in these regions. Although there has been a general increase in the amount of catch since the late 1960's in all areas, the trophic level of the catch has been high and stable over the last 25 years.

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

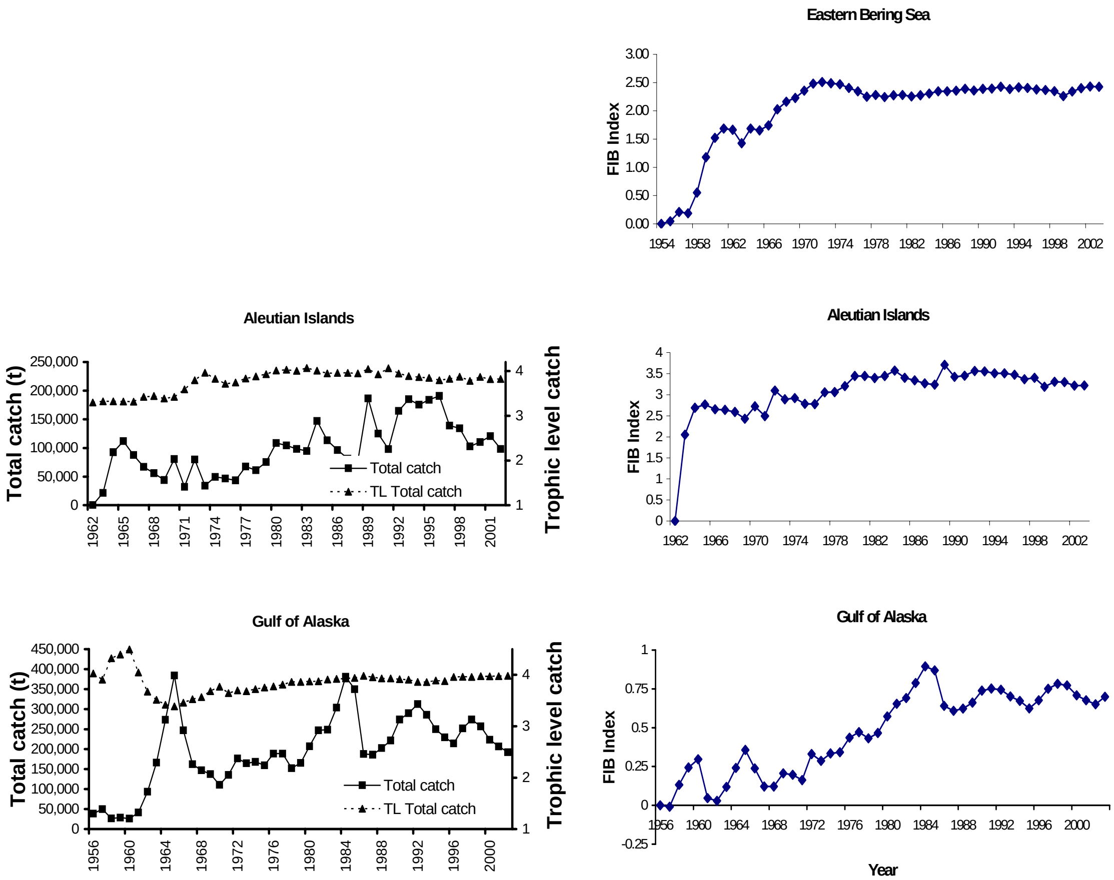


Figure 140. FIB Index values for the EBS, AI, and GOA through 2003.

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

Table 24 summarizes the status of Alaskan groundfish, crab, salmon and scallop stocks or stock complexes managed under federal fishery plans in 2003 from the May 2004 NMFS report to Congress available on the web at: http://www.nmfs.noaa.gov/sfa/reports.html

Table 24. Description of major and minor stocks managed under federal fishery management plans off Alaska, 2003. (Major stocks have landings of 200 thousand pounds or greater.)

Stock Group	Number of Stocks	2001 Landings (X1,000 Pounds)	Overfishing? Yes	Overfishing? No	Overfishing? Not Known	Overfished? Yes	Overfished? No	Overfished? Not Known	Approaching Overfished Condition
Major	59	4,849,592	0	49	10	1	28	30	0
Minor	137	2,019	0	30	107	1	3	133	0
Total	196	4,851,611	0	79	117	2	31	163	0

Two stocks are considered in the overfished category (Bering Sea Tanner crab and Pribilof Island Blue king crab). No BSAI or GOA groundfish stock or stock complex is overfished and no BSAI or GOA groundfish stock or stock complex is being subjected to overfishing. In 2003, there were 30 stocks that are defined as major stocks for which overfished status is unknown. Many species in Alaska are monitored as part of a group or complex, but are considered individually for the purposes of the report. The overfishing determination for the individual species is listed as “unknown”, but the species’ complex is determined to be “not subject to overfishing” based on the abundance estimates for the entire complex. This determination is applicable for some sharks, skates, sculpins, octopus, and squid complexes in the GOA Groundfish FMP. In the BSAI Groundfish FMP, similar determinations are made for some stocks in the sharks, skates, sculpins, octopus, rockfish, and flatfish complexes.

Total annual surplus production and overall exploitation rate of groundfish
Contributed by Franz Mueter; Joint Institute for the Study of the Atmosphere and Oceans, University of Washington; fmueter@alaska.net

Description of indices: Total annual surplus production (ASP) of groundfish on the Eastern Bering Sea (EBS) and Gulf of Alaska (GOA) shelves was estimated by summing annual production across all commercial groundfish stocks for which assessments were available (excluding flathead sole and Dover sole in the GOA). These species represent at least 70-80% of the total catch retained in bottom trawl surveys. Assuming that all biomass estimates correspond to beginning of year estimates (prior to when the fishery occurs), annual surplus production in year *t* can be estimated as the change in total adult groundfish biomass across species from year *t* (B_t) to year *t*+1 (B_{t+1}) plus total catches in year *t* (C_t, All estimates of B and C are based on 2003 stock assessments):

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

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

$$u_t = C_t / B_t$$

Status and trends: The resulting indices suggest high variability in groundfish production in the EBS (Figure 141) and a decrease in production between 1978 and 2003 (slope = - 74,000 mt / year, $t = -1.54$, $p = 0.14$). Production in the GOA was much lower on average, less variable, and decreased slightly from 1978 to 2001 (slope = - 15,000 mt/ year, $t = -0.80$, $p = 0.43$).

Total exploitation rates were generally much higher in the EBS than in the GOA and were highest in the early part of the time series due to high exploitation rates of walleye pollock (Figure 142). Total exploitation has remained relatively constant in both systems from the mid-1980s to the present. Exploitation rates in the EBS reached a low in 1999 and have increased since, while they are at their lowest value in 25 years in the GOA.

Factors causing trends: Annual Surplus Production is an estimate of the sum of new growth and recruitment minus deaths from natural mortality (i.e. mortality from all non-fishery sources) during a given year. It is highest during periods of increasing total biomass (e.g. 1978-1985 in the EBS) and lowest during periods of decreasing biomass (e.g. 1992-2000 in the GOA). In the absence of a long-term trend in total biomass, ASP is equal to the long-term average catch. Long-term declines in ASP and low production in recent years in the EBS suggest that extra precaution may be required in the near future. These trends are a result of low recruitment, reduced growth, increased natural mortality or some combination thereof.

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 make up the majority of the biomass in the GOA. If arrowtooth flounder is excluded, rates are comparable to those in the EBS.

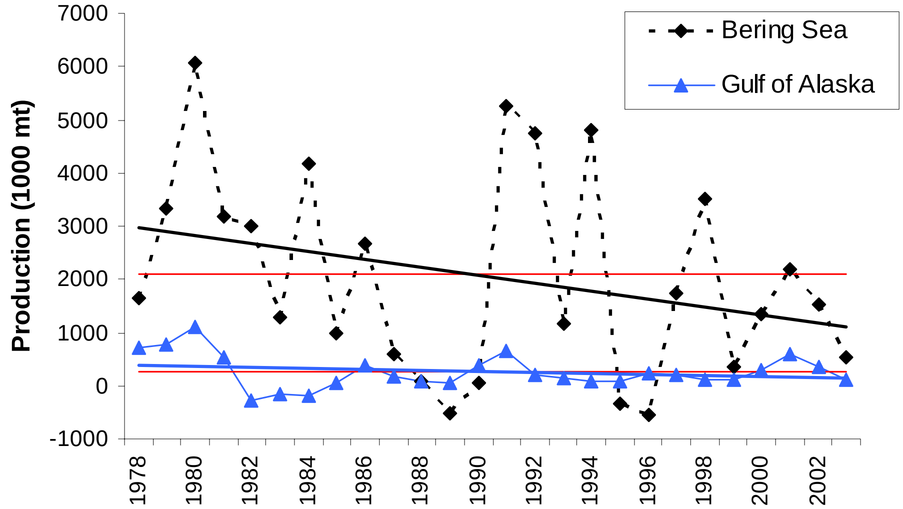


Figure 141. Total annual surplus production (change in biomass plus catch) across all major groundfish species in the Gulf of Alaska and Bering Sea with estimated linear trends (solid lines) and long-term means (red).

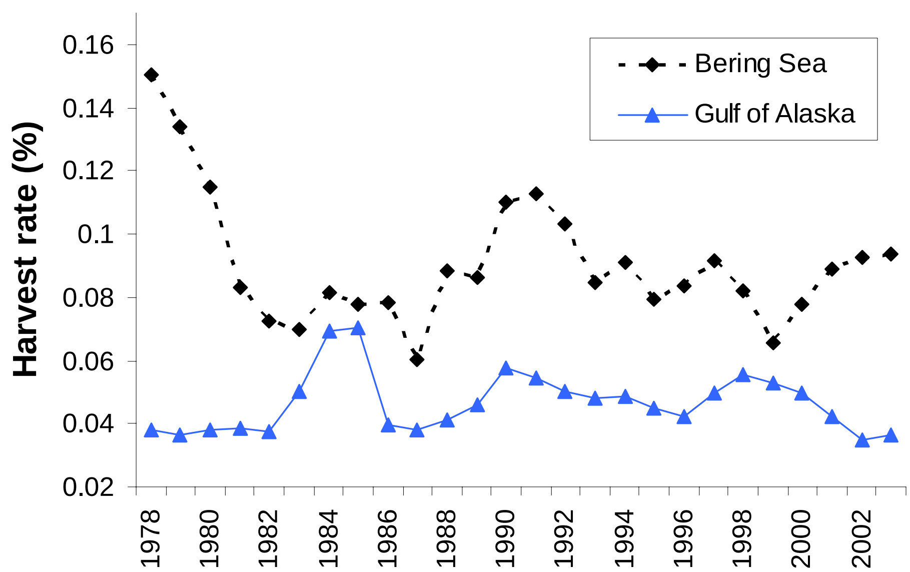


Figure 142. Total exploitation rate (total catch / total biomass) across all major groundfish species in the Gulf of Alaska and Bering Sea.

Ecosystem indicators for the bottom trawl fish community of the eastern Bering Sea (not updated for 2004)

Shannon Bartkiw, Pat Livingston, and Gary Walters, AFSC

Ecosystem-based fisheries management requires analyses beyond assessments of species that are targets of fisheries. The ICES working group on "Ecosystem Effects of Fishing Activities" has provided some ideas for developing additional ecosystem management indicators that measure more system-wide properties that might change due to fishing. Two indicators that have been found to be relatively explanatory of fishing induced changes at a more system-wide level are community size spectrum (CSS) and k-dominance curves. These indicators have been derived for several systems (Greenstreet and Hall 1996, Rice & Gislason 1996, Duplisea et al. 1997, Greenstreet et al. 1999, Bianchi et al. 2000, Zwanenburg 2000) using time series of survey information. Size spectrum involves the relationship between numbers by size interval across the sampled size range of the whole community. Some factors, such as fishing, may change the abundance of organisms of different size classes, particularly the amount of larger animals, affecting the slope of the descending limb of the size spectrum. For example, in an exploited fish assemblage, larger fish generally suffer higher fishing mortality than smaller individuals and this may be one factor causing the size distribution to become skewed toward the smaller end of the spectrum (Zwanenburg 2000), and leading to a decrease in the slope of the size relationship over time with increasing fishing pressure. Similarly, k-dominance curves, which measure the combined dominance of the k most dominant species (Lambshead et al. 1983), of disturbed communities will differ from those in unperturbed communities (Rice 2000, Bianchi et al. 2000). These indicators were derived for the eastern Bering Sea to ascertain the degree of influence fishing may have had on the characteristics of the size spectrum and k-dominance patterns and how those compare with other exploited marine systems. The k-dominance curves will be presented in the October 2004 draft.

The bottom trawl fish community appears to have fewer small individuals and more large individuals through time (Figure 143a). The slope and intercept of the CSS decreased from 1982-1987, primarily due to non-target fish. Since 2002 the both slope and intercept values have been relatively stable (Figure 143 b and c). Factors other than fishing, such as the regime shift in 1988/89, may have had an influence on the community size spectrum.

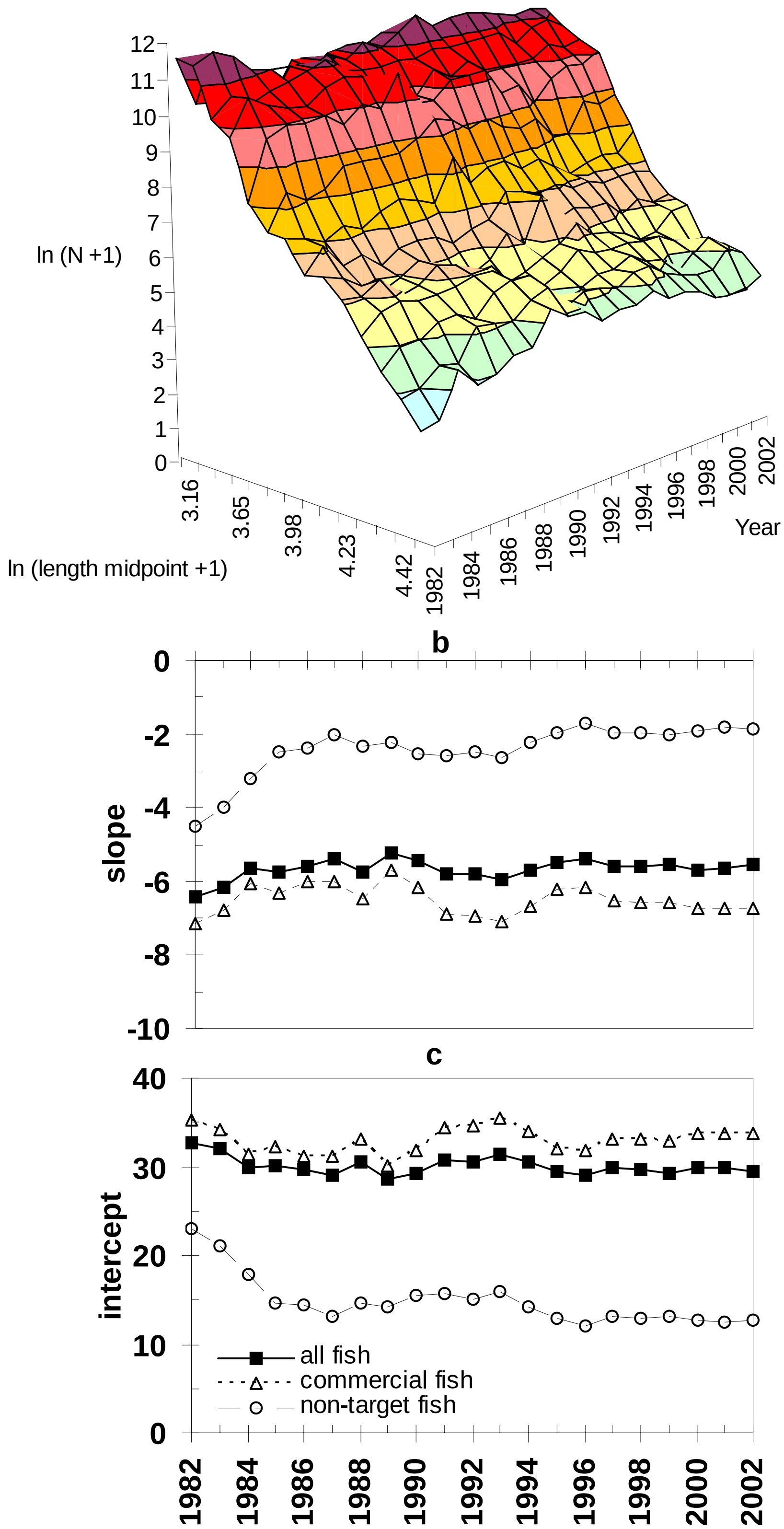


Figure 143. Eastern Bering Sea demersal fish (20-90 cm) community size spectrum (CSS), 1982-2002 (a); changes in slope (b) and intercept (c) of the CSS 1982 to 2002.

Ecosystem Goal: Humans are part of ecosystems

Fishing overcapacity programs

Contributed by Ron Felthoven (NMFS, Alaska Fisheries Science Center) and Jessica Gharrett (NMFS, Alaska Regional Office)

Overview

Overcapacity, wherein there is an excessive level of investment or effort relative to the available fisheries resources, is considered a problem in fisheries throughout the world. The problem is often manifested in short fishing seasons, increased enforcement and safety problems, and reduced economic viability for vessel owners and crew-members. Under certain conditions, overcapacity can 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 recommended by the Council will, beginning in 2005, manage most crab fisheries of the Bering Sea and Aleutian Islands (BSAI) under a quota system, in which quota shares are issued to harvesters (including vessel captains) and processors. The program also includes community protection measures (hence the term "three-pie" program), and provides for voluntary harvesting cooperatives. Some features of this crab program had to be authorized by Congressional action. The Council also is considering comprehensive rationalization of Gulf of Alaska (GOA) groundfish fisheries and sector allocations of groundfish in the BSAI.

Congress has provided additional statutory tools to help relieve overcapacity. The American Fisheries Act (AFA) retired nine catcher-processors, limited entry of additional harvesting vessels, authorizes harvesting cooperatives to which a portion of the total allowable catch of BSAI pollock is granted, prevents pollock fishery participants from expanding historical activities to other fisheries, and stabilized deliveries to shoreside processors. Congress later authorized a BSAI crab "buyback" program that, if approved by industry, will retire crab licenses, vessels, and vessel histories prior to implementation of the crab quota program. And, as a prelude to the more complex GOA rationalization program, Congress recently directed NMFS, in consultation with the Council, to develop a two-year demonstration quota program for Gulf of Alaska rockfishes.

Moratorium on New Vessels

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

License Limitation Program for Groundfish and Crab

The LLP for groundfish and crab vessels was implemented on January 1, 2000 to replace the vessel moratorium. The original LLP, approved in 1995, was intended as the second step in fulfilling the Council's commitment to develop a comprehensive and rational management program for fisheries off Alaska. Amendments to that program recommended by the Council in 1998 and April 2000 tightened the LLP program and included additional restrictions on crab vessel numbers and on fishery crossovers. The amendments also limited participation in the non-trawl BSAI Pacific cod fisheries. The LLP reduced the number of vessels eligible to participate in the BSAI crab fisheries by more than 50% relative to the vessel moratorium (down to about 375 licenses, of which an estimated 330 are currently being used). The number of current LLP groundfish licenses (1,876) 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 1,476 groundfish LLP licenses name vessels. However, the LLP is more restrictive in terms of the crab fisheries in which a license holder may participate, the groundfish areas in which a license holder can fish, and the types of gear that may be deployed. Also important to note is that the vast majority of the vessels that can be deployed under the LLP are longline vessels less than 60' (and are only eligible to participate in Gulf of Alaska fisheries). These vessels have typically had relatively small catch histories in past years.

License Limitation Program for Scallops (LLPS)

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

Bering Sea and Aleutian Islands Crab Rationalization and Buyback

The North Pacific Fishery Management Council has developed a plan to rationalize the BSAI crab fishery. The preferred alternative, a "three-pie voluntary cooperative program," is a program that attempts to balance the interests of several identifiable groups that depend on these fisheries. Allocations of harvest shares would be made to harvesters, including captains. Processors would be allocated processing shares. Community protection measures would help provide economic viability of fishery-dependent communities. Designated regions would be allocated landings and processing activity to preserve their historic interests in the fisheries. Harvesters would be permitted to form cooperatives to realize efficiencies through fleet coordination. The novelty of the program has compelled the Council to include several safeguards into the program, including a binding arbitration program for the resolution of price disputes and extensive data collection and review programs to assess the success of the rationalization program. These safeguards, together with the Council's continuing development of the program through a series of ongoing amendments and clarifications, demonstrate the Council's commitment to a fair and equitable rationalization program that protects the interests of those dependent on the BSAI crab fisheries.

A statutory change to the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) authorizes an industry-funded buyback program for the crab fisheries. This program would permanently retire vessels, LLP licenses, and vessel histories. The program is subject to an industry referendum in which a majority of participants must approve the proposed effort reduction and debt retirement burden.

Sablefish and Halibut Individual Fishing Quotas

The halibut and sablefish fisheries provide good examples of how the Council is working to control overcapacity in fisheries off Alaska. From 1975 to 1994 the Central Gulf of Alaska halibut fishing seasons decreased from approximately 125 days to single day openings, while catches increased. Faced with very short seasons and increasing fishing effort, the Council recommended an IFQ program for both the halibut and fixed gear sablefish fisheries. These programs were initiated in 1995. After implementation, the traditional short, pulse fisheries were extended to more than eight months long. IFQs have allowed participants to better match fishing capacity with the amount of fish they are allowed to harvest during a year, improving economic efficiency for harvesters and decreasing gear conflicts on fishing grounds, among other salutary effects. In recent years the numbers of vessels and persons have declined, even as the TACs have been increasing. A total of 4,828 persons were initially issued halibut quota share (QS) and 1,051 were initially issued sablefish QS. As of the end of 2003, 3,485 persons held halibut QS and 886 held sablefish QS. The number of vessels landing halibut in the IFQ fishery declined from 3,450 in 1994 to 1,338 at the end of 2003; the number landing sablefish in the IFQ fishery declined from 1,191 in 1994 to 409 in 2003.

American Fisheries Act

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

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

Under the AFA, the PCC is currently allocated 91.5% of the total offshore pollock allocation (the rest is allocated to members of the HSCC). When the new fishery cooperative structure was adopted in 1999, not all of the eligible catcher/processors fished during the 1999 late winter and early spring pollock seasons; four catcher/processors opted not to fish during the A/B season and six chose not to fish during the C/D season. This pattern continued in 2000 and 2001 when four and three catcher/processors were idle in the A/B season, respectively. Five of the catcher/processors were idle in both 2000 and 2001 for the C/D season. In 2002, three vessels were idle in the A/B season and four were idle in the C/D season. In 2003, sixteen of nineteen vessels harvested pollock during the year. This increase in vessel participation relative to earlier post-AFA years can probably be attributed to the increase in the pollock TAC.

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

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

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. Only 83 vessels each delivered more than 10 mt of pollock to inshore processors in 2003.

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

Groundfish fleet composition

Contributed by Joe Terry, Alaska Fisheries Science Center

Fishing vessels participating in federally-managed groundfish fisheries off Alaska principally use trawl, hook and line, and pot gear. The pattern of changes in the total number of vessels harvesting groundfish and the number of vessels using hook and line gear have been very similar since 1994. They both were high in 1994 and then decreased annually through 1998 before increasing in 2000. The total number of vessels was about 1,404 in 1994, decreased to 1,151 in 1998, and was 1,037 in 2003, the most recent year for which we have complete data (Figure 144). Hook and line vessels accounted for about 1,114 and 720 of these vessels in 1994 and 2003, respectively. The number of vessels using trawl gear has tended to decrease; during this ten-year period it decreased from 255 to 210 vessels. During the same period, the number of vessels using pot gear peaked in 2000 at 315, but decreased to 205 in 2003. Vessel counts in these tables were compiled from blend and Catch Accounting System estimates and from fish ticket and observer data.

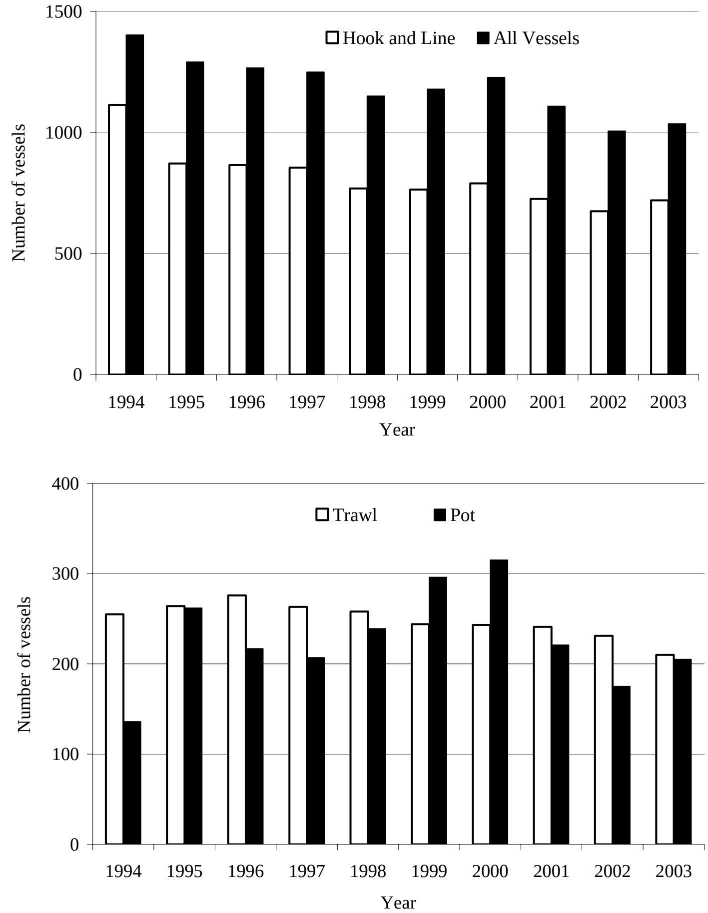


Figure 144. Number of vessels participating in the groundfish fisheries off Alaska by gear type, 1994-2003.

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